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Violable is variable: Optimality theory and linguistic variation

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ABSTRACT

Optimality theory (OT) (McCarthy & Prince, 1993; Prince & Smolensky, 1993) has been proposed as a constraint-based theory of phonology in which the phonological facts of each language are accounted for by a language-specific ordering of a universal inventory of constraints. The constraints, expressing desirable (i.e., optimal) phonological states, evaluate possible candidate forms, selecting the optimal output. Any constraint may be violated by a surface form if it is overridden by a higher-ranked constraint; the ordinal sequence of constraints provides a weak quantification of constraint effects. Variability has been treated within OT by varying constraint orders. This model is analogous in several important respects to the variable rule model (VR) of Labov (1969) and Cedergren and Sankoff (1974). In VR, variable constraints express desirable phonological states which are variably realized on the surface, when not overridden by other constraints; constraints are probabilistically quantified. This article compares the OT and VR models, arguing that the VR model is superior on theoretical and empirical grounds: constraint effects in VR are stable, transparent, and learnable. Moreover, the probabilistic treatment of constraint effects allows VR to model successfully cases in which multiple violations of a single constraint lead to a cumulative reduction in likelihood of a form; such cases cannot be efficiently treated in OT.

PRINCIPLES AND CONSTRAINTS IN PHONOLOGICAL THEORY

Theoretical work in phonology over the last decade or so has made the study of phonological constraints and principles one of its main points of focus. This interest reflects two general tendencies in recent linguistic theory. First, there is the need—ever since the establishment of the overly powerful generative model—to devise principled constraints on the theory; second, there is interest in the Chomskyan research program of discovering universal features of the human language faculty and universal grammar (UG). In phonological theory, these themes can be seen to underlie many of the proposals that have been made of general, possibly universal, principles such as the Obligatory Contour Principle, the Elsewhere Condition, the Strict Cycle Condition, and others. Most of these were proposed as

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tentative features of UG. However, extensive cross-linguistic work revealed that it was often difficult to formulate such principles in ways that held true of all languages. What emerged was a picture of what Goldsmith (1993) termed "soft universals," which we could informally characterize as phonological states of affairs that are cross-linguistically preferred or avoided, but are not universally, categorically true or false.

Recently, there have been several attempts to systematize the treatments and formal status of these principles, constraints, and conditions and to capture this insight about soft universals. Optimality theory (OT) is one such approach that has been widely influential (McCarthy & Prince, 1993; Prince & Smolensky, 1993). OT proposes that there is a universal inventory of constraints which have this soft character: preferred by UG but not required. A crucial notion in this theory is that these constraints can be violated.[1]

This is a significant theoretical step for generative phonology, which has historically tended toward a categorical view of valid generalizations. The categorical view of phonological rules is that a rule that is violable is no rule at all. What good is a set of laws that specifically allow themselves to be broken? To overcome this objection, OT proposes precise limitations on permissible violations. The basic limitation is that a given constraint can be violated only if it conflicts with some other constraint. Thus, given two constraints and a case where both cannot be simultaneously satisfied, one must lose. This principle is familiar from the legal sphere, as expressed in the maxim "Don't cry 'fire' in a crowded theatre"; the right to free speech is overridden by the right to public safety.

Now, given such conflicts in phonology between otherwise valid constraints, how do we decide which should prevail in a given case? OT solves the precedence problem with the technique of hierarchical ordering. The constraints are all assigned a rank order, and when there is a conflict, the higher-order constraint automatically wins. This provides a deterministic solution to the problem of constraint conflict; a unique outcome is predicted for any situation, no matter how many constraints are involved.

Of course, such an approach still leaves several issues to be addressed. First, the model depends crucially on the ordering of the constraints. Where does this come from? Is it given by theory or empirically determined? Is it universal or language-specific? Second, how do languages differ? If the constraints we have been working with are soft universals, their softness arises precisely from the fact that they are not always true in all languages. In this model, if all languages had the same constraints in the same order, they would not differ, except lexically, and the universals would be hard, not soft. In OT, as currently formulated, the inventory of constraints is envisaged as universal, part of UG, but the ordering is largely language-specific, to be worked out empirically from the facts of each language. Thus, a language with CV syllable structure would have the constraint *Coda ranked very highly, while for English, the same constraint still exists, but is buried so deep in the hierarchy that there is very little evidence for it. The differences between languages therefore lie in their differing constraint orders.

TABLE 1. *An OT account of apocope in Faetar (from Nagy & Reynolds, 1997)*

Tableau 14: /bró.kə.lə/	LX≈PR	FILL	*CXONS	*CODA	PARSE	ALIGN PRWD	ONS	HNUC	*SCHWA
brok				*!	***				
bró.kə					**!	*			*!
bró.kl					**!	*		*	
☞ bró.kə.lə						**			**

The theory can be exemplified by recent work applying it to variation. Nagy and Reynolds (1997) described variable apocope in Faetar using an OT model. Their Tableau 14 (reproduced here in Table 1) illustrates how one order of constraints could select a non-apocopated surface form for the word *brokele* 'fork'. The shortened alternative [brok] is ruled out as a violation of the constraint against syllable codas (*Coda), while the forms [brokl, brokə] violate a faithfulness constraint (Parse), which requires maximal parsing of the underlying form (i.e., inclusion of all underlying material in the surface form). Hence, the full form is selected in this example, even though it violates a constraint requiring final syllable stress (Align-PrWd) and another prohibiting schwa (*Schwa). These violations are permitted because this form satisfies higher-ranked constraints. However, if the constraints were ordered differently, different outcomes would ensue; for example, if Align-PrWd were ranked above *Coda and Parse, the form [brok] would be preferred.

The OT view of constraints might therefore be summarized as follows. Constraints are phonological states which are universally preferred (or in the case of negative constraints, universally avoided), but which may be locally violated. They also vary in order from language to language, and they vary in strength; some are more preferred than others.

Now it comes as no surprise to scholars of language variation that there has existed for some 25 years another model that allows constraints to be violated, to vary in strength, and to vary between languages. I refer, of course, to the variable rule model (VR) (Cedergren & Sankoff, 1974; Labov, 1969). A variable rule describes a preferred phonological state in the form of a rule output. The realization of that state is subject to constraints which also express phonological states that are preferred or avoided. Both the rules and the constraints on them can, in principle, be variable; that is, the states they describe are sometimes satisfied and sometimes violated. In addition, each rule and each constraint is probabilistically quantified. This quantification has several consequences, but the most important one for present purposes is that it allows certain elements in a phonology to vary in strength: some states are more likely to occur than others. Some variable rules are more probable than others, and some contexts favor a given outcome more than others. Hence, in VR, the probabilities associated with rules and constraints are also rankable, in order of probability. Finally, within certain limits, languages may differ in constraint strengths.[2]

Thus, the central innovations of OT are contained within VR. Violable is, in an important sense, the same as variable, and ranking constraints is a weak form of quantification. Therefore, we now turn our attention to the question of the differences between these approaches and to the problem of choosing between them.

COMPARING THE THEORIES

There are four main areas of difference that I highlight in this section: (1) the status of rules; (2) the question of determinism versus inherent variability; (3) the issue of universality; and (4) the treatment of quantification. The question of rules turns out to be less important than it at first seems. OT relies on constraint satisfaction rather than derivation to account for surface forms and hence does not use phonological rules. The VR model, as the name implies, has customarily been used in connection with rule-based formalisms. But, as is often pointed out, it is not intrinsically wedded to such models. Rather, it is a model for quantifying the occurrence of particular states and the interactions among constraints on those states. The rewrite rule is a convenient device for modeling the generation of binary variables, but VR has been easily generalized to polynomial variables and can be applied to any kind of linguistic alternation. Wherever there are choice points in the grammar, where alternative outcomes can ensue, the VR model can apply. It will even handle deterministic, non-alternating cases, by assigning the unique outcome a probability of 1. A generative grammar is a device for specifying all possible productions in a language. Therefore it has many possible states, each defining a different possible production. The VR framework supplies a model for quantifying those states, however they are represented, thus defining not only possible productions, but also likely and unlikely or, as Labov (1972) put it, "relations of more and less."

