



Faithfulness, Correspondence, and Perceptual Similarity: Hypotheses and Experiments*

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1 Introduction

The principle of faithfulness—one of the many characteristics specific to Optimality Theory (OT Prince and Smolensky, 1993/2004)—has opened up new lines of research. The questions addressed in these lines of research have been difficult or even impossible to address in previous theories of phonology. This paper discusses how the principle of faithfulness sheds light on the issues surrounding the phonetics-phonology interface. After reviewing new theories and hypotheses that were made possible to address by principle of faithfulness, this paper reports two similarity judgment experiments that test some of the premises of these theories.

OT has two types of constraints: markedness constraints and faithfulness constraints. OT liberates output markedness problems from solutions by which those problems are solved, whereas a rule-based theory packages markedness problems and solutions into one format. This characteristic of OT has allowed grammar to encode phonetic reasons behind phonological alternations in the formulation of markedness constraints (Hayes and Steriade, 2004; Myers, 1997).¹ Since the issue of encoding phonetic naturalness via markedness constraints has been extensively discussed in the literature already, this paper instead discusses how faithfulness constraints have provided us with a novel way to investigate the relation between phonetics and phonology.

This paper starts with brief discussion of faithfulness constraints in OT in section 2, and moves on to discuss how the principle of faithfulness allows grammar to directly express perceptibility effects in phonology (section 3). Section 4 discusses Correspondence Theory, which has provided a fresh view on the parallel between phonology and verbal art. Section 5 and 6 report similarity judgment experiments that test some premises of the hypotheses discussed in Section 3 and 4. Throughout this paper, I touch on many current issues in OT, but some of these may distract the main flow of the paper—I thus leave the discussion of those current debates in footnotes.²

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¹OT for this reason has brought about a renewed interest in research on phonetically-driven phonology. However, OT itself is a theory of constraint interaction, which has nothing to do with phonetic naturalness in phonology. Therefore it is mistaken to extend one's argument against phonetically-driven phonology to an argument against OT in general.

²Footnotes are great places to find research topics in general (McCarthy, 2008a, p.163).

2 Faithfulness constraints in Optimality Theory

Faithfulness constraints in OT militate against changes from underlying forms (input) to surface forms (output) (see de Lacy, to appear, for a recent overview). As intuitive as this principle sounds, previous rule-based theories of phonology did not explicitly recognize this principle. In fact Halle (1995, p.28) asserts that “... the existence of phonology in every language shows that Faithfulness is at best an ineffective principle that might well be done without.” The principle of faithfulness is crucial in OT (see Prince 1997 for a reply to Halle 1995), because otherwise all input forms would be reduced to the most unmarked form of that language, say [ba] (Chomsky, 1995, p.380). One of the characteristics of OT, therefore, is that it explicitly recognizes the role of faithfulness in its theory. This principle was first formulated as Containment Theory (Prince and Smolensky, 1993/2004). In this theory, no segments are literally deleted or added; instead deletion is captured as unparsing to a higher prosodic level and epenthesis as an unfilled prosodic position. However Containment Theory of faithfulness has largely been replaced by the by-now standard theory in the current literature, Correspondence Theory (McCarthy and Prince, 1995).

Correspondence Theory of faithfulness has two characteristics: (i) any two representations can stand in correspondence, and (ii) faithfulness constraints prohibit disparity between the two representations, i.e., maximize the similarity between them. The following discussion illustrates how these two characteristics have allowed us to express certain generalizations in our linguistic behavior that previous theories of phonology failed to capture.

3 Maximizing perceptual similarity

Acknowledging the principle of faithfulness in phonological theory has allowed us to entertain and pursue the hypothesis that speakers maximize the *psychoacoustic* or *perceptual* similarity between inputs and outputs. Perhaps the most influential—and also provocative—formulation of this hypothesis is the P-map hypothesis proposed by Steriade (2001/2008; 2001a). The problem that she tackles is the observation that languages resolve coda voiced obstruents by devoicing them, but not by any other means (say epenthesis or nasalization). Kenstowicz (2003) likewise observes that when speakers whose language lacks voiced stops borrow words with voiced stops, they borrow them as voiceless stops, never as nasal stops. This example is a tip of an iceberg, a problem that has come to be known as a “too-many-repairs/solutions” problem.³ Steriade argues that languages prefer coda devoicing over other phonological resolutions because devoicing involves a less perceptible change than other phonological changes would. Given the principle of P-map—i.e. speakers maximize the perceptual similarity between input and output—speakers should resort to devoicing, to the extent that devoicing involves the least perceptible change.⁴ In its most general form, the more perceptible the change a phonological alternation involves, the higher the rank of the faithfulness constraint it violates.

³It would be mistaken to blame OT for predicting too many solutions for particular markedness problems. On the contrary, OT has allowed us to see that there is a problem to be solved. OT in its original formulation does predict that any markedness problem can in principle be resolved by multiple phonological means, while in actuality we observe certain limited ways in which some markedness problems can be solved. However, a rule-based theory of phonology makes the same prediction; this too-many-solutions problem is an issue that any adequate theory of phonology must account for (Blumenfeld 2006; Lombardi 2001; McCarthy 2008a; Steriade 2001/2008). Some proposals regarding the too-many-solutions problem within and out of OT include the fixed-ranking approach based on P-map (Steriade, 2001/2008), OT with Candidate Chains (OT-CC) (McCarthy, 2008b), Targeted constraints (Wilson, 2001), procedural markedness constraints (Blumenfeld, 2006), MAX feature constraints (Lombardi, 2001), and restrictions on diachronic paths leading to phonologization (Myers, 2002).

⁴The original P-map hypothesis predicts that languages would always choose one phonological change for a particular markedness problem, the one chosen being the one that is the least perceptible. However, some markedness problems are solved by various phonological alternations. A typical example is nasal-voiceless stop clusters, which can be resolved by post-nasal voicing, nasalization of stop, denasalization of nasal, etc (Pater, 1999) (see also Zuraw and Lu 2009). One emerging theory to address this problem is to say that constraint rankings projected from P-map are default rankings rather than fixed rankings (Steriade, 2001b; Wilson, 2006). The prediction of this amendment is that novel, emerging phonological patterns follow the ranking predicted by the P-map.

This principle may seem like a simple restatement of the principle of faithfulness, but it is innovative in that it reformulates the notion of similarity as perceptual similarity.⁵

Another example in which perception-based faithfulness constraints have proven useful is the observation that nasal consonants are more likely to assimilate in place than oral consonants (Mohan, 1993). There are no languages in which only oral consonants assimilate in place, but there are languages in which only nasal consonants assimilate (e.g. Malayalam: Mohan 1993). In standard phonological feature theories, the asymmetry remains a puzzle because [place] in nasal and [place] in oral consonants are not distinct, and in fact should not be distinct to the extent that homorganic nasal-stop clusters share the same [place] feature, as assumed in standard autosegmental phonology (Goldsmith, 1976). So where does the asymmetry come from?

Jun (2004) argues that the asymmetry comes from the perceptibility of [place] in nasal and oral consonants. He argues that [place] in nasals is less perceptible than [place] in oral consonants and that speakers rank the faithfulness constraint for oral [place] higher than the faithfulness constraint for nasal [place]. The difference in perceptibility of [place] in nasal and oral consonants is supported by some phonetