LEXICALLY RANKED OCP-PLACE CONSTRAINTS IN MUNA

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Abstract. In this paper, we analyze the consonant co-occurrence restrictions in the Austronesian language Muna. As in Arabic and other languages, homorganic segments are underrepresented, particularly ones that are also similar in other ways. However, in Muna [voice] plays an unusually central role in this pattern. We analyze the Muna restrictions within Optimality Theory, using OCP-PLACE constraints relativized to [voice], [continuant], and [sonorant]. We claim that these constraints are ranked according the frequency with which they are violated in the lexicon. Interspersed amongst these OCP-PLACE constraints are lexically specific faithfulness constraints. We show how such a grammar can be used to explain gradient phonological well-formedness judgments; a nonce word is assigned a well-formedness score based on how often it would be parsed faithfully, given its indexation to each of the lexically specific constraints. We also show how a grammar that is sensitive to lexical frequency can be learned using a slightly augmented version of the Biased Constraint Demotion algorithm (Prince and Tesar 2004). Finally, we discuss the similarity avoidance model of Frisch *et al*. (2004); we find that the Muna data are consistent with some of its claims, but problematic for its basic premise that similarity is mediated by inventory structure.

Like many other languages, Muna (van den Berg 1989) has a restriction on the co-occurrence of homorganic consonants within a word, which is observed in the statistical underrepresentation of homorganic consonant pairs in the lexicon. And as in other languages, the strength of this restriction differs according to place of articulation, and according to how similar the consonants are in other respects. Muna is unique, however, in the degree to which [voice] agreement correlates with the underrepresentation of homorganic pairs. We advance an analysis of the Muna data in terms of OCP-PLACE constraints (McCarthy 1988) that are relativized to place of articulation and other features, including [voice] (cf. Padgett 1995). We propose a ranking of these constraints that corresponds to the degree to which they are obeyed in the lexicon. We also analyze the Muna data in terms of Frisch, Pierrehumbert and Broe's (2004) similarity metric. The Muna data are consistent with some aspects of their proposal, but pose a challenge for the central claim that differences in inventory structure are responsible for differences in similarity between consonant pairs that have the same number of features in common. Differences in inventories can explain neither the differences across place of articulation in Muna, nor the differences in the importance of [voice] agreement between Muna and Arabic.

The rest of this paper is structured as follows: In section 1, we discuss the details of the consonant co-occurrence restrictions in Muna. In section 2, we develop an account of these restrictions using OCP-PLACE constraints, and in section 3, we show how this grammar can be learned within a version of the Biased Constraint Demotion Algorithm (Prince and Tesar 2004). Finally, in section 4, we consider the relevance of the Muna data for Frisch *et al.*'s (2004) similarity based account of consonant co-occurrence patterns.

1. CONSONANT CO-OCCURRENCE PATTERNS IN MUNA

The best-known restriction against homorganic consonants is the one that obtains between consonants in adjacent positions within the Arabic verbal root (Greenberg 1950; McCarthy 1988, 1994; Pierrehumbert 1993; Padgett 1995; Frisch *et al.* 2004). Given Arabic's root-and-pattern morphological system, these consonants are often separated by vowels supplied by other morphemes, so they are not necessarily adjacent in the phonological string. There are a number of exceptions to this general restriction, but the distribution of these exceptions is not random. Frisch *et al.* (2004) examined the representation of pairs of consonants in a list 2,674 roots taken from a dictionary of standard Arabic (Cowan 1979). For each pair, they calculated an Observed/Expected ratio, that is, the number of observed words with a particular pair of consonants divided by the number that would be expected if the consonants co-occurred freely (see below for details on how this is calculated). A consonant pair with an O/E-value below one occurs less frequently than what would be expected under a chance combination of consonants, and a pair with an O/E-value over one appears more frequently than expected. Frisch *et al.*'s results, which they collapse over place of articulation, are shown in Table 1. It should be noted that they omitted pairs with identical consonants, which behave differently; we have also omitted pharyngeals, since they are irrelevant to a comparison with Muna.

In this table, O/E-values for pairs of homorganic consonants are generally near zero. However, within in the coronals, there are several degrees of representation. Pairs of coronals that are both plosives, both fricatives, or both sonorants are highly underrepresented. Sonorants co-occur with plosives and fricatives at a rate slightly higher than expected. Fricative-plosive pairs co-occur at an intermediate rate. In other words, coronal pairs that agree in sonorancy are more restricted than pairs that disagree in sonorancy, and within the obstruents, pairs that agree in continuancy are more restricted than pairs that disagree.

	Labial b f m	**Dorsal** k g q	**Coronal Sonorant** l r n	**Coronal Fricative** θ ð s z sˤ zˤ ʃ	**Coronal Plosive** t d tˤ dˤ
Labial	0.00				
Dorsal	1.15	0.02			
Coronal Sonorant	1.18	1.48	0.06		
Coronal Fricative	1.31	1.16	1.21	0.04	
Coronal Plosive	1.37	0.80	1.23	0.52	0.14

Table 1: O/E-values for "adjacent" consonants in Arabic verbal roots

Two approaches to the role of similarity in the Arabic restrictions have been proposed. One is to limit the application of the relevant constraint, OCP-PLACE, so that it targets only consonants that are similar along particular dimensions (McCarthy 1988 *et seq.*). In section 2, we discuss such relativized OCP constraints in more detail, and propose an account of Muna in these terms. Pierrehumbert (1993) and Frisch *et al.* (2004) propose that these restrictions are due to a single gradient restriction against homorganic consonants whose strength is correlated with similarity. In section 4, we apply Frisch *et al.*'s similarity metric to the Muna data.

Although place co-occurrence restrictions are best known for their appearance in Semitic languages (Greenberg 1950), there is a growing list of languages from several unrelated families that have been shown to have similar patterns.

(1) a. Javanese (Uhlenbeck 1949; Mester 1986; Yip 1989)
b. English, French, Latin (Berkeley 2000)
c. Russian (Padgett 1995)
d. Japanese (Kawahara *et al.* 2006)
e. Rotuman (McCarthy 2003b)

In this section, we report on the consonant co-occurrence restrictions in the Western Austronesian language Muna (van den Berg 1989). Here we focus on documenting the broad generalizations in the Muna data, and on testing their robustness statistically, before moving onto more detailed analysis in the following sections.

Muna's consonantal inventory is presented in (2).[1]

(2) Consonantal inventory of Muna

	labial	*coronal*	*velar*	*uvular*	*glottal*
voiceless	p	t	k		
voiced	b	d	g		
implosive	ɓ	ɗ			
nasal	m	n	ŋ		
voiceless pre-nasalized	^{m}p	^{n}t ^{n}s	^{ŋ}k		
voiced pre-nasalized	^{m}b	^{n}d	^{ŋ}g		
voiceless fricative	f	s			h
voiced fricative				ʁ	
trill		r			
lateral		l			
glide	w				

In his grammar of Muna, van den Berg (1989) examined the consonantal co-occurrence patterns in a set of 1100 CVCV roots. He found restrictions against multiple prenasalized obstruents as in Timugon Murut (Prentice 1971) and in Gurindji (McConvell 1988; Evans 1995), and against pairs of unlike liquids as in Sundanese (Cohn 1992). Van den Berg also notes that homorganic stops that differ in voicing do not co-occur, nor do nasals and homorganic

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[1] Muna also has a set of palatals recently borrowed from Indonesian, which are omitted from the inventory in (2), and from all other discussion in this paper. Van den Berg (1989, p. 16) states: "The palatal consonants /c/, /j/, and /y/ are marginal loan phonemes. The number of words containing these recent loan phonemes is very low." He further notes that they are replaced in all but very recent loans with native phonemes.

obstruents. These last two gaps are suggestive of a broader generalization: a restriction on non-identical homorganic segments, as observed in the languages in (1).

To further investigate these co-occurrence patterns, we compiled a list of all the (V)CVCV and (V)CVCVCV roots in an electronic version van den Berg and Sidu's (1996) Muna dictionary, which yielded a total of 5854 roots. Our focus here is on the patterns of co-occurrence found between consonants in what Frisch *et al.* (2004) call "adjacent" position – that is, ones separated by at most one vowel. The total number of such pairs of consonants in our corpus is 7892; it is greater than the total number of roots, since (V)CVCVCV roots each have two adjacent pairs. Following Frisch *et al.* (2004), we counted the number of times in our corpus that each pair of consonants occurs in adjacent position (observed frequency), and then calculated the number of times that each pair would have occurred if consonants combined freely (expected frequency). Expected frequency is calculated by first determining the probability of a pair of consonants - the product of the independent probabilities of each of the consonants in the relevant positions. The product of the pair probability and the total number of consonantal pairs yields the expected frequency. We then use the observed and expected frequencies to calculate O/E-values for different consonant pairs. Again, values greater than 1 indicate overrepresentation, and less than 1, underrepresentation. In the rest of this section, we report on these O/E-values.

1.1. Homorganicity and identity

Studies of the consonant co-occurrence patterns in other languages (see (1) above) have found restrictions that hold between homorganic consonants – i.e. pairs of homorganic consonants are underrepresented while pairs of heterorganic consonants are over-represented. In some cases, pairs of adjacent identical consonants typically have O/E-values above one, indicating that identical consonants are exempt from the restriction against homorganic consonants. We begin by showing that homorganicity and identity function in this way in the Muna data.

Table 2 below shows the observed and expected frequencies, and O/E-values for pairs of identical consonants.[2] Of the 17 pairs of consonants, 14 are overrepresented (have O/E-values higher than one). Assuming that the probability of overrepresentation is really 0.5, this is a significant by a one-tailed binomial test (*p* = .006). In this regard, Muna is just like several of the languages in (1) – identical consonants are not restricted in their co-occurrence. For this reason, we exclude pairs of identical consonants from all further tables and calculations in this paper.

Although the identity exemption in Muna is familiar from other languages, there is a way in which the Muna exemption differs from other languages. Consonants that are identical except that one is pre-nasalized (e.g. [k-ᵑk]) might be taken to differ in only one feature, and to be therefore highly similar in terms of their featural makeup. The expectation would then be that they should be highly restricted in their co-occurrence. They can be compared with homorganic pairs that differ in terms of prenasalization and one additional feature such as voicing (e.g. [k-ᵑg]). Such pairs differ in two features and are hence less similar, so that the expectation is that they would be less severely restricted and occur more freely than pairs that differ only in terms

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[2] We exclude from this and all further tables and calculations pairs of pre-nasalized consonants. There is an independent absolute restriction against such pairs that even applies to heterorganic segments. Our corpus of 5854 Muna roots contain no example of a root with more than one pre-nasalized segment.

of prenasalization. This expectation is not borne out. In fact, the opposite is observed – pairs of consonants that differ only in prenasalization occur more freely than pairs that differ in prenasalization and voicing. Table 3 contains the observed, expected and O/E-values for pairs of prenasalized plosives and ordinary plosives. In 5 out the 6 instances, the O/E-value for the consonants that differ only in prenasalization (e.g. [k-^{ŋ}k]) is higher than that of consonants that differ in both pre-nasalization and voicing (e.g. [g-^{ŋ}k]). Assuming that the probability of higher O/E-values for the pair that differ only in pre-nasalization is really 0.5, then the likelihood of this happening in at least 5 instances tends towards significance by a one-tailed binomial test (*p* = .11).[3] Pairs of homorganic consonants that differ only in prenasalization seem to pattern more like identical consonants than like non-identical consonants, perhaps because identity is computed on the oral portion of the complex segment. Like the pairs of identical consonants, we exclude these pairs from further tables and calculations.

	Observed	**Expected**	**O/E**
p~p	29	19.8	1.46
b~b	14	5.0	2.80
ɓ~ɓ	17	10.0	1.70
m~m	14	11.3	1.24
f~f	6	2.4	2.50
w~w	23	11.3	2.04
t~t	48	47.0	1.02
d~d	24	9.5	2.53
ɗ~ɗ	9	3.1	2.90
n~n	29	9.9	2.93
s~s	45	37.1	1.21
l~l	93	104.0	0.89
r~r	26	57.8	0.45
k~k	44	53.7	0.82
g~g	16	3.6	4.44
ŋ~ŋ	3	1.7	1.76
ʁ~ʁ	21	5.9	3.56

Table 2: Adjacent identical consonants Muna

Our analysis in section 2 abstracts away from the identity effect, because further study is needed to determine its source. In particular, we note that in many cases the identical consonants do precede identical vowels, suggesting some form of reduplication. We did exclude all affixes that were marked as such in van den Berg and Sidu (1986) from our corpus; nonetheless, it is still possible that some of the identical pairs are either diachronically or synchronically due to reduplication (see Yip 1989 on Javanese).

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[3] The lone exception is for the coronals. As we will see below, the non-identical coronals tend to occur much more freely with each other than non-identical labials or dorsals. The reason for the freer co-occurrence of [^{n}t] with [d] is therefore most likely because the restriction against the co-occurrence of coronals is not that strong to begin with.

Differ in voicing?	**Pair**	**Observed**	**Expected**	**O/E**
No	^{m}p~p	16	20.36	0.79
Yes	^{m}p~b	2	9.82	0.20
No	^{m}b~b	8	15.46	0.52
Yes	^{m}b~p	10	32	0.31
No	^{n}t~t	27	36	0.74
Yes	^{n}t~d	14	15.30	0.92
No	^{n}d~d	17	13	1.31
Yes	^{n}d~t	40	32.91	1.22
No	^{ŋ}k~k	29	44.81	0.65
Yes	^{ŋ}k~g	0	9.35	0.00
No	^{ŋ}g~g	5	2.22	2.25
Yes	^{ŋ}g~k	0	10.06	0.00

Table 3: Adjacent consonants that differ only in prenasalization, and that differ in prenasalization and voicing.

Non-identical homorganic consonants are restricted in their co-occurrence; this becomes clear in a comparison with non-identical heterorganic consonants, which co-occur freely. Table 4 presents the O/E-values for non-identical consonants by place of articulation.[4] Inspection of the table will confirm that the values for pairs of homorganic consonants are all below 1, while the values for pairs of heterorganic consonants are all above 1. Our corpus contains 156 pairs of homorganic consonants, and 123 out of these (79%) have O/E-values below 1 – i.e. occurred less frequently than what would be expected if consonants combined freely. The number of these pairs that are underrepresented differ significantly from chance by a one-tailed binomial test ($p < .001$). The opposite is true for the heterorganic pairs. There are 411 such pairs in our corpus and 272 of these (66%) have O/E-values above 1 – a proportion significantly different from chance by a one-tailed binomial test ($p < .001$). More homorganic pairs are therefore underrepresented than what would be expected by chance, while more heterorganic pairs are overrepresented than what would be expected by chance. Since the co-occurrence restrictions apply only to homorganic consonants, we limit the discussion in the rest of the paper to these consonant pairs.

	Labial			**Coronal**			**Dorsal**		
	Obs	Exp	**O/E**	Obs	Exp	**O/E**	Obs	Exp	**O/E**
Labial	132	441.9	**0.30**						
Coronal	2741	2179.0	**1.26**	1338	1686.0	**0.79**			
Dorsal	875	770.9	**1.14**	1766	1522.5	**1.16**	29	163.6	**0.18**

Table 4: Adjacent homorganic and heterorganic consonants in Muna.

As Table 4 shows, pairs of homorganic consonants can be ordered as follows in terms of their O/E-values: coronal > labial > dorsal. It therefore seems to be the case that coronals are least restricted in their co-occurrence, with labials in an intermediate position and dorsals the most

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[4] Excluding pairs of consonants that are both prenasalized, pairs of identical consonants, and pairs of consonants that differ only in terms of prenasalization – see the discussion earlier in this section.

restricted. We used the non-parametric Wilcoxon Rank-Sum (Mann-Whitney) test in order to test whether these differences are statistically significant (Mann and Whitney 1947). The difference between the O/E-values for the pairs of labials and pairs of coronals differ significantly (*Wilcoxon* $W = 2208.5$, $z = -4.98$, $p < .001$), as do the O/E-values for pairs of dorsals and pairs of coronals (*Wilcoxon* $W = 912.5$, $z = -4.22$, $p < .001$). However, although there is a trend for the O/E-values of pairs of dorsals to be lower than that of pairs of labials, this difference did not reach significance (*Wilcoxon* $W = 965$, $z = -1.52$, $p = .13$).[5]

The observed, expected and O/E-values for all homorganic consonant pairs (excluding identical pairs, and pairs that are identical except that one is prenasalized) can be found in Appendix A.

1.2. The influence of major class and manner features

We have now established that Muna has co-occurrence restrictions against adjacent non-identical, homorganic consonants, just like the other languages in (1). In these other languages, it is not always the case that all pairs of consonants within some place of articulation are equally underrepresented. In Arabic, for instance, the co-occurrence of coronals is sensitive to similarity on other dimensions such as sonority and continuancy. In this section, we show that Muna has a particularly elaborate variegation of the strength of the restrictions within the places. Specifically, we show that homorganic pairs of consonants that agree in terms of [voice], [continuant] or [sonorant] occur less freely than pairs that differ in terms of these features.

Table 5 contains the observed, expected and O/E-values for pairs of consonants that agree and differ in terms of each of the features [voice], [continuant] and [sonorant]. As explained above, we exclude from this table the values for heterorganic consonants, pairs of prenasalized consonants, identical consonants, and consonants that differ only in terms of prenasalization. In reporting on [voice], we also exclude the implosives.[6] Unlike in the tables used in section 1.1, we preserve the order between the consonants in each pair. However, this is done only for statistical reasons and is not crucial to the point illustrated here. Inspection of the tables will show that O/E-values for the pairs of consonants that differ in some feature are generally very similar irrespective of the order between the consonants – i.e. the O/E-values for {+F, -F} and {-

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[5] The lack of a significant difference between the O/E-values for dorsals and labials is most likely caused by the fact that for both of these groups there is a large number of pairs that do not occur at all (i.e. O/E = 0). Out of the 28 dorsal pairs, 16 have O/E-values of zero, and out of the 50 dorsal pairs, 15 have O/E-values of zero. Since O/E-values lower than zero are not possible, clustering of O/E-values at zero cancels out some of the difference between these two places of articulation.

[6] Inspection of the tables Appendix Awill confirm that the implosives co-occur less frequently with the nasals than do the voiceless stops. In this regard, they act as if their similarity to the nasals is higher than the similarity of the voiceless stops to the nasals – i.e. they act as if they are [+voice]. On the other hand, the implosives occur somewhat more frequently with the voiced oral and prenasalized stops than with the voiceless ones (only the coronal oral stops buck this trend). In this regard, they act as if they are less similar to the voiced stops than to the voiceless stops, and hence as if they are [-voice]. The tables in the appendix also shows that the pair [ɓ-f] occurs at about the same rate as [p-f], and less frequently than [b-f], in which [ɓ] acts like voiceless [f]. However, [ɗ-s] occurs at about the same rate as [d-s], and more frequently than the pair [t-s]. In this respect [ɗ] therefore acts more like voiced [d]. In sum, the implosives seem to be neutral with respect to voicing. Because of this, we left out the implosives in all calculations reported below about the effect of the effect of [voice] on co-occurrence.

F, +F} are both higher than 1. In Table 5 (b), the plosives and nasals were counted as stops, while fricatives, liquids and glides were counted as continuants.

(a) [sonorant]

C2 C1	**Sonorant**	**Obstruent**
Sonorant	O = 80 E = 261 O/E = 0.31	O = 428 E = 247 O/E = 1.73
Obstruent	O = 690 E = 509 O/E = 1.36	O = 301 E = 482 O/E = 0.62

(b) [continuant]

C2 C1	**Continuant**	**Stop**
Continuant	O = 359 E = 434 O/E = 0.83	O = 397 E = 322 O/E = 1.23
Stop	O = 502 E = 427 O/E = 1.18	O = 241 E = 316 O/E = 0.76

(c) [voice]

C2 C1	**Voiced**	**Voiceless**
Voiced	O = 304 E = 452 O/E = 0.67	O = 329 E = 181 O/E = 1.82
Voiceless	O = 658 E = 510 O/E = 1.29	O = 57 E = 205 O/E = 0.28

Table 5: The effects of [sonorant], [continuant], and [voice] on co-occurrence of homorganic, non-identical consonants.

Inspection of Table 5 will show that all three of these features contribute to the co-occurrence restriction. In Table 5 (a), 5 (b) and 5 (c), the cells that correspond to adjacent segments that agree in the relevant features (top left, and bottom right) all have O/E-values below 1, while the cells corresponding to adjacent segments that differ in terms of the relevant feature (bottom left, top right) all have O/E-values above 1. The deviations from the expected values are significantly different from chance for all three features by a χ^2-test. Adjacent segments that agree in terms of the feature [sonorant] occur less frequently than what is expected under chance ($\chi^2 = 390$, $p < .001$), as do adjacent segments that agree in [continuant] ($\chi^2 = 62$, $p < .001$), and adjacent segments that agree in terms of [voice] ($\chi^2 = 318$, $p < .001$).

The contribution of [sonorant] and [continuant] to the place co-occurrence restriction is not surprising in light of the findings on Arabic, as well as the other languages mentioned in (1). In all of these languages, agreement in sonorancy is the main determinant of the strength of the restriction, with continuancy playing a secondary role (see esp. Padgett 1995). In terms of the contribution of the features [sonorant] and [continuant] to the co-occurrence restrictions, Muna patterns with the other languages. However, the strong contribution that [voice] makes to the co-occurrence restrictions in Muna is different from previously reported languages. In fact, there is even evidence that is strongly suggestive that [voice] is more important than [sonorant] and [continuant] in determining the co-occurrence restrictions in Muna.

Across all three places of articulation, pairs of consonants that agree in [voice] but differ in [sonorant] (i.e. [nasal, voiced stop]-pairs) are more underrepresented than pairs that differ in [voice] but agree in [sonorant] (i.e. [voiced stop, voiceless stop]-pairs). The observed, expected and O/E-values for these pairs of consonants in Muna are reported in Table 6. This pattern is different from Arabic, where obstruents, irrespective of their voicing, occur more freely with sonorants than with other obstruents.

Agree in [sonorant], differ in [voice]				**Agree in [voice], differ in [sonorant]**			
	O	E	**O/E**		O	E	**O/E**
t-d	26	43.6	**0.60**	n-d	5	19.9	**0.25**
p-b	2	20.0	**0.10**	m-b	1	15.2	**0.07**
k-g	2	30.33	**0.07**	ŋ-g	0	5.97	**0.0**

Table 6: The interaction if [voice] and [sonorant].

There is similar evidence suggestive that agreement in [voice] trumps agreement in [continuant]. Table 7 contains the observed, expected and O/E-values for pairs of obstruents that agree in [continuant] but differ in [voice] (i.e. voiced and voiceless stops), and for the pairs agree in [voice] but differ in [continuant] (i.e. stops with similar voiced fricatives). The observed values for labials and dorsals are very small so that it is not safe to make strong statements about these two places of articulation. However, for the coronals, it is clear that the pair that agrees in [voice] ([t-s]) is more underrepresented than the pair agrees in [continuant] ([t-d]).

Agree in [continuant], differ in [voice]				**Agree in [voice], differ in [continuant]**			
	O	E	**O/E**		O	E	**O/E**
t-d	32	43.57	**0.73**	t-s	31	83.51	**0.37**
p-b	2	20.01	**0.10**	p-f	3	13.82	**0.22**
k-g	2	30.33	**0.07**	g-ʁ	0	9.32	**0.00**

Table 7: The interaction if [voice] and [continuant].

There is also evidence that prenasalization plays a role in determining the co-occurrence restrictions. We have shown above that pairs that are identical except that the one is prenasalized (e.g. [k-^{ŋ}k]) occur more freely than pairs that differ both in prenasalization and voicing (e.g. [g-^{ŋ}k]). This lead us to conclude that pairs like [k-^{ŋ}k] are treated similar to identical pairs in spite of their difference in prenasalization. However, this does not mean that prenasalization is completely inert in determining the patterns of consonant co-occurrence in Muna. When a prenasalized segment is paired with a homorganic segment that is not identical to its oral portion (e.g. [k-^{ŋ}g]), the difference in prenasalization does seem to mitigate the strength of the co-occurrence restriction – these pairs are less underrepresented than the corresponding pairs that agree in prenasalization (e.g. [k-g]). The values for all these pairs that can be compared across place of articulation are shown in Table 8. This same effect is seen in the how the coronal fricatives [s] and [^{n}s] co-occur with [t] and [d]. The pair [d-s] that agrees in prenasalization has a lower O/E-value than the pair [d-^{n}s] that differs in prenasalization (0.55 vs. 1.68). However, agreement in [voice] trumps agreement in prenasalization: the pair [t-^{n}s] has no advantage over the pair [t-s] in spite of the fact that [d-^{n}s] differs in prenasalization. In fact, [d-^{n}s] is more underrepresented than [t-s] (0.05 vs. 0.37). The fact that [d-^{n}s] agrees in voicing seems to cancel out any advantage that this pair has because of its difference in prenasalization.