Thus, the more important differences between VR and OT lie not in the use of rules, but in the treatment of determination, universality, and quantification. OT, as I noted, is intended to give a unique output for any input; it is therefore deterministic, like previous theories of generative phonology. But VR is explicitly non-deterministic; it associates probabilities with various possible outcomes, and in variable cases it sees the outcome in a particular utterance as partially random. Thus, in VR, a given constraint may be violated not just to satisfy a higher constraint, but randomly, as a consequence of the inherent variability of language. We can state the incidence of these non-satisfactions in a corpus of observations with great quantitative precision, but we are unable to predict deterministically any particular instance. So these models could be summarized as follows: generative theories before OT are categorical and deterministic; OT is non-categorical and deterministic, while VR is non-categorical and non-deterministic.

Of course, this oversimplifies somewhat. Most models incorporate some optional elements in the grammar in order to account for the fundamental empirical fact of variation. How is this dealt with in the theories under consideration?

The VR model, of course, represents variation directly by a probabilistic component in the grammar. In OT, several scholars have appealed to varying constraint orders to account for variation. This is an obvious move, since the theory allows languages and dialects to differ in constraint ordering. Thus, Iverson and Lee (1994) accounted for differences between dialects in Korean by varying the orders of constraints on Peripherality and Coda Sonority. The same device can also account for stylistic variation within one dialect. Kiparsky (1993) went further. He proposed that individual speakers possess competing grammars with different constraint orders, and that variation arises from the selection of one grammar or another. He accounted for some of the quantitative patterns of English coronal stop deletion (see Guy, 1991) by attaching probabilities to the selection of grammars (or the imposition of constraints) in production. Finally, a third approach is represented by Nagy and Reynolds (1997) (see also Nagy, 1996; Reynolds, 1994), who proposed the variation of constraint orders within one grammar. In their model, a constraint can float within a certain range on the hierarchy. At different points in its range, it licenses different surface outputs, depending on which other constraints it eclipses or is eclipsed by. Counting up licensed forms across all possible orders appears to predict correctly the observed rates of apocope in Nagy's Faetar data.[3]

The approaches taken by Kiparsky and by Nagy and Reynolds adapt OT to account for within-dialect variability. I return to these approaches later when I look at some data, but first I discuss issues of universality and quantification.

UNIVERSALITY OF CONSTRAINT EFFECTS

OT, as we have noted, makes the explicit claim that the constraint inventory is universal, even innate, and is part of UG. Hence, all speakers of all languages have implicit access to all the constraints required for any language. This leaves a substantial problem for the theory to explain. Why is there no evidence in so many languages for so many of the constraints? The theory makes the claim that constraints that cannot be observed in a given language are nonetheless present in its grammar, but are located too low in the hierarchy to find expression. This claim is obviously undisprovable and therefore does not merit serious scientific consideration. It also leads to a logical conundrum. What happens when a language has several such unexpressed constraints, but must nevertheless assign each of them a unique and specific ranking? How do speakers go about figuring out the order of several constraints that all show no evidence? The model clearly requires representation for a position in the constraint hierarchy equivalent to tied-for-last.

The VR model, on the other hand, makes no general claim about the universality of constraints. Work within this framework generally assumes that some constraint effects are universal, especially where such universality is independently motivated (see, e.g., the effects of sonority of adjacent segments on deletion processes, as discussed in Santa Ana, 1996). However, other constraints are quite clearly language-specific. For instance, English coronal stop deletion is favored by a following /l/, because rightward linking of the final stop is blocked by the language-specific prohibition on *tl-, *dl- onsets (Guy, 1991). Therefore, an imaginable constraint that is not in evidence for a particular language is simply assumed not to exist for it, and this would constitute evidence against the universality of that constraint. Nevertheless, VR has an explicit quantitative representation for a constraint that has no effect. Such a constraint is assigned a neutral weighting, which neither favors nor disfavors any outcome. In the currently preferred logistic model, this is expressed by a factor weight of .5. This representation can be assigned to any number of ineffective constraints, thus avoiding the need to differentiate equally neutral standings.

VR makes a further specific and testable claim about the status of factor weights and rankings. The constraint weightings are hypothesized to be uniform within a dialect or speech community; indeed, this is one of the instantiations of the shared grammar that characterizes the community. However, values may vary between speech communities, although, as we have noted, some of these are evidently universal. OT does not explicitly address the question of uniformity within the speech community, but evidently assumes that a given order defines a grammar and would therefore be shared by any speakers who share a dialect (or idiolect?).

But how may speakers within a speech community differ? This question turns up a sharp distinction between OT and VR. In OT, the only way to model difference between lects is differing constraint orders. So the difference between speakers within a speech community would be of the same theoretical type as the difference between one community and another. In VR, the two situations are hypothesized to be quite different. Constraint weights are fixed within the community, and speakers differ on an entirely different parameter: the input probability, which is an overall weighting of the likelihood attached to any particular rule, process, or outcome. This imposes additional tight constraints on possible grammars. Speakers may have higher or lower overall rates of expression of some outcome, but they have the same ordering of proportions of occurrence in favorable and unfavorable contexts. Thus, in the English coronal stop deletion data to be discussed, preceding obstruents favor deletion more than do sonorants for all speakers in the same proportion. However, their idiosyncratic differences in input probability allow some speakers to have low rates and some to have high rates of deletion; they also allow them to vary stylistically on this parameter so long as they preserve the weightings (and rank orderings) given by the grammar of their speech community.

These are empirically testable predictions and so far are empirically well validated. No English speaker has been found who reliably reverses the community order by deleting coronal stops more after sonorants than after obstruents or more past tense forms than monomorphemes, but speakers vary widely in overall rates. OT cannot explain either finding. Difference of any sort should involve different constraint orders, and differences of pure frequency of use cannot be modeled at all.

TABLE 2. *OT constraint weightings: Hypothetical example*

Candidate Forms	A	B	C	D	E
	Constraints				
w	*!			*	
x		*!			
⇒ y			*	*	*
z		*!			*

QUANTIFICATION IN OT AND VR

Quantification in VR, relying on probability theory, is stronger and more precise than the rank order quantification of OT. Constraint strength is expressed in VR not by mere ordinals, but by real numbers. This has several consequences. For one thing, VR supplies a gauge of constraint strength. Whereas OT can only say that constraint *x* is ranked higher than *y*, VR can say that *x* is stronger than *y* by a particular amount.

But the more important consequence of probabilistic quantification is that it provides a logically different condition under which a constraint can be overridden. In an OT tableau, a form that violates a large number of lower-ordered constraints may nevertheless be preferred because it satisfies a higher-order constraint. Thus, in a hypothetical situation like Table 2, form *y* is chosen over all the other candidates, even though it violates three constraints, while *x* violates only one, and *w* and *z* each violate two.

In a VR model, however, we do not predict the outcome by looking for the form whose highest-ranked violation is lower than any other, but rather by computing an overall optimality function that takes into account all constraints impinging on a particular form. Thus, a form like *y* in the table, which is disfavored by several lower-ordered constraints, might turn out to be less optimal than one like *x*, which is disfavored by only one constraint. Thus, outcome *x* could beat *y* even though the constraint that *x* violates is ordered higher than all the constraints violated by *y*.

As a simple demonstration of this quantitative consequence, we could construct an additive model for violation strength as follows. We assign arbitrary integers to represent the strengths of the constraints: value 5 for A, 4 for B, down to 1 for E. We then use these to compute weighted violation scores for each form in Table 2. Form *w*, which violates a 5 point constraint and a 2 point constraint, would have 7 violation points; *x*, *y*, and *z* would have 4, 6, and 5 points, respectively. Under these weightings, *x* would turn out to be the optimal (i.e., it has the lowest violation weighting). Form *y* is not chosen because its disoptimality for three lower-ranked constraints outweighs its satisfaction of the higher-ranked constraint B.

Orthodox OT does not allow this kind of situation. Prince and Smolensky are quite explicit on this point: "A parse found wanting on one constraint has absolutely no hope of redeeming itself by faring well on any or even all lower-ranking constraints" (1993:78). Nevertheless, it is a logical possibility for a constraint interaction that is readily modeled in the VR framework, and it is one that is empirically instantiated in virtually all studies of variation. Most linguistic variables are characterized by some constraint that is strongly disfavoring, but where the variant or the rule nonetheless occurs at least occasionally because other conditions are favorable. For example, one of the strongest constraints against the operation of English coronal stop deletion is the morphological status of the stop as a past tense marker. There is far less deletion in *missed* and *bowled* than in *mist* and *bold*. Nevertheless, deletion does sometimes occur in past tense forms. In the corpus studied in Guy (1991), for example, regular past tense forms were found to undergo deletion 16% of the time ($N = 181$), while the deletion rate for noninflected forms like *mist* was 39% ($N = 449$). Deletion in this disfavored morphological context is especially likely when other favorable constraints are satisfied, such as the presence of preceding and following obstruents, as in *miss(ed) me*. That such deletions are frequent and natural in informal speech is evidenced by the children's chant "You missed me, you missed me, now you hafta kiss me," which depends on stop deletion in *miss(ed)* for a good rhyme.