Differ in prenasalization?	**Pair**	**Observed**	**Expected**	**O/E**
No	p~b	2	20.01	0.10
Yes	^{m}p~b, ^{m}b~p	12	41.74	0.29
No	t~d	26	43.57	0.60
Yes	^{n}t~d, ^{n}d~t	54	48.21	1.12
No	k~g	2	30.33	0.07
Yes	^{ŋ}k~g, ^{ŋ}g~k	2	19.41	0.10

Table 8: Pairs that differ in voicing, and that either agree or differ in prenasalization.

1.3. General [voice] disagreement?

Since Muna is unique in the extent to which disagreement in [voice] functions to weaken the place co-occurrence restriction, one might seek an alternative explanation for the lower O/E-values seen in pairs that agree in [voice]. One such alternative could be that [voice] disagreement is general in the language, and not specific to homorganic pairs. In this subsection, we show that there is no such general restriction on pairs that agree in [voice].

Table 9 contains the observed, expected, and O/E-values for pairs of adjacent heterorganic consonants that differ and agree in voicing. This table should be compared with Table 5 (c) above, where the same values were reported for homorganic consonants. Inspection of Table 9 will show that the O/E-values in this table are much closer to 1 than what was the case in Table 5 (c). Further, in Table 9, the O/E-values for the pairs of consonants that agree in terms of [voice] (the top left and bottom right cells) are slightly above1, and the O/E-values for pairs that differ in [voice] (top right and bottom left) are slightly below 1. This is directly opposite to the pattern observed for the homorganic consonants in Table 5 (c). The distribution of the heterorganic consonants in terms of voicing agreement differs significantly from chance by χ^2-test (χ^2 = 20.27, p < .001). However, since pairs that agree in terms of [voice] agree more rather than less frequently than expected, this confirms that there no restriction on the co-occurrence of heterorganic consonants that agree in [voice]. This restriction is limited to homorganic consonants.

C2 **C1**	**Voiced**	**Voiceless**
Voiced	O = 1722 E = 1646 O/E = 1.05	O = 851 E = 927 O/E = 0.92
Voiceless	O = 1459 E = 1535 O/E = 0.95	O = 941 E = 865 O/E = 1.09

Table 9: Heterorganic adjacent consonants that agree or differ in terms of [voice]

2. MUNA AND RELATIVIZED OCP-PLACE CONSTRAINTS

2.1. Relativized OCP-Place constraints in Arabic

Relativized OCP-Place constraints were first introduced to account for the co-occurrence patterns amongst coronals in Arabic; Table 10 repeats the relevant O/E-values from Frisch *et al.* (2004).

	Sonorant l r n	**Fricative** θ ð s z sˤ zˤ ʃ	**Plosive** t d tˤ dˤ
Sonorant	0.06		
Fricative	1.21	0.04	
Plosive	1.23	0.52	0.14

Table 10: O/E-values for adjacent coronals in Arabic verbal roots

McCarthy (1988) accounts for the fact that sonorants and obstruents co-occur freely by specifying that the constraint against homorganic segments, the OCP for consonantal place, applies only within the subclasses of coronals defined by the feature [+/-sonorant]. In Dresher (1989), Selkirk (1991), and Padgett (1995), the general OCP constraint is elaborated into a set of more specific constraints that are violated only by segments that are identical in particular ways (see especially Padgett 1995 on this aspect of the proposal). Definitions of the relativized OCP-Place constraints required for the Arabic case appear in (3). In these earlier analyses, the consonants in question are assumed to be adjacent at a derivational level in which intervening vowels are absent. We continue to use the term ‘adjacent’, but under the standard OT assumption that markedness constraints apply at the surface, adjacency must be defined so as to ignore intervening vowels, but not intervening consonants (see Suzuki 1998; Rose 2000).

(3)		
	a. OCP-COR[-SON][αCONT]	No adjacent coronal obstruents agreeing in continuancy
	b. OCP-COR[+SON]	No adjacent coronal sonorants
	c. OCP-COR[-SON]	No adjacent coronal obstruents
	d. OCP-COR	No adjacent coronals

The constraints in (3a) and (3b) are clearly active in Arabic, given the low O/E-values along the diagonal in Table 10, while (3d) is clearly inactive, given the overrepresentation of the pairs disagreeing in sonorancy. However, OCP-COR[-SON] seems to occupy an intermediate status, which poses a quandary for a theory with inviolable constraints (cf. McCarthy 1994; Padgett 1995). If it is active, then coronal plosive-fricative sequences should be absent from the lexicon, or nearly so. If it is inactive, then they should be unrestricted. Neither of these seems accurate, given their intermediate degree of representation.

This sort of gradience is one factor that leads Frisch *et al.* (2004) to reject an OCP-based account of the Arabic data. Here we instead modify the relativized OCP account by making use of constraint violability and ranking to capture the gradient nature of this restriction. In particular, we propose that OCP-PLACE constraints are ordered in the grammar on the basis of lexical frequency. The Arabic data in table 11 motivate a ranking like that in (4):

(4) OCP-COR[-SON][αCONT], OCP-COR[+SON] >> OCP-COR[-SON] >> OCP-COR

This ranking represents Arabic speakers’ knowledge of the lexical regularities, as represented in the phonological grammar. According to this ranking, a word violating a constraint in the topmost stratum will be judged as worse than one violating a constraint in the middle stratum, which will in turn be dispreferred relative to a word violating only the lowest ranked constraint. While there is no direct evidence of this particular pattern of judgments in the experimental literature, it is clear that speakers of Arabic, and other languages, do make gradient judgments of this kind when confronted with nonce words with various patterns of OCP violation (see further section 3.2). For evidence that these judgments are based on abstract knowledge, rather than direct analogy from the lexicon see especially Frisch and Zawaydeh (2001), Coetzee (2004), Berent and Shimron (1997), and Berent *et al.* (2001a, b).

Section 3 discusses how rankings based on lexical frequency may arise in learning, and how judgments are projected from them. For now, we focus on presenting the ordering of relativized OCP-PLACE constraints that is consistent with the Muna lexical data.

2.2. Relativized OCP-Place constraints in Muna

As discussed in section 1.1, the Muna place co-occurrence restriction differs according to place of articulation; pairs of dorsals are somewhat more restricted than pairs of labials, and both are much more restricted than pairs of coronals. And as discussed in section 1.2, the restriction is also stronger amongst homorganic segments that agree for other features, including [voice], [continuant], and [sonorant].

In this section, we show how these factors interact by providing an analysis of one part of the Muna data in terms of relativized OCP constraints. The data that we analyze includes just those segment types that can be compared across place of articulation, and excludes prenasalized stops. In following sections, we discuss how this analysis can be extended to other aspects of the data. Table 11 contains the O/E-values for all the relevant consonant pairs from Muna, as well as an example of a Muna word containing each of the observed consonant pairs.

	Coronal	**Labial**	**Dorsal**
Voiced Stop + Voiceless Stop	d-t: 0.60 datu	b-p: 0.10 pabu	g-k: 0.07 kagala
Nasal + Voiced Stop	n-d: 0.25 da:no	m-b: 0.07 bomu	ŋ-g:0.00 –
Nasal + Voiceless Stop	n-t: 0.70 tunani	m-p: 0.39 mopi	ŋ-k: 0.10 kaŋia
Nasal + Fricative	n-s: 1.17 nasi	m-f: 1.04 mafaka	ŋ-ʁ: 0.00 –
Fricative + Voiced Stop	s-d: 0.55 sida	f-b: 0.58 febuni	ʁ-g: 0.00 –
Fricative + Voiceless Stop	s-t: 0.37 tisore	f-p: 0.07 fopanto	ʁ-k: 0.40 kaʁa

Table 11: O/E-values for voiced and voiceless stops, fricatives, and nasals

The constraints we employ are OCP constraints relativized to place of articulation, and to agreement for [voice], [continuant], and [sonorant]. They are defined in (5):[7]

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[7] We follow Suzuki (1998) and define OCP-PLACE in rather traditional terms, rather than reformulating it in terms of Local Conjunction (see Smolensky 1995, 2005 on Local Conjunction and Alderete 1997 on Local Conjunction and

(5) Relativized OCP-PLACE constraints

OCP-PLACE-[αVCE]	No adjacent segments that agree in Place and in voicing
OCP-PLACE-[αSON]	No adjacent segments that agree in Place and in sonorancy
OCP-PLACE-[αCONT]	No adjacent segments that agree in Place and continuancy
OCP-PLACE-[αSON, βCONT]	No adjacent segments that agree in Place, sonorancy and continuancy

Where 'Place' is one member of the set {Dorsal, Labial, Coronal}

Because the effect of voicing agreement in Muna cuts across manner categories, it is unnecessary to further relativize the OCP-PLACE-[αVCE] constraints to sonorancy or continuancy (though cf. 2.3.1). The constraint OCP-PLACE[αSON, βCONT] is used only when it is necessary to distinguish homorganic pairs that differ in [voice] but agree in [sonorant] and [continuant] ([k-g], [p-b], [t-d]) from either pairs that differ in [voice] but agree only in [sonorant] ([k-ʁ], [b-f], [d-s]) or in [continuant] ([ŋ-k], [m-p], [n-t]). Since [k-g] patterns differently from [k-ʁ], and since [p-b] patterns differently from both [b-f] and [m-p], we do employ the dorsal and labial versions OCP-PLACE[αSON, βCONT]. However, since [t-d], [d-s] and [n-t] all pattern roughly similar, it is not necessary to distinguish [t-d] from [d-s] and [n-t]. We therefore do not use the coronal version of OCP-PLACE[αSON, βCONT].

The figure in (6) shows the ranking of these constraints that corresponds to the Muna O/E-values in Table 11. Ranking is indicated by vertical order; OCP-DOR[αVCE] is the highest ranked constraint, while OCP-LAB and OCP-COR are the lowest. To highlight the effect of place, the constraints for each place of articulation are vertically aligned. Constraints are placed as high in the hierarchy as is consistent with the data. For example, OCP-DOR[αVCE] is ranked at the top of the hierarchy, because none of the sequences it targets are attested; OCP-DOR[αSON] ranks lower because it targets a sequence that has an O/E-value of 0.40.

The horizontal lines indicate groupings of constraints into strata, with no internal ordering. For constraints in a stratum, the O/E-values of the sequences they target are close together. These groupings are to a certain extent arbitrary. For example, there is no reason why a sequence with an O/E-value of 0.55 should be grouped with one with a value of 0.70 rather than 0.40. However, imposing other groupings would introduce no counter-examples to our analytic claims. It would simply move constraints between strata, or introduce more strata to make finer-grained distinctions. With one exception (more directly below), all of the constraints target consonant pairs with O/E-values that do not overlap with the O/E-values of consonant pairs targeted by any other constraint. The constraints could therefore be placed in a complete linear ordering corresponding to the O/E-values of the consonant pairs that they target. The lone exception in this regard is the ranking between the constraints OCP-COR[αSON] and OCP-LAB[αSON]. OCP-COR[αSON] targets sequences with O/E-values (0.55 and 0.60) that falls on either side of the O/E-value (0.58) of the sequence targeted by OCP-LAB[αSON]. Ranking these two constraints based on the O/E-values of the sequences that they target would therefore require OCP-

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OCP-PLACE; see Itô and Mester 2003, p. 59-61) on issues with the Local Conjunction approach to OCP-PLACE). Because of our concerns with the typological effects of free Local Conjunction (see again Itô and Mester 2003, as well as McCarthy 1999, 2003), we do not derive the relativized constraints from conjunctions of constraints like OCP-VOICE with OCP-PLACE (cf. Suzuki 1998). We instead see it as a substantive component of OCP-PLACE constraints that they are relativized in this way.

Cor[αSon] to be ranked both above and below OCP-Lab[αSon]. However, we suspect that differences in O/E-values of the three sequences targeted by these two constraints are most likely too small to affect native speaker judgments, so that these two constraints can safely be ranked in the same stratum.[8] Ultimately the question of how sensitive speakers are to differences in O/E-values is an empirical question that should be answered experimentally.