The VR approach to constraint quantification has three desirable features. First, there is what we can call the stability of constraint effects. In VR, the effect of a given constraint is always exerted, and any factor present in the context of a variable rule always contributes its value to the computation of the optimality of the output. For example, in the English *-t,d* deletion case just mentioned, the deletion-favoring effect of a following consonant-initial word is operative even in the presence of the strongly disfavoring morphological constraint against deletion in past tense verbs. In standard OT, by contrast, the effect of a constraint is completely suspended the moment a higher-order constraint happens to apply to a particular form (in Table 1 from Nagy & Reynolds, 1997, the shading indicates the constraint effects that have been rendered irrelevant to the outcome). The dominant constraint for a given form in OT is like a trump card, overruling all subordinate considerations, no matter how many or how strong or how valid. But unlike bridge, in OT the trump suit is not the same from trick to trick. Rather, it changes depending on what constraints are relevant to a given token. So a desideratum that decisively determines the form of one word is itself instantly ignored and freely violated once a higher-ranked constraint comes into play. Thus, constraint effects in the OT model are unstable precisely because of their violability, while in the VR approach, they are both violable and stable.

Such trump-card constraints have long been considered in the VR framework, where they are informally called knock-outs: categorical constraints that admit no variation. They are integrated into the mathematics of the VR model as the extreme cases: where no variation is possible, the associated constraint is assigned a probability of 1 or 0, and the knock-out effect follows from the mathematics of the model (see Rousseau & Sankoff, 1978, for fuller discussion). Empirically, such cases are not uncommon, and in their presence the stability of other constraints is not observable. Nevertheless, every studied linguistic variable also exhibits assorted constraints that are not knock-outs. These variable constraints are common and stable cases in VR, but OT postulates that every constraint is a knock-out.

The second advantage of VR is the transparency of the data. This is the flip side of stability. Since every constraint always exerts its effect whenever it applies to a token, every token always gives evidence about the effect of any relevant constraint. Only the occurrence of a knock-out masks the effect of a VR constraint, but, as we have noted, OT makes every constraint a knock-out, rendering invisible the effect of all lower-ranked constraints. Furthermore, the estimation of constraint effects in VR is absolute and not relative to all other constraints. Relative orderings of constraints in VR are derivative, not primary, and are determined by the quantitative measures of constraint strength rather than by pairwise comparisons of the constraints in utterances where they conflict. Hence, there is a direct, transparent relationship in VR between any corpus and the strengths of all instantiated constraints. In OT, on the other hand, much of the data provide no evidence at all about the strengths of masked constraints; to decide the relative ranking of a given pair of constraints, one might have to wait indefinitely for the occurrence of that unique token in which they happen to conflict.[4]

The third desirable feature of the VR model is its superior learnability, which arises as a consequence of its advantages in stability and transparency. OT, like any theory that postulates language-specific hierarchical orders, suffers from the well-known problems associated with extrinsic ordering. These issues were amply discussed in the debates that used to rage about the ordering of rules. The same problems arise if we now have to order extrinsically a number of constraints. The basic problem is that there are a very large number of possible orderings of any set of items; for *n* constraints, the number of possible orderings is $n!$ (*n*-factorial). Given that existing work in OT already envisions a fairly large number of constraints in the universal inventory, the number of possible orderings for a language is therefore astronomical. A set of just 20 constraints, far fewer than are necessary to account for all phenomena in all languages, would have about 2.35×10^{18} possible orderings. If the order used by a specific language is not known but must be figured out from evidence, it is questionable whether there is enough time in the life of a speaker, or even enough decisive lexical items in the language, to resolve all the possibilities—unless, as we shall shortly consider, some efficient search algorithm is available.