(6) Relative strength of OCP-Place constraints

OCP-Constraint			**Targeted Pairs (O/E)**	**O/E-Range**
Dor[αvoice]			ŋ-g (0) ʁ-g (0) ŋ-ʁ (0)	0
	Lab[αvoice]		f-p (0.07) m-b (0.07)	0.07 – 0.10
Dor[αson,βcont]			g-k (0.07)	
Dor[αcont]			ŋ-k (0.07)	
	Lab[αson,βcont]		b-p (0.10)	
		Cor[αvoice]	n-d (0.25) s-t (0.37)	0.25 – 0.40
	Lab[αcont]		m-p (0.39)	
Dor[αson]			ʁ-k (0.40)	
Dor				
		Cor[αSon]	s-d (0.55) d-t (0.60)	0.55 – 0.70
	Lab[αSon]		f-b (0.58)	
		Cor[αCont]	d-t (0.60) n-t (0.70)	
	Lab		m-f (1.04)	> 1
		Cor	n-s (1.17)	

The most striking thing about this analysis is that across places of articulation, the constraint relativized to [voice] is highest ranked. Padgett (1995) claims that while OCP-Place can be specified to apply only to segments that are identical in sonorancy or continuancy (as well as subsidiary place, like [anterior] or [distributed]), it cannot be limited to segments that are identical for voicing (or nasality). The Muna data show that this claim is too strong, as does evidence from other languages on restrictions on homorganic sequences of consonants that are not separated by a vowel (see Côté 2004, as well as Shiels-Djouadi 1975 and Guy and Boberg 1997).

More broadly, it is significant that this Muna place restriction is sensitive to the presence of a non-contrastive feature (see also Frisch *et al.* 2004; cf. Yip 1989, Padgett 1995). OCP-Place[αvce] applies to voiced stops paired with nasals, or with the voiced fricative [ʁ], and to voiceless stops paired with the voiceless fricatives. Voicing is contrastive in neither the nasals nor the fricatives. This is especially relevant in the context of a derivational theory with underspecification (see Steriade 1995 for a review that focuses on the role of contrast). Because these constraints operate on the lexicon, they would provide evidence for the specification of non-contrastive [voice] at the earliest stages of the derivation. Thus, the inertness of non-

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[8] One might be tempted to conduct a statistical analysis to determine which of the differences in O/E-values are significant, prior to constructing a phonological analysis that would reflect only the statistically significant differences. We opted not to do this, because conducting this many pairwise comparisons would dramatically inflate the possibility of Type 1 errors, if we did not adjust the significance level. If we did apply a Bonferroni adjustment, then we would likely fail to find any comparisons that reach significance. Instead, we rely on the statistical tests in section 1 to provide evidence that each of the factors in our analysis (Place, [voice], [sonorant] and [continuant]) does in fact affect O/E.

contrastive voicing in other languages could not be attributed to a universal principle of lexical underspecification (see again Steriade 1995 for discussion).

In Muna, the feature [continuant] patterns in fashion similar to [voice]. OCP-Place[αcont] applies across the sonorancy divide to restrict co-occurrence of nasals with stops ([ŋ-k], [m-p]) relative to stop-fricative pairs ([ʁ-k], [b-f]) pairs. This is not to say that agreement for [sonorant] is unimportant; pairs that agree in sonorancy are consistently underrepresented with respect to those that agree. This is reflected in the higher rank of OCP-Place[αson] above unrelativized OCP-Place for each instantiation, dorsal, labial, and coronal.

The analysis in (6) displays a particularly intricate interplay between place of articulation and manner agreement. The ranking of each set of relativized OCP-Place constraints (e.g. the OCP-Place[αvoice] constraints), is consistent with the order Dorsal >> Labial >> Coronal. This ordering is either completely instantiated (e.g. for OCP-Place[αvoice], OCP-Place[αcont]), or it is not contradicted (e.g. OCP-Place[αson] for labials and coronals fall in the same stratum).[9] This is in line with the proposals that the non-coronal markedness constraints *Dorsal and *Labial are in a universally fixed ranking above *Coronal (Prince and Smolensky1993/2004; cf. de Lacy 2002), and that such rankings are preserved in more complex constraints that make use of the atomic constraints (see e.g. Prince and Smolensky 1993/2004 ch. 5; Alderete 1997; de Lacy 2002; Gouskova 2004, McCarthy 2002, p. 21; Itô and Mester 2003, p. 59-61). In our view, there is a template for place constraints like that in (7). This template is filled in with different values for Place, and for subsidiary features like [sonorant], [voice] and [continuant], and combinations thereof. For any constraint with subsidiary feature(s) x, that applies to coronals, the version that applies to labials and dorsals is universally ranked higher.

(7) OCP-Place-[x] ‘No adjacent consonants that agree in Place and agree in feature [x]’
Where ‘Place’ ∈{Dorsal, Labial, Coronal}

While the coronal/non-coronal relationship may be universally fixed in this way, the labial and dorsal preference can be reversed on a language specific basis (see e.g. Coetzee 2004 on English). The differences between Muna and Arabic show that the individual manners are not in a fixed relationship; Muna clearly has higher ranked OCP-Place[αvoice] constraints than does Arabic.

2.3. Other obstruent/sonorant interactions

Since earlier proposals about relativized OCP-Place constraints were based on interactions of Arabic coronals, it is particularly useful to examine the comparable Muna data. Table 12 presents the O/E-values for all of the Muna coronals that have Arabic counterparts; it leaves out the prenasalized obstruents and the implosive. In the rest of this section, we discuss the additional OCP-constraints that would be necessary to capture the co-occurrence patterns between these consonants, and show how these additional constraints could be ranked.

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[9] In OT, a portion of a fixed hierarchy fails to be instantiated if no conflicting constraint is placed within it. We have thus far presented no constraints that conflict with the OCP-Place constraints; see section 3 for a proposal on how faithfulness constraints are interspersed in hierarchies reflecting lexical frequency.

	t	**d**	**s**	**l**	**r**
d	0.60				
s	0.37	0.55			
l	0.78	0.79	1.13		
r	0.88	0.84	1.08	0.19	
n	0.70	0.25	1.17	0.32	0.56

Table 12: O/E-values for Muna coronals

In Arabic, [n] is highly underrepresented with [l] and [r], and overrepresented with [d].[10] In Muna, on the other hand, [n] is underrepresented with [l] (0.32), [r] (0.56) and [d] (0.25). Unlike in Arabic, it is therefore necessary in Muna that there be a constraint that can target the consonant pair [n-d]. Initially, it would seem that OCP-COR[αVOICE] could be used for this. However, [l] and [r] occur relatively freely with [d] (0.79 and 0.84), and they also agree in voicing with [d]. Similarly, it is not possible to use OCP-COR[αCONT] to account for the underrepresentation of [n-d]. The reason is that [n-t], that also agrees in continuancy, is not nearly as underrepresented as [n-d] (0.70 vs. 0.25). Both OCP-COR[αVOICE] and OCP-COR[αCONT] therefore have to rank so low that they cannot explain the underrepresentation of [n-d]. We need a constraint that can target [n-d] to the exclusion of [l-d], [r-d] and [n-t]. This gives evidence that we need OCP-COR[αCONT][βVOICE] in Muna – [n-d] agrees in both [continuant] and [voice], while [l-d] and [r-d] agree in only [voice], and [n-t] in only [continuant]. There is also some evidence for the activity of the constraint OCP-COR[αSON][βVOICE] in Muna. Within the class of coronal obstruents, those that agree in voicing ([s-t]) have a somewhat lower O/E-value than those that differ in voicing ([s-d], [t-d]) (0.37 vs. 0.55 and 0.60). We can pick out the pair [s-t] to the exclusion of the pairs [s-d] and [t-d] with the constraint OCP-COR[αSON][βVOICE]. In addition to these two constraints, we still need OCP-COR[αSON] to account for the co-occurrence patterns of the obstruents that differ in voicing, and general OCP-COR for the pairs that differ in voicing and sonorancy. The relative ordering of this expanded set of OCP-Cor constraints is shown in (8).[11]

(8)	OCP-COR[αCONT][βVOICE]	n-d (0.25), l-r (0.19)
	OCP-COR[αSON][βVOICE]	n-l (0.32), r-n (0.56), t-s (0.37)
	OCP-COR[αSON]	s-d (0.55), t-d (0.60)
	OCP-COR	t-l (0.78), t-n (0.70), d-l (0.79), d-r (0.84), t-r (0.88), s-l (1.13), s-r (1.08), s-n (1.17)

The coronals thus provide some evidence that for the interaction of [voice] agreement with the [continuant] and [sonorant] in defining classes targeted by relativized OCP-PLACE. The dorsals and labials show a sort of ceiling effect, in that all pairs that agree in [voice] are nearly unattested. Furthermore, in the coronals we see the same groupings of consonants into classes

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[10] Frisch *et al.* (2004) unfortunately do not give the O/E-value for all the individual pairs of consonants. They do, however, report the O/E-value for pairs of non-identical coronal sonorants as 0.06. This implies that pairs the [n-l] and [n-r] are highly underrepresented. They also report that the O/E-value for the coronal sonorants with the coronal plosives is 1.23, implying that the pair [n-d] is overrepresented.

[11] Interestingly, the stop-liquid pairs are slightly underrepresented, and the fricative-liquid pairs are slightly overrepresented. Insofar as the liquids and the fricative are both specified as [continuant], and the voiceless stops have no feature in common with the liquids other than [consonantal], this seems mysterious.

defined by [+/-sonorant] and [+/-continuant] that we find in Arabic and in other languages, but also the strong effect of the grouping by [+/-voice] that is specific to Muna: [n-d] and [t-s], which agree in [voice] but disagree in [sonorant] and [continuancy] have much lower O/E-values than [t-d], which disagrees in just [voice] (0.25 and 0.37, vs. 0.60). In Arabic this is reversed; [t-d] is more restricted than [n-d] or [t-s].

The labial approximant [w] also interacts with obstruents; it never appears with the voiced stop [b], while it does sometimes appear with the voiceless stop [p] (O/E = 0.19). However there is some evidence that /w/ may not be a true sonorant. René van den Berg (p.c.) notes that though it is described as an approximant in van den Berg (1989), it is sometimes realized as a voiced bilabial fricative. Because of this uncertainty, we cannot conclude much from its behavior.

2.4. Prenasalization and the computation of similarity

In section 1.2, we showed that prenasalized segments are restricted in co-occurrence with non-prenasalized homorganic segments (modulo identity effects). But we also saw that, as with the manner and class features, disagreement in prenasalization weakens the restriction. For example, [p-^{m}b] and [b-^{m}p] (that differ in prenasalization) co-occur at a rate of 0.31 and 0.20 respectively, which is much lower than expected, but somewhat higher than [p-b] which agree in prenasalization (0.10).

It is generally agreed that there is no feature [+/-prenasal], and that a prenasalized segment is composed of [+nasal] and [-nasal] portions (Sagey 1986). One possible approach would be to invoke relativized OCP constraints that apply only under agreement for [nasal], where prenasals agree in nasality with neither plain oral nor plain nasal segments. This constraint would fail to apply to pairs in which one segment is prenasalized, and would apply to pairs in which both are fully oral, consistent with the underrepresentation of the latter.[12]

Since we have focused on place co-occurrence restrictions, we have not discussed the restriction against pairs of prenasalized segments, which applies to both homorganic and non-homorganic pairs and is unviolated in the Muna lexicon (our corpus of 5854 Muna roots contain no single example with more than one prenasalized segment). This constraint also results in alternations (van den Berg 1989). As Alderete (1997) and Itô and Mester (2003) note, this sort of restriction escapes the traditional autosegmental OCP formulation (Leben 1973). The autosegmental OCP bans features that are adjacent on some tier, and without a feature [prenasal], pairs of prenasalized segments do not introduce such a configuration. Following Suzuki (1998), our definitions of OCP constraints do not invoke tier adjacency; the only adjacency they require is that there be no intervening consonant.[13] As such, it is formally possible to define an OCP-[prenasal] consonant as in (9):

(9) OCP-PRENASAL No adjacent consonants specified as [-nasal][+nasal]

This constraint is not broad enough for the Muna case, since it ignores intervening consonants. But this can be easily circumvented by defining the constraint to apply to non-

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[12] It would also apply to pairs of non-identical homorganic consonants that are both nasal, had such pairs existed. However, since there is only one nasal per place of articulation, so such pairs exist.