This problem of computability raises enormous difficulties for acquisition. If constraint order is language-specific, all of the $n!$ orders must be entertained as possibilities by the language learner. The lack of transparency referred to earlier then means that the only strategy available is to wait—possibly forever—until one hears those decisive tokens in which a certain pair of constraints conflict.

Now there are various steps that the theory might take to minimize this difficulty, and recent work in the OT framework has begun to address the learnability problem (e.g., Tesar & Smolensky, 1995). OT might postulate that some constraints are ordered universally; or that the relative order of some constraints may be immaterial because they never affect the same tokens; or that the requirement of an absolute ordering for all constraints could be relaxed, giving clusters of constraints that are not ordered with respect to each other. Perhaps the most effective algorithm for making the task computable is to postulate that the ordering is linear and transitive, in which case most relative orders could be deduced without direct evidence. But unfortunately this strategy conflicts with the use of variable constraint orderings to model variability! (If some unknown number of constraints vary their positions across an unknown range in the hierarchy, the learner cannot assume transitivity, because successive observations might show A $\gg$ B, B $\gg$ C, and C $\gg$ A.)

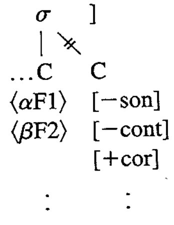
In any case, there remains a sizable, well-recognized problem associated with any reliance on extrinsic ordering. When this problem was understood in connection with rule ordering, it led many theoreticians to prefer rule systems that did not require much extrinsic ordering. Insofar as possible, rule sets were designed to be either not crucially ordered, intrinsically ordered, or ordered on the basis of general principles like the Elsewhere Condition (the particular takes precedence over the general). OT would seem to require some such conventions limiting possible orders.

In the VR framework, these computability and learnability problems do not arise, because constraint effects are stable and all data bear a transparent relationship to all relevant constraints. The task of the learner is to estimate constraint effects, not to determine relative order, so there is no need to wait for decisive cases. The probabilistic effect of a constraint is systematically observable, not routinely masked by any higher-order constraint, so the task of acquisition is facilitated.

DATA: THE OBLIGATORY CONTOUR PRINCIPLE

As an empirical example of some of these issues, let us consider constraints on one well-known variable from English phonology: coronal stop deletion. This variable involves the omission of final stops from coda clusters, so that *west* and *old* become *wes'* and *ol'* (e.g., *wes' side*, *ol' man*). The facts are modeled in Guy (1991) as a delinking rule, which I will formulate for present purposes as in (1).

(1) English coronal stop deletion
⟨variable, unmarked domain of application⟩



This process is constrained by several features of linguistic context. Two that are of no concern here are the morphological structure of the cluster and the following phonological context. These have been addressed in an OT framework by Kiparsky (1993, 1994). By allowing different orderings in competing grammars, he showed how the quantitative data can be partially modeled. He assumed that the selection of a particular order is associated with a certain probability, and that the combination of these selection probabilities generates the exponential order of morphological categories described in Guy (1991, 1992).

The third constraint on this rule is indicated in (1), namely, the effect of the preceding segment. This is the constraint I focus on here. The segment preceding a deletable coronal stop has long been known to affect the deletion rate. Roughly speaking, obstruents promote deletion more than sonorants, so *act* and *west* show more deletion than *build*. But the details and the explanation of this effect have remained somewhat obscure, subject to a variety of incomplete explanations. Guy and Boberg (1997) proposed a solution to the problem based on the Obligatory Contour Principle (OCP).

Following McCarthy (1986, 1988) and Yip (1988), Guy and Boberg (1997) took a generalized version of the OCP as a universal disfavoring of same-tier sequences of adjacent identical features. This can be formulated as a constraint, as in (2).

(2) The Obligatory Contour Principle (generalized)
$*[\alpha F]\ [\alpha F]$

If such a constraint is incorporated into the VR model, it accurately predicts the preceding segment effect on coronal stop deletion. Preceding segments favor deletion of the final coronal stop to the extent that they share features with that stop, thus creating OCP clashes. The more features that are shared, the more likely it is that deletion will occur.

This is illustrated in Table 3, from Guy and Boberg (1997). Preceding stops, sibilants, and /n/ all share two features with the coronal stop target, and all promote deletion at a high rate. Next, laterals and noncoronal fricatives and nasals all share one feature with the target stop and are associated with a lower rate of deletion. Furthermore, neither the differences among the various two-shared-feature categories nor the differences among the various one-shared-feature categories are statistically significant. However, there is a significant difference between sharing two features with the target and sharing only one.

We interpreted this to mean that the generalized OCP in (2) is generating these effects. It does not matter which features are shared between context and target; it only matters how many. The more clashes there are, the more likely it is that deletion will be triggered. The model can be extended to the extreme cases. The English prohibition on geminates, itself a categorical OCP effect, means that there are no cases where a coronal stop precedes the final coronal stop. In other words, where all relevant features are shared, the probability that the final stop is absent is 1. Second, preceding vowels and diphthongs share none of the relevant features, and in most English dialects, they are associated with a very low deletion rate.

TABLE 3. *Preceding segment effect on coronal stop deletion: An OCP analysis (Guy & Boberg, 1997, corpus)*

	Deletion		
Preceding Segment	*N*	%	Factor Weight
All features shared with target			
/t, d/ [+cor, −son, −cont]	—	(categorical absence, i.e., 1.00)	
Two features shared with target			
/s, z, ʃ, z/ [+cor, −son]	276	49	.69
/p, b, k, g/ [−son, −cont]	136	37	.69
/n/ [+cor, −cont]	337	46	.73
One feature shared with target			
/f, v/ [−son]	45	29	.55
/l/ [+cor]	182	32	.45
/m, ŋ/ [−cont]	9	11	.33
No features shared with target			
/r/ —[a]	86	7	.13
vowels —	—	(nearly categorical retention, i.e., .00)	
Total *N* = 1,071			

[a] We consider /r/ in this position to be functioning structurally as a glide, following Veatch (1991). Such cases are post-vocalic and phonetically realized as the *r*-colored schwa central vowel; hence, we argue they are marked [−cor].

Of particular interest for present purposes is that the various features involved in this OCP clash all appear to have approximately equal effects. This is explicitly shown in Table 4, which gives factor values from a VR analysis in which each relevant feature of the preceding segment is assigned a separate factor group. Whenever a feature of the context matches a target feature, deletion is systematically favored by a factor weight of .62 to .64.

These results can be very neatly accounted for in the VR framework, drawing on its quantitative advantages outlined earlier. Putting together several OCP violations results in increased probability of deletion, while putting together several non-violating features results in a decrease. Mixing violations and non-violations gives an intermediate rate of deletion. The effects seem equal and straightforwardly cumulative, not hierarchically ordered and trumplike, as in OT. Like good VR constraints, they are stable and transparent (and hence, we assume, learnable).

How might this effect be modeled in OT? There seems to be no reasonable way to do it. A variety of constraints could be considered relevant, but the basic issue appears to be that final stop deletion would violate faithfulness constraints, like PARSE. Deletion should therefore only occur when retention would violate something that outranks PARSE, but fail to occur when PARSE dominates. According to Guy and Boberg's analysis, the constraint that offending clusters violate is the OCP. There seems to be no reason to appeal to other constraints on optimal coda structure in the face of the data in Tables 3 and 4. So, the relevant constraints are OCP and PARSE.

TABLE 4. *Feature analysis of preceding segment effect on coronal stop deletion (Guy & Boberg, 1997, corpus)*

Features of Preceding Segment	Factor Weight (for deletion)
Sonority	
[−son]	.62
[+son]	.38
Continuancy	
[−cont]	.62
[+cont]	.38
Coronal Place	
[+cor]	.64
[−cor]	.36
Targeted features: /t, d/ = [+cor, −son, −cont]	

If we followed Nagy and Reynolds and attempted to model these facts by means of floating constraints, the results would be as follows. When OCP ≫ PARSE, all the tokens with any shared features would be deleted, while if PARSE ≫ OCP, none would be deleted. How then could we differentiate the one-feature violations from the two-feature violations? In Nagy and Reynolds's data, the variable ordering technique works to select among realizations that violate different constraints. But the Guy and Boberg data distinguish realizations that violate the same constraint different numbers of times. This cannot be modeled by tweaking the ordering, because at a given time a constraint has only one position in the hierarchy, regardless of how many times a candidate form violates it.