[13] It is therefore something of a misnomer to call them OCP constraints at all: they are more accurately called "Anti-Similarity constraints". We retain the traditional name to indicate that our account builds on earlier relativized OCP proposals, as well as on Suzuki's (1998) Generalized OCP.

adjacent consonants (see McCarthy 1988 and Pierrehumbert 1993 on OCP-Place effects on non-adjacent consonants in Arabic):

(10) OCP-PRENASAL No two consonants in a word specified as [-nasal][+nasal]

Like Suzuki (1998), we see OCP-PLACE constraints as one set of a broad family of anti-similarity constraints, including OCP-PRENASAL. We do not follow Alderete (1997) and Itô and Mester (2003) in treating them as part of an even broader family of locally conjoined constraints (Smolensky 1995, 2005), because of the excessive power of free local conjunction (McCarthy 1999, 2003a, 2003c; Itô and Mester 2003).

3. LEARNING AND USING RANKINGS BASED ON LEXICAL FREQUENCY

The analysis in the last section proposed that the relative ordering of OCP-PLACE constraints reflects the relative frequency of structures in the lexicon. In this section we address the questions of how acceptability judgments are projected from these rankings, and how these rankings are learned.

3.1. Using rankings based on lexical frequency

In (11) we repeat part of our earlier analysis. Beneath each constraint is a sequence targeted by that constraint, along with the O/E-value associated with the specific sequence.

(11) OCP-DOR[αVCE] ≫ OCP-DOR ≫ OCP-COR
ŋ-g (0)   ʁ-k (0.40)   n-s (1.17)

There is ample experimental evidence that show that speakers are sensitive to the frequency of sound patterns in the lexicon, and that these frequencies influence their judgments in word-likeness rating tasks (see section 3.2). Specifically, tokens that contain sound sequences or combinations that are well represented in the lexicon typically receive higher ratings than tokens with sound combinations that are less well represented. Based on this, it is plausible to assume that a Muna speaker would make at least a three-way distinction between the sequence that is unattested ([ŋ-g]), the pair that freely co-occurs ([n-s]), and the pair with an intermediate degree of representation ([ʁ-k]). The problem is that neither standard OT, nor the versions that have been proposed to handle variation, allow the ranking in (11) to express a Muna speaker's knowledge of the observed lexical gradience.

Standard OT makes only a two-way distinction between unacceptable and acceptable. For a markedness constraint to be violated, a conflicting constraint must outrank it. Because we are not dealing with alternations, we will use the undifferentiated faithfulness constraint in (12):

(12) FAITH The Input representation and the Output representation are identical

FAITH must be ranked above OCP-COR, so that obstruent-sonorant pairs surface intact. It must be ranked beneath OCP-DOR[αVCE], so that [ŋ-g] is ruled out. The issue is the ranking of FAITH with respect to OCP-DOR. If FAITH is placed below OCP-DOR, the sequence [ʁ-k] is ruled out. If FAITH is placed above OCP-DOR, [ʁ-k] is deemed perfectly well-formed. Neither of these seems correct, and we are faced with the same dilemma as earlier accounts based on inviolable constraints: is OCP-DOR active or not?

Most models of variation in OT allow the ranking between some constraints to vary each time the grammar is employed (see e.g. Anttila 1997 and Boersma 1998; cf. Coetzee 2004 for an alternative where constraint rankings do not vary). If we let the ranking of OCP-Dor vary with Faith, then a word with a [ʁ-k] pair will vary between a faithful output, and one that is altered (for example by deleting, or changing the place, of one of the segments). But lexical items in Muna that have dorsal stop-fricative pairs are not reported to show variation, nor are Arabic stop-fricative pairs (section 2.1; see also Frisch *et al*. 2004, p. 220). Zuraw (2000) and Hayes and Londe (to appear) do extend Boersma's (1998) theory to patterned exceptionality, but this account only covers cases involving alternation. Hammond's (2004) approach to lexically gradient acceptability does not distinguish between variation and exceptionality, and without further modification also leaves this issue unresolved. Coetzee (to appear) also develops an OT model that accounts for the difference between the non-variant output of existing lexical forms while allowing gradient ratings of nonce forms. However, this model is not well suited for dealing with gradience that originates from co-occurrence patterns in the lexicon.

One way to allow for constraints to have different rankings in a single language's grammar, but without producing variation in the output of a given lexical item, is to introduce lexically indexed constraints (Kraska-Szlenk 1997; Fukuzawa 1999; Itô and Mester 2001; Pater 2000, to appear). A lexically indexed constraint applies only to items that are indexed for their application. These have been used to account for exceptions to generalizations in both phonotactics (i.e. lexical patterns of the type we have been discussing here), and alternations. Here we show how they can be useful in accounting for gradient phonotactic generalizations.

For the portion of the Muna grammar we have been discussing, we require a version of Faith that is indexed to words that contain the dorsal stop-fricative pairs. This constraint, Faith-L, ranks above OCP-Dor, thus protecting them from its demands. General Faith still ranks below OCP-Dor, and can hence not protect dorsal stop-fricative pairs. OCP-Dor[αvce] also still outranks all faithfulness constraints, and forms that violate this constraint therefore still go unprotected by any faithfulness constraint:

(13) OCP-Dor[αvce] >> Faith-L >> OCP-Dor >> Faith >> OCP-Cor

The next step is to provide a means by which a speaker could compute the relative grammaticality of forms from the ranking in (13). So far, one might simply say that a speaker knows that forms with dorsal stop-fricative pairs must be lexically marked as exceptions, and that this gives them an intermediate status between forms that are ruled out completely (for which the relevant markedness constraints dominate Faith-L), and those that are perfectly acceptable (for which the relevant markedness constraints are dominated by general Faith).

However, this would not be sufficient to deal with further degrees of gradience. As far as we know, no study has directly addressed the question of how fine-grained phonological grammaticality judgments are. But we do suspect that they go beyond the three-way distinction 'acceptable' 'exceptionally acceptable' and 'unacceptable'. In our analysis, we postulated a distinction between dorsal stop-fricative pairs, and coronal stop-fricative pairs, corresponding to the differences in their degrees of underrepresentation ([ʁ-k] 0.40 vs. [s-d] 0.55). In the analysis presented in (6) above, the ranking OCP-Dor ≫ OCP-Cor[αSon] accounted for this difference. Since coronal obstruents pairs ([s-d], [d-t]) are more underrepresented that the coronal obstruent-sonorant pair [n-s] (0.55 and 0.60 vs. 1.17), we also assumed the ranking OCP-Cor[αSon] ≫ OCP-Cor in our analysis in (6). In (14), we add the constraint OCP-Cor[αSon] into its place in the hierarchy from (13). The ranking in (14) also contains an additional lexically specific faithfulness constraint: FAITH-L2 now applies to dorsal stop-fricative pairs, and FAITH-L1 to coronal stop-fricative pairs.

(14) OCP-DOR[αVCE] ≫ FAITH-L2 ≫ OCP-DOR ≫ FAITH-L1 ≫ OCP-COR[αSON] ≫
FAITH ≫ OCP -COR

This ranking represents four grades of acceptability: ungrammatical (pairs of voiced dorsals), marginally acceptable (pairs of dorsals disagreeing in [voice], like the stop-fricative pair), moderately acceptable (pairs of coronal obstruents) and acceptable (pairs of coronals disagreeing in sonorancy). Ungrammaticality is expressed by the fact that a word with a pair of voiced dorsals will never surface intact, no matter which faithfulness constraint it is indexed to (this is an application of Richness of the Base; Prince and Smolensky 1993/2004). Perfect acceptability is expressed by the fact that a word with an obstruent-sonorant pair of coronals will always surface faithfully.

One way to distinguish intermediate grades is by submitting a word to the grammar with each lexical indexation (see Coetzee 2004 for another OT-based approach). The more often it surfaces faithfully, the more acceptable it is (cf. Anttila's 1997 approach to variation). Given a form that contains a dorsal fricative-stop pair, indexing it to FAITH-L2 will allow it to surface faithfully, while indexing it to FAITH-L1, or leaving it unindexed, will force it to be altered to satisfy OCP-DOR. That is, in 1/3 of the possible indexations, a dorsal stop-fricative pair will surface faithfully. This is shown in the tableau in (15).

(15) Outcomes of possible indexations for a dorsal stop-fricative pair

Input	Output	FAITH-L2	OCP-DOR	FAITH-L1	OCP-COR[αSON]	FAITH
ʁ-k	ʁ-k		*!			
	☞ ʁ-t					*
ʁ-k$_{L1}$	ʁ-k		*!			
	☞ ʁ-t			*		*
ʁ-k$_{L2}$	☞ ʁ-k		*			
	ʁ-t	*!				

On the other hand, a pair of coronal obstruents disagreeing in sonorancy will surface faithfully with 2/3 of the indexations: it will be altered only if it is left unindexed. This is shown in (16).

(16) Outcomes of possible indexations for a coronal stop-fricative pair

Input	Output	FAITH-L2	OCP-DOR	FAITH-L1	OCP-COR[αSON]	FAITH
s-t	s-t				*!	
	☞ s-k					*
s-t$_{L1}$	☞ s-t				*	
	s-k			*!		
s-t$_{L2}$	☞ s-t				*	
	s-k	*!				*

In (17), we show the outcomes for the indexations of consonant pairs of all four degrees of well-formedness, and the harmonic ordering imposed by this calculation.

(17)					
	a.	*ŋ-g	*ŋ-g$_{L1}$	*ŋ-g$_{L2}$	0/3
	b.	*ʁ-k	*ʁ-k$_{L1}$	✓ʁ-k$_{L2}$	1/3
	c.	*t-s	✓t-s$_{L1}$	✓t-s$_{L2}$	2/3
	d.	✓s-n	✓s-n$_{L1}$	✓s-n$_{L2}$	3/3

Harmonic ordering: s-n ≻ t-s ≻ ʁ-k ≻ ŋ-g

In this proposal, all possible indexations are considered when evaluating the well-formedness of a nonce word, whose indexation is unknown. In this way, the model can account for the gradience observed in well-formedness ratings of nonce words. However, the grammar is used in a very different way in ordinary production oriented parsing. Each lexically specific constraint targets a specific set of words; just those that bear the corresponding index. When a word is submitted to the grammar in production oriented parsing, it is evaluated by only the lexically faithfulness constraints that correspond to its lexical indexation. Real words are therefore always treated the same by the grammar in production oriented parsing. In this way, the model accounts for the fact that real words, even words containing a consonant sequence that is highly underrepresented in the lexicon, are always pronounced the same. As an example, consider the Muna word *kagha* [kaʁa] ‘yard’. This word contains the underrepresented sequence [k-ʁ], yet is always pronounced faithfully. In order to ensure that is this case, this word is stored in the lexicon indexed to FAITH-L2, and every time this word is submitted to the grammar, it brings with itself its lexical indexation. This word is therefore every time evaluated by FAITH-L2, and since FAITH-L2 dominates OCP-DOR, it will surface faithfully. This is illustrated in the tableau in (18). The crucial difference between existing words and nonce words is therefore that the former has a fixed lexical indexation and is hence always treated the same by the grammar, while the latter has no indexation and the grammar considers all possible lexical indexations for such forms when they are evaluated.

(18) /kaʁa/$_{L2}$ → [kaʁa] ‘yard’

/kaʁa/$_{L2}$	FAITH-L2	OCP-DOR	FAITH-L1	OCP-COR[αSON]	FAITH
☞kaʁa		*		*	
taʁa	*!				*

Under the learnability proposal discussed in the section 3.3, an actual word will be indexed to the lowest ranked faithfulness constraint that will allow it to surface faithfully (this is a consequence of the proposal, rather than a description of it). Thus, a real word with a dorsal fricative-stop pair will be indexed to FAITH-L2 and will always be evaluated by this faithfulness constraint, while a real word with a coronal stop-fricative pair will be indexed only to FAITH-L1 and will always be evaluated by this faithfulness constraint.

3.2. Experimental findings and predictions

In this section, we briefly review the experimental literature indicating that speakers have knowledge of the kinds of consonant co-occurrence restrictions that are displayed in Muna, and that well-formedness judgments are gradient. We then discuss the novel predictions our own account of lexically gradient phonotactics makes.

A common measure of phonological well-formedness is the rating of nonce words for how word-like they are, and several studies have used this methodology to study speakers' knowledge of restrictions on non-adjacent consonants. Berent and colleagues (Berent and Shimron 1997; Berent *et al.* 2001a, b) examined the processing of identical consonants by Hebrew speakers. As in Arabic, identical consonants are permitted in the second two positions of a root, but not in the first two (in C_2/C_3 but not C_1/C_2 of $C_1VC_2VC_3$). Ratings of nonce words show not only a difference between such possible and impossible forms, but also a preference for words lacking identical consonants over those that possess them, even in the position in which they are allowed. Thus, for structures that do occur in Hebrew, there is a difference in degree of well-formedness.

Frisch and Zawaydeh (2001) investigated Arabic speakers' judgments of nonce words that have homorganic, non-identical consonants. They found that these words were not treated uniformly, and that the similarity of the consonants, as measured by Frisch *et al.*'s (2004) similarity metric, correlated with the scores on a word-likeness task. Again, this suggests that speakers have knowledge of degrees of well-formedness.

Coetzee (2004, to appear) studied English speakers' ratings of words of the structure sCVC, where the two consonants were homorganic voiceless stops. The English lexicon contains words of this structure with coronals (e.g. *state*), but none with either labials or dorsals. He found that words with a pair of labials were rated worst, ones with a pair of coronals best, and ones with a pair of dorsals in between. Once again, we have evidence of knowledge of a restriction on non-adjacent consonants that goes beyond 'acceptable' vs. 'unacceptable'.

None of these studies were designed to directly examine whether these gradient restrictions were affected by the lexical frequency of the structures at issue. In fact, they all aimed to control for lexical frequency. It is clear that the judgment of the word-likeness of a nonce word is affected by lexical factors. Two of the best-studied are neighborhood density, the number of similar words in the lexicon, and transitional probability, the probability of the nonce word's phoneme sequences in words of the lexicon (Vitevitch and Luce 1998, 1999; Bailey and Hahn 2001; etc.). In these studies, neighborhood density and transitional probability are controlled across word types so as to test for the independent contribution of the co-occurrence restriction.

Thus, we do not have direct evidence of the distinctions of the type that our account of Muna predicts: ratings of homorganic pairs of consonants that correlate with their lexical frequency. However, insofar as the similarity ratings of Frisch *et al.* (2004) are correlated with frequency of homorganic pairs, the Frisch and Zawaydeh (2001) results may be seen as consistent with that prediction. Coetzee's (2004) results may also be interpreted in this fashion. While there are no *skVk* words, there are s-initial words with pairs of voiceless dorsal stops with an additional intervening consonant (*skunk*, *skulk*, *skank*) and words with a pair of non-identical dorsal stops (*skag*, *skeg*). Words of this form with labials are unattested, and words of this form with coronals are common. This is consistent with the scale *stVt* > *skVk* > *spVp* (see further Pater and Coetzee 2005; cf. Coetzee 2004, to appear for another account).

An important avenue for further research is to experimentally distinguish purely statistical models of gradient phonotactics from the phonological one presented here (see also Hayes 2005). Because our model relies on rankings of phonological constraints, it will encode some patterns but not others. Given a universal constraint set, as is standard in OT, it will encode only patterns that can be expressed by those constraints. This leads to the prediction that a structure that violates a universal constraint should be rated as worse than a structure that does not, even if these two structures are of equal lexical frequency in the language. Furthermore, if a structure that is absent from the lexicon is part of a general pattern in the language, then it will be again be rated as less well formed than a structure that is an 'accidental' gap (see Frisch and Zawaydeh 2001, Moreton 2002 for related experimental work).

3.3. Learning rankings based on lexical frequency

Our proposal for grammatically encoding knowledge of lexical frequency differences between marked structures relies on a ranking of markedness constraints that is correlated with lexical frequency, as well as a set of lexically specific faithfulness constraints interspersed between them. In this section, we show how such a ranking can be learned using the Biased Constraint Demotion Algorithm (Prince and Tesar 2004), by making just one additional core assumption.

The result that we want to obtain is illustrated in (19). This is the portion of the Muna grammar discussed in 3.1, with examples of words with each of the indexations.

(19) Grammar: OCP-DOR[αVCE] >> FAITH-L2 >> OCP-DOR >> FAITH-L1 >>
OCP-COR[αSON] >> FAITH >> OCP-COR
Lexicon: kaʁa$_{L2}$ sida$_{L1}$ nasi

We have thus far provided no reason to assume that words that violate OCP-DOR are indexed to FAITH-L2, and that words that violate OCP-COR[αSON] are indexed to FAITH-L1. But as we will see, this is a crucial component in our explanation for how the markedness constraints get into the frequency-based order, and for why there are interspersed faithfulness constraints.

The problem is that standard OT, and standard OT learnability, would create the grammar in (20), with no lexical indexation, and no dispersion amongst the markedness constraints beyond that which is required to distinguish between attested and unattested forms (though there may be a universal ranking of OCP-DOR above OCP-COR; see section 2.2)

(20) Grammar: OCP-DOR[αVCE] >> FAITH >> OCP-DOR, OCP-COR[αSON], OCP-COR
Lexicon: kaʁa sida nasi

This grammar is inadequate, insofar as phonological grammar is responsible for phonological grammaticality judgments, and Muna speakers do make graded distinctions based on the lexical frequency that parallel those of speakers of other languages.

Why do learners posit lexically specific constraints, and arrange the markedness and faithfulness constraints in this sort of order? Our answer to the first of these questions is that learners are initially conservative, in that when they encounter a word that requires an adjustment to the grammar, they first assume that this adjustment is specific that word. More formally, in terms of Tesar and Smolensky (1998) *et seq*., when Error-Driven Constraint Demotion produces a Mark-Data pair, faithfulness constraints preferring the winner are indexed to the lexical item in question. When this proposal is incorporated into Prince and Tesar's (2004) Biased Constraint Demotion Algorithm (BCD), it automatically yields an answer to the ordering problem.

When Error-Driven Constraint Demotion detects an error, it creates a Mark-Data pair that provides the information used for constraint demotion. The learning datum is called the Winner, and the incorrect output of the learner's grammar is called the Loser. Constraints assign a 'W' when they prefer the Winner, and an 'L' when they prefer the Loser. We adopt Tesar's (1998) proposal that Mark-Data pairs are retained for further learning, forming a set that Tesar and Prince (2004) term a support. The main elaboration that we propose is that when Mark-Data pairs are formed, faithfulness constraints that prefer the winner are indexed to the lexical item in question.

BCD iteratively places constraints in strata according to the following steps, which favor high-ranking markedness constraints, and hence a restrictive grammar:

(21) i. Identify constraints that prefer no losers
ii. If any of these are markedness constraints, install them in the current stratum, and return to step i.
iii. If there are no available markedness constraints, install faithfulness constraints that prefer winners, and return to step i.
iv. If there are no faithfulness constraints that prefer winners, install those that prefer no losers, and return to step i.

Once a constraint that prefers a winner for a given mark-data pair has been installed, that mark-data pair can be eliminated from further consideration, since the winner is guaranteed to emerge as optimal in the resulting grammar (a winner-preferring constraint dominates all loser-preferring constraints.

To illustrate how this modified BCD algorithm creates a stratified grammar, we use the constraint set, and lexicon in (22). For expository simplicity, instead of the actual set of words, we use the smallest set that is compatible with the relative frequency of the relevant structures: 3 words with coronals that disagree in sonority, 2 words with coronals that agree in sonority, and 1 word with dorsals that disagree in voicing.

(22) Words: kaʁa sida tada nasi sono suna

Constraints: OCP-DOR[αVCE], OCP-DOR, OCP-COR[αSON], OCP-COR, FAITH

Before any data are presented to the algorithm, it creates the following grammar, with the markedness constraints ranked above the faithfulness constraint:

(23) OCP-DOR[αVCE], OCP-DOR, OCP-COR[αSON], OCP-COR >> FAITH

If this grammar is used to parse any word with a pair of consonants violating one of the markedness constraints, it will yield an error. For example, given [nasi], the grammar will yield something like [ŋasi], which satisfies OCP-COR, and violates FAITH. A Mark-Data pair is then created, with an indexed faithfulness constraint. The only difference between our proposal and standard BCD at this point, is the use of the indexed FAITH-L1 rather than general FAITH.

(24)

Input	W ~ L	OCP-DOR [αVCE]	OCP-DOR	OCP-COR [αSON]	OCP-COR	FAITH-L1
nasi_{L1}	nasi ~ ŋasi				L	W

By clause (i) of the BCD, the three markedness constraints that do not prefer a loser are installed first. Since there is no markedness constraint left that prefers no losers, clause (iii) next applies, installing Faith-L1, giving the grammar in (25).

(25) OCP-DOR[αVCE], OCP-DOR, OCP-COR[αSON] >> FAITH-L1 >> OCP-COR

Since the indexed constraint applies only to /nasi/, the grammar in (25) would also produce errors upon encountering [sono] and [suna]. In fact, since all of the words violate one or more of the markedness constraints, they will all lead to errors and the creation of Mark-Data pairs with indexed faithfulness constraints. The full support for this language, representing the stage before any learning has occurred, will thus be as in (26).

(26)

Input	W ~ L	OCP-DOR [αVCE]	OCP-DOR	OCP-COR [αSON]	OCP-COR	F-L1	F-L2	F-L3	F-L4	F-L5	F-L6
nasi$_{\mathrm{L1}}$	nasi ~ ŋasi				L	W					
sono$_{\mathrm{L2}}$	sono ~ soŋo				L		W				
suna$_{\mathrm{L3}}$	suna ~ suŋa				L			W			
sida$_{\mathrm{L4}}$	sida ~ siga			L	L				W		
tada$_{\mathrm{L5}}$	tada ~ taga			L	L					W	
kaʁa $_{\mathrm{L6}}$	kaʁa ~ taʁa		L								W

The first step in BCD is to search for a markedness constraint that prefers no losers. This picks OCP-DOR[αVCE] for installation in the topmost stratum. Because OCP-DOR[αVCE] is undominated, the resulting grammar will correctly filter out any words with sequences of dorsals agreeing in [voice], even if the putative word supplied by Richness of the Base included a lexical indexation. The grammar constructed to this point would be as in (27):

(27) OCP-DOR[αVCE] >>

There are no other markedness constraints that prefer no winners, so we need to choose amongst the lexically specific faithfulness constraints. Prince and Tesar (2004: 267) propose that the choice amongst faithfulness constraints is made by identifying ones that "free up" markedness constraints for ranking:

(28) "**Smallest effective F sets.** When placing faithfulness constraints into the hierarchy, place the *smallest set* of F constraints that *frees up some markedness constraint.*"

To free up a markedness constraint means to eliminate all the mark-data pairs to which it assigns L marks. There are three markedness constraints left. To free up OCP-DOR requires just the installation of FAITH-L6; all of the others require more than one faithfulness constraint to be installed. Thus, FAITH-L6 is now placed, in the next stratum. This yields the ranking in (29), along with the support from which /kaʁa/ has been eliminated.

(29) OCP-DOR[αVCE] >> FAITH-L6

Input	W ~ L	OCP-DOR	OCP-COR [αSON]	OCP-COR	F-L1	F-L2	F-L3	F-L4	F-L5
nasi$_{L1}$	nasi ~ ŋasi			L	W				
sono$_{L2}$	sono ~ soŋo			L		W			
suna$_{L3}$	suna ~ suŋa			L			W		
sida$_{L4}$	sida ~ siga		L	L				W	
tada$_{L5}$	tada ~ taga		L	L					W

As anticipated, OCP-DOR now prefers no losers, and can be installed in the next stratum:

(30) OCP-DOR[αVCE] >> FAITH-L6 >> OCP-DOR

Before proceeding further, it is worth noting the important role of the “Smallest effective F sets” clause to the success of BCD in creating a stratified grammar. Part of the goal is to have markedness constraints ranked according to how often they are violated in the language, with higher rank correlating to fewer violations (see also Boersma 1998 in the context of variation).[14] A lexically specific faithfulness constraint is created for each occurrence of a word with a violation of a markedness constraint. A markedness constraint that is violated rarely will create few faithfulness constraints. This will be a “small effective F set”, and it, followed directly by this markedness constraint, will be installed before a markedness constraint that is violated more often since its effective F set will be larger. In the present example, * OCP-DOR is only violated once, and so its associated effective F set consists only of FAITH-L6. OCP-COR[αSON] is violated twice, so its effective F set consists of FAITH-L5 and FAITH-L4.