Kiparsky's competing-grammar approach runs into the same problem, selecting all or none of the violating forms, but not differentiating the two segment sets appropriately. His strategy of attaching probabilities to the selection of constraint orderings would only work for these data if it were complicated in some way. For example, we could hypothesize that a speaker makes an independent selection among the possible constraint orderings each time a feature tier is evaluated (e.g., selecting PARSE ≫ OCP when checking the [son] feature, but the reverse ranking when checking [cont]). Alternatively, another device that is used in OT for resolving ordering problems is to permit a constraint to be exploded into multiple subvariants. Thus, one might explode the OCP into a separate constraint for each feature (OCP-coronal, OCP-sonorant, etc.) and allow these OCP quarks to occupy different places with respect to PARSE in the hierarchy (or one could similarly explode PARSE). But each of these solutions comes at considerable cost. A system that allows us to apply a different constraint ordering—in effect, a different grammar—to every feature in a representation would appear to be no system at all. Its generative operations would be terrifically complex, and decoding and learning its output would not be significantly different from impossible. And exploding the OCP crucially fails to explain why the three different features have exactly the same constraint values in Table 4. If the OCP quarks are separate constraints, they could each have unique ranges in the ranking, generating different surface frequencies. That they fail to do so implies that there is in fact just one unitary constraint.

Furthermore, these approaches do not give the right quantitative predictions for coronal stop deletion. If the statistical distribution of forms is determined by the number of orders that license each form (as Nagy and Reynolds as well as Kiparsky assume), the facts of Table 3 are not successfully modeled. Three OCP quarks and PARSE would have 24 possible orderings, which would select deletion 12 times for words with one feature shared between target and trigger and 16 times for two-shared-feature cases. In Nagy and Reynolds's approach, this predicts deletion percentages of 50% (12 of 24 possible orders) and 66.7% (16/24), respectively, which are appreciably higher than the observed values of 30.5% and 45.4%. Worse still, this method does not predict categorical absence of the geminate case: deletion in a *-tt* cluster would be selected in only 75% of their tableaux.[5]

CONCLUSIONS

The data, along with the usual scientific considerations of economy and adequacy, require us to prefer the VR model over OT, at least as it is now formulated. The quantification of VR is more desirable in that effects are cumulative, stable, and transparent, instead of appearing and disappearing in peekaboo fashion, and the VR model is more adequate to the data. OT is to be commended for taking the first steps away from categoricality, by recognizing that there can be valid generalizations that are not always true on the surface and by recognizing the need for relations of more and less, rather than just either/or. Violable is variable, and rank ordering is quantification, and a rose by any other name will smell as sweet. But a probabilistically quantified theory is required in order to give an account of the data that achieves true optimality.

NOTES

1. Another interesting theory that shares several similarities with OT and actually predates it is the Theory of Constraints and Repair Strategies (TCRS) (cf. Paradis, 1988). This theory also has hierarchically organized violable constraints, so many of the points of comparison with the VR model also apply to TCRS. However, it differs from OT in important ways that, in my view, make it more plausible. For example, the constraints are not all required to be universal, which avoids the untestable claim of OT that many universal constraints for which a language shows no evidence are present but ordered so low that they are unexpressed. Also, TCRS retains rules and assigns a role to constraints that is more limited and more firmly founded. I focus on OT and neglect TCRS in the main body of this article not because of any difference in merit, but rather because OT has achieved such sudden popularity and has been the basis of several explicit treatments of variation.

2. See, however, the discussion below regarding universal versus language-specific constraint effects in VR. See Guy (1991) and Guy and Boberg (1997) for examples of possible universal constraints on certain VR factor effects.

3. Another use of flexible constraint orders is found in Zubritskaya (1997), who represents sound change as a diachronic re-ordering of constraints.

4. In a version of OT using variable constraint orders, as Nagy and Reynolds proposed, the nontransparency problem would be ameliorated in a corpus, because different productions of a single lexical item would give evidence for different constraints. But the instability problem would still exist since lower-ranked constraints would still be eclipsed in any given production.

5. Other constraint explosions fare even worse. Exploding PARSE by feature predicts more deletion for the one-shared-feature cases: 50% versus 33%. Simultaneously exploding both PARSE and OCP predicts 50% deletion in all preceding contexts.

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