Once we have installed OCP-DOR, FAITH-L5 and FAITH-L4 will be installed together to free up OCP-COR[αSON]. The result is as in (31).

(31) OCP-DOR[αVCE] >> FAITH-L6 >> OCP-DOR >> FAITH-L5, FAITH-L4

Input	W ~ L	OCP-COR [αSON]	OCP-COR	F-L1	F-L2	F-L3
nasi$_{L1}$	nasi ~ ŋasi		L	W		
sono$_{L2}$	sono ~ soŋo		L		W	
suna$_{L3}$	suna ~ suŋa		L			W

The rest repeats steps we have already seen. OCP-COR[αSON] is installed in the next stratum because it prefers no losers. Next, the remaining faithfulness constraints are installed to free-up

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[14] Since Boersma’s (1998) Gradual Learning Algorithm is sensitive to frequency, it could plausibly be adapted to deal with lexically gradient phonotactics, as well as with variation. However, we know of no proposal along these lines.

the last markedness constraints, OCP-COR. Finally, OCP-COR is installed in the last stratum, giving the final grammar in (32).

(32) OCP-DOR[αVCE] >> FAITH-L6 >> OCP-DOR >> FAITH-L5, FAITH-L4 >> OCP-COR[αSON]
>> FAITH-L1, FAITH-L2, FAITH-L3 >> OCP-COR

Lexically specific constraints can be collapsed as follows:

(33) Merge instantiations of any constraint that occupy the same stratum

This produces the following grammar, and lexicon:

(34) Grammar: OCP-DOR[αVCE] >> FAITH-L3 >> OCP-DOR >> FAITH-L2 >>
OCP-COR[αSON] >> FAITH-L1 >> OCP-COR
Lexicon: /kaʁa$_{L3}$/ /sida$_{L2}$/ /tada$_{L2}$/ /nasi$_{L1}$/ /sono$_{L1}$/ /suna$_{L1}$/

Further collapse of lexically specific constraints is necessary to produce a non-stratified grammar when a structure is well attested in a language. This can be accomplished by imposing a maximum size on the set of words targeted by a lexically specific constraint:

(35) If the number of words indexed by a constraint is greater than *x*, remove indexation

Once indexation has been removed, the learner will also stop making errors, and creating Mark-Data pairs and lexically specific constraints. For example, if we assumed that $x = 2$,[15] the step in (35) would result in (36) for our hypothetical language.

(36) Grammar: OCP-DOR[αVCE] >> FAITH-L2 >> OCP-DOR >> FAITH-L1 >>
OCP-COR[αSON] >> FAITH >> OCP-COR
Lexicon: /kaʁa$_{L2}$/ /sida$_{L1}$/ /tada$_{L1}$/ /nasi/ /sono/ /suna/

If a learner with this grammar encountered another word with a pair of coronals disagreeing in sonorancy, it would parse it faithfully, and no Mark-Data pair would be created.

The grammar in (36) now corresponds to the one we used to model knowledge of gradient well-formedness in section 3.1. Because rankings based on lexical frequency are a substantial departure from standard OT, it might seem that learning them would also require a substantial departure from standard OT learning algorithms. In this section, we have shown that perhaps surprisingly, this is not the case. Once we add the assumption that learners create lexically specific faithfulness constraints, BCD automatically places markedness constraints in a frequency-based order, with interspersed lexically specific faithfulness constraints.

4. MUNA AND THE NATURAL CLASSES SIMILARITY METRIC

Frisch *et al.* (2004) propose an analysis of the Arabic place co-occurrence restrictions that is very different from the relativized OCP-PLACE account we have extended to Muna. In this section, we discuss the implications of the Muna data for their proposal.

In Frisch *et al.* (2004), relative rates of co-occurrence of pairs of homorganic consonants are predicted to inversely correlate with the similarity of those consonants. Similarity is calculated for a segment pair by dividing the number of natural classes that both segments belong to within their place of articulation by the sum of the number of natural classes to which each segment

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[15] It is of course impossible to know exactly what value *x* should have, though 2 is clearly too low for real cases. The larger *x* is, the more well-formedness distinctions will be made by the grammar.

belongs within that place of articulation. The number of natural classes in this calculation is influenced by inventory size. The larger the set of contrasts is at a given place of articulation, the more features are available with which to define natural classes for the pairs of segments in that place. Frisch *et al.* (2004) show that the similarity values calculated over the Arabic inventory do inversely correlate with the O/E-values computed over the Arabic verbal roots.

There are some shared properties of our relativized OCP-Place analysis and Frisch *et al.*'s proposal. One is the basic notion that place co-occurrence restrictions are strengthened by similarity. This is inherent to the way relativized OCP-Place constraints are formulated: given two pairs *a-b* and *c-d* where *a-b* is more similar along some featurally defined dimension, there will be a relativized OCP-PLACE constraint that penalizes *a-b*, and not *c-d*. Another is that both models predict that what Frisch *et al.* (2004) call cross-classification is possible. Recall that Muna [n] co-occurs less often with [d] than [t] due to its specification as [+voice], and co-occurs less often with [l] and [r] than [d] does because of its specification as [+sonorant]. This cross-classification is possible in Frisch *et al.*'s system because similarity is calculated over the entire feature set, and is possible in ours because relativized OCP-PLACE constraints are postulated for both [voice] and [sonorant]. And finally, both models allow non-contrastive features to play a role. In both approaches, to see the effect of a featural distinction, it must serve to contrast some segments (e.g. [voice] distinguishing voiced from voiceless obstruents), but there is no requirement for that feature to be absent on segments on which it is not minimally contrastive (e.g. [voice] in voiced sonorants).

Muna can be seen as providing striking confirmation for those aspects of Frisch *et al.*'s model, since the dominant role of [voice] creates more robust evidence in Muna than Arabic for both cross-classification and redundant feature activity (see sections 1.2, 2.2, 2.3 above). There are however ways in which the predictions of the similarity metric differ from those of relativized OCP-Place constraints, and for those the Muna data are problematic.

The central claim of the similarity metric is that O/E-values should correlate with the structure of the inventory. Frisch *et al.* use this property of the model to explain the weakening of OCP-Place effects in the Arabic coronals. Because the coronal inventory is larger than the labial and dorsal inventories, coronals participate in more natural classes. Thus, in the calculation of similarity, the denominator for coronals will be larger, yielding lower similarity scores, and lower predicted O/E-scores. Besides differences in inventory size, the similarity metric provides for no other way of generating language-specific variation. This can be contrasted with the present model, in which the rankings of relativized OCP-PLACE constraints can be reordered in a language-specific fashion, subject to the coronal/non-coronal fixed rankings discussed in section 2.2.

Muna proves problematic in two ways for inventory-based similarity calculation. First, the Muna coronal inventory is not much larger than that of the labial and dorsal inventories, resulting in similarity values that are not far enough apart to explain the much tighter restrictions on the non-coronals. And second, there is no difference between the Muna and Arabic inventories that explains the difference in the degree to which shared voicing contributes to the underrepresentation of a pair.

To determine how well Muna fits the predictions of the similarity metric, we calculated similarity values using the featural classifications in Appendix B. These were calculated as in Frisch *et al.* (2004): by dividing the number of natural classes that both segments belong to by the sum of the numbers that each belongs to. We checked our calculations by using Adam Albright's segmental similarity calculator (http://web.mit.edu/albright/www/software/).

Figure 1 plots the similarity values against Observed/Expected, for all of the homorganic pairs, except pairs of prenasalized segments, pairs of identical segments, and ones in which the oral portion of a prenasalized segment is identical to the other segment (see sec 1.1 on the special behavior of these segment types). We also fitted a both a linear (solid line) and a logarithmic regression (broken line) line to these data. As expected, the general trend is that as similarity increases, the O/E-value decreases. However, this correlation is far from perfect; pairs with low similarity have a wide range of O/E-values. The r^2-value for the linear regression on these data is only 0.23. The logarithmic regression is marginally better with an r^2-value of 0.29. There is therefore 70% to 80% of the variation in the data for which the similarity values do not account.[16]

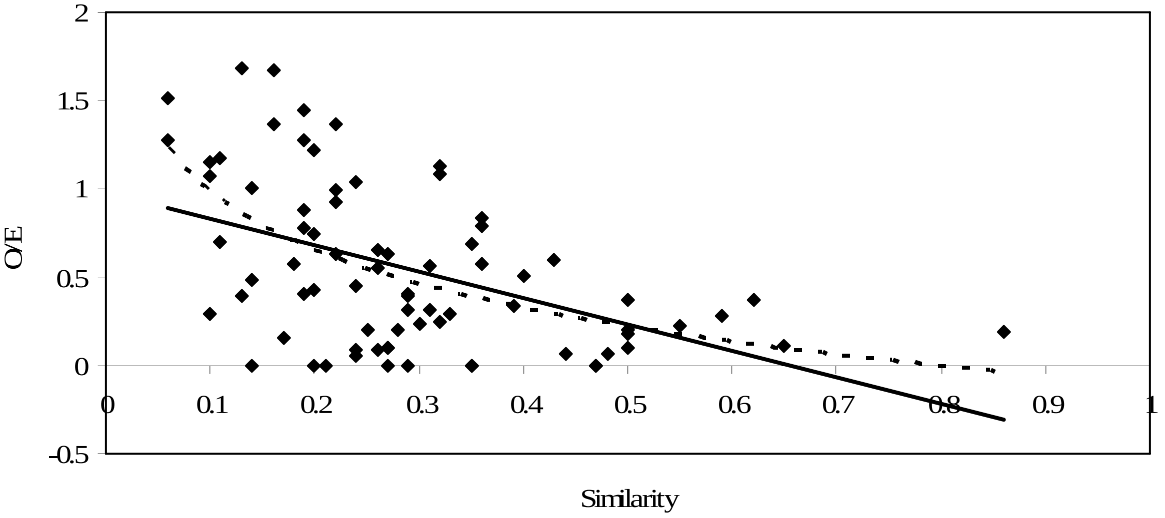

Figure 1 Similarity vs. Observed/Expected

To show in detail where the similarity metric succeeds and fails, the tables in Appendix C present the results for each place of articulation, with O/E-values in parentheses. By comparing corresponding pairs across the places of articulation, we can assess how well the similarity

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[16] A reviewer suggests that we divide the consonant pairs into 10 groups according to their similarity values (0-0.1, 0.1-0.2, 0.2-0.3, etc.), and that we then compute the O/E-values for each of these 10 groups. The reviewer also suggests that the regression analyses be performed on this smaller number of transformed values. We have opted not do this, as we believe that this will artificially reduce the variance in the O/E-values, especially for consonants that have low similarity values. Consider, for example, the consonant pairs with similarity values ranging from 0.11 to 0.2. If we sum the observed values and the expected values for these consonant pairs, and use these summed values to calculate an aggregate O/E-value for these pairs, we get an O/E-value of 0.89 – a value that lies close to the value predicted by both the linear and logarithmic regression. However, inspection of Figure 1 shows that these consonant pairs have this mean not because most of the pairs lie close to the mean. The O/E-values for these pairs are actually quite variable (the standard deviation of their O/E-values is 0.52). Using the aggregate value would therefore artificially reduce the variance in the data exactly in the parts of the data where the regression lines fail to account adequately for the actual O/E-values, so that a high r^2-value for any regression performed on the aggregate O/E-values would be artificially high. It should be noted that Frisch *et al.* (2004, p. 203) represent their data using aggregate O/E-values calculated like this. If their data had the same structure as ours, this casts some doubt on the validity of the conclusions that they drew based on the aggregate O/E-values.

metric does at predicting the weakening of the co-occurrence restrictions amongst coronals, as well as the more subtle difference between labials and dorsals. Looking at the voiced and voiceless stops in the top left corner of the tables, one would conclude that it does not do very well: the similarity values are roughly equivalent, yet the coronals have a much higher O/E-value. The average similarity and the aggregate observed, expected and O/E-values for the pairs that can be compared across all three places of articulation (voiced and voiceless stops, nasals, and prenasalized stops), omitting those that may be subject to the identity effect or the ban on multiple prenasalized stops, are presented in Table 13. (The values for the individual pairs of consonants are listed in the Appendix A.)

	Coronals			Labials			Dorsals		
	O	E	O/E	O	E	O/E	O	E	O/E
	146	188.3	0.78	38	143.4	0.27	8	93.5	0.09
Similarity	0.22			0.33			0.29		

Table 13: O/E and average similarity values

The differences amongst the similarity values are relatively small; these would all be grouped together in the table comparing O/E and similarity in Frisch *et al.* (2004, p. 203). The O/E-values, however, fall dramatically from the coronals to the labials. And in the case of the labials and dorsals, the predicted inverse correlation between similarity and O/E is not found at all.

The similarity metric derives the fact that OCP effects are diminished in coronals from the large size of the Arabic coronal inventory, which increases the comparison space. As an inspection of the inventory in (2) shows, the coronal inventory size in Muna is only marginally larger than that of the labials. McCarthy (2003b) finds a similar problem in Rotuman: like Arabic, co-occurrence between coronals is much freer across sonorancy classes than within them, but unlike Arabic, the coronal inventory is not particularly large. The Rotuman and Muna facts suggest that the weakness of OCP effects between coronals is not simply a factor of inventory size.

The other difficulty that the similarity metric has with Muna is the strength of the voicing effect. As shown in Table 14, the voiced stops are less similar to nasals than to voiceless stops, yet are more restricted in their co-occurrence. (The values for the individual pairs of consonants are listed in the Appendix A.)

	Nasals+ Voiced Stops			Voiced Stops+ Voiceless Stops		
	O	E	O/E	O	E	O/E
	6	41.1	0.15	30	93.9	0.32
Similarity	0.42			0.46		

Table 14:O/E and average similarity values

A particularly dramatic instance of this difficulty is the pair /ŋ-ʁ/, whose members have little in common but voicing and thus have a low similarity value, yet is unattested.

From the differences between Muna and Arabic one might conclude that languages weight features differently in how they function in computing similarity in place co-occurrence. Frisch *et al.* (2004, p. 204) find that for Arabic, the similarity metric results in values that are too high for /d-n/, but too low for /n-l/ and /n-r/, in comparison with the O/E-values for Arabic. They suggest, following Bachra (2000), that this could be resolved by weighting [sonorant] more than other features, such as [voice]. In Muna, on the other hand, [voice] appears to be the feature in need of a boost. Thus not only do features need to be weighted, as Frisch *et al.* (2004) suggest, but the weighting must be allowed to vary between languages. This is captured in the relativized OCP-PLACE model by allowing constraint rankings to vary between languages.

5. CONCLUSIONS

The lexical data we have presented from Muna add to our understanding of the cross-linguistic range of place co-occurrence restrictions. We have analyzed these data in terms of relativized OCP-Place constraints, including constraints relativized to [voice], which Muna uniquely motivates. We have further proposed that markedness constraints are ranked according to the degree with which they are obeyed in the lexicon, thus capturing the gradience in their application. By interspersing these rankings with lexically specific faithfulness constraints, we have provided a model of how speakers project grammaticality judgments from these rankings, and how these rankings are learned. We have also shown that the Muna data support some aspects of Frisch *et al.*'s (2004) similarity metric, but are problematic for a central distinguishing aspect of their proposal: that differences in similarity, and hence co-occurrence, stem from differences in inventory shape.

APPENDIX A: OBSERVED, EXPECTED AND O/E-VALUES

The tables below contain the observed, expected, and O/E-values for pairs of homorganic consonants in Muna. Excluded from these tables are pairs of identical consonants, as well as pairs of consonants that differ only in terms of prenasalization. See section 1.1 for the reasons for why these pairs are excluded.

Dorsals

	k	**g**	**ᵑk**	**ᵑg**	**ʁ**
g	O=2 E=30 **O/E = 0.07**				
ᵑk	O=29 E=45 **O/E = 0.65**	O=0 E=9 **O/E = 0.00**			
ᵑg	O=2 E=10 **O/E = 0.20**	O=5 E=2 **O/E = 2.25**	O=0 E=3 **O/E = 0.00**		
ʁ	O=15 E=38 **O/E = 0.40**	O=0 E=9 **O/E = 0.00**	O=6 E=12 **O/E = 0.48**	O=0 E=12 **O/E = 0.00**	
ŋ	O=3 E=30 **O/E = 0.10**	O=0 E=6 **O/E = 0.00**	O=0 E=6 **O/E = 0.00**	O=1 E=2 **O/E = 0.62**	O=0 E=8 **O/E = 0.00**

Labials

	p	b	ᵐp	ᵐb	ɓ	f	w
b	O=2 E=20 **O/E = 0.10**						
ᵐp	O=16 E=20 **O/E = 0.79**	O=2 E=10 **O/E = 0.20**					
ᵐb	O=10 E=32 **O/E = 0.31**	O=8 E=15 **O/E = 0.52**	O=0 E=12 **O/E = 0.00**				
ɓ	O=3 E=28 **O/E = 0.11**	O=4 E=14 **O/E = 0.28**	O=5 E=15 **O/E = 0.34**	O=16 E=23 **O/E = 0.69**			
f	O=3 E=14 **O/E = 0.22**	O=4 E=7 **O/E = 0.58**	O=1 E=7 **O/E = 0.29**	O=1 E=11 **O/E = 0.09**	O=2 E=10 **O/E = 0.20**		
w	O=5 E=31 **O/E = 0.16**	O=0 E=15 **O/E = 0.00**	O=4 E=14 **O/E = 0.29**	O=16 E=22 **O/E = 0.74**	O=9 E=22 **O/E = 0.40**	O=7 E=11 **O/E = 0.65**	
m	O=12 E=31 **O/E = 0.39**	O=1 E=15 **O/E = 0.07**	O=6 E=14 **O/E = 0.43**	O=5 E=22 **O/E = 0.23**	O=0 E=22 **O/E = 0.00**	O=11 E=11 **O/E = 1.04**	O=2 E=23 **O/E = 0.09**

Coronals

	t	**d**	**ɗ**	**ⁿt**	**ⁿd**	**s**	**ⁿs**	**l**	**r**
d	O=26 E= 44 **O/E = 0.60**								
ɗ	O=9 E=24 **O/E = 0.37**	O=2 E=11 **O/E = 0.18**							
ⁿt	O=27 E=36 **O/E = 0.74**	O=14 E=15 **O/E = 0.92**	O=1 E=10 **O/E = 0.10**						
ⁿd	O=40 E=33 **O/E = 1.22**	O=17 E=13 **O/E = 131**	O=4 E=9 **O/E = 0.45**	O=0 E=10 **O/E = 0.00**					
s	O=31 E=84 **O/E = 0.37**	O=21 E=38 **O/E = 0.55**	O=11 E=21 **O/E = 0.51**	O=20 E=32 **O/E = 0.63**	O=29 E=29 **O/E = 1.01**				
ⁿs	O=1 E=18 **O/E = 0.05**	O=13 E=8 **O/E = 1.68**	O=0 E=5 **O/E = 0.00**	O=0 E=6 **O/E = 0.00**	O=0 E=5 **O/E = 0.00**	O=18 E=16 **O/E = 1.12**			
l	O=117 E=149 **O/E = 0.78**	O=50 E=63 **O/E = 0.79**	O=39 E=39 **O/E = 0.99**	O=54 E=50 **O/E = 1.07**	O=60 E=41 **O/E = 1.45**	O=148 E=131 **O/E = 1.13**	O=35 E=26 **O/E = 1.37**		
r	O=100 E=113 **O/E = 0.88**	O=40 E=47 **O/E = 0.84**	O=41 E=30 **O/E = 1.37**	O=43 E=37 **O/E = 1.15**	O=39 E=30 **O/E = 1.28**	O=107 E=99 **O/E = 1.08**	O=32 E=19 **O/E = 1.67**	O=30 E=155 **O/E = 0.19**	
n	O=34 E=49 **O/E = 0.70**	O=5 E=20 **O/E = 0.25**	O=5 E=20 **O/E = 0.39**	O=20 E=16 **O/E = 1.28**	O=7 E=12 **O/E = 0.57**	O=50 E=43 **O/E = 1.17**	O=12 E=8 **O/E = 1.51**	O=21 E=65 **O/E = 0.32**	O=27 E=48 **O/E = 0.56**

APPENDIX B: FEATURES FOR SIMILARITY CALCULATIONS

Dorsals

	k	**g**	**^{ŋ}k**	**^{ŋ}g**	**ʁ**	**ŋ**
sonorant	-	-	-	-	-	+
continuant	-	-	-	-	+	-
voice	-	+	-	+	+	+
nasal	-	-	-	-	-	+
prenasal	-	-	+	+	-	-
dorsal	+	+	+	+	+	+
consonantal	+	+	+	+	+	+

Labials

	p	**b**	**^{m}p**	**^{m}b**	**ɓ**	**f**	**w**	**m**
sonorant	-	-	-	-	-	-	+	+
continuant	-	-	-	-	-	+	+	-
voice	-	+	-	+		-	+	+
nasal	-	-	-	-	-	-	-	+
prenasal	-	-	+	+	-	-	-	-
sonorant	-	-	-	-	-	-	+	+
implosive					+			
consonantal	+	+_	+	+	+	+	-	+

Coronals

	t	**d**	**ɗ**	**^{n}t**	**^{n}d**	**s**	**^{n}s**	**l**	**r**	**n**
sonorant	-	-	-	-	-	-	-	+	+	+
continuant	-	-	-	-	-	+	+	+	+	-
voice	-	+		-	+	-	-	+	+	+
nasal	-	-	-	-	-	-	-	-	-	+
prenasal	-	-	-	+	+	-	+	-	-	-
sonorant	-	-	-	-	-	-	-	+	+	+
implosive			+							
consonantal	+	+	+	+	+	+	+	+	+	+
+lateral								+	-	

APPENDIX C: SIMILARITY VALUES FOR NON-IDENTICAL HOMORGANIC CONSONANTS OF MUNA (WITH O/E-VALUES)

Dorsals

	k	**g**	**ᵑk**	**ᵑg**	**ʁ**
g	0.44 (0.07)				
ᵑk	0.42 (0.65)	0.21 (0.00)			
ᵑg	0.25 (0.20)	0.44 (2.25)	0.42 (0.00)		
ʁ	0.29 (0.40)	0.47 (0.00)	0.14 (0.48)	0.27 (0.00)	
ŋ	0.27 (0.10)	0.47 (0.00)	0.14 (0.00)	0.27 (0.62)	0.29 (0.00)

Labials

	p	**b**	**ᵐp**	**ᵐb**	**ɓ**	**f**	**w**
b	0.50 (0.10)						
ᵐp	0.28 (0.79)	0.28 (0.20)					
ᵐb	0.29 (0.31)	0.48 (0.52)	0.62 (0.00)				
ɓ	0.65 (0.11)	0.59 (0.28)	0.39 (0.34)	0.35 (0.69)			
f	0.55 (0.22)	0.36 (0.58)	0.33 (0.29)	0.24 (0.09)	0.50 (0.20)		
w	0.17 (0.16)	0.35 (0.00)	0.10 (0.29)	0.20 (0.74)	0.19 (0.40)	0.26 (0.65)	
m	0.29 (0.39)	0.48 (0.07)	0.20 (0.43)	0.30 (0.23)	0.35 (0.00)	0.24 (1.04)	0.26 (0.09)

Coronals

	t	**d**	**dˤ**	**ⁿt**	**ⁿd**	**s**	**ⁿs**	**l**	**r**
d	0.43 (0.60)								
dˤ	0.62 (0.37)	0.50 (0.18)							
ⁿt	0.38 (0.74)	0.22 (0.92)	0.27 (0.10)						
ⁿd	0.20 (1.22)	0.45 (1.31)	0.24 (0.45)	0.38 (0.00)					
s	0.50 (0.37)	0.26 (0.55)	0.40 (0.51)	0.22 (0.63)	0.14 (1.01)				
ⁿs	0.24 (0.05)	0.13 (1.68)	0.20 (0.00)	0.46 (0.00)	0.22 (0.00)	0.40 (1.12)			
l	0.19 (0.78)	0.36 (0.79)	0.22 (0.99)	0.10 (1.07)	0.19 (1.45)	0.32 (1.13)	0.16 (1.37)		
r	0.19 (0.88)	0.36 (0.84)	0.22 (1.37)	0.10 (1.15)	0.19 (1.28)	0.32 (1.08)	0.16 (1.67)	0.86 (0.19)	
n	0.11 (0.70)	0.32 (0.25)	0.13 (0.39)	0.06 (1.28)	0.18 (0.57)	0.11 (1.17)	0.06 (1.51)	0.31 (0.32)	0.31 (0.56)

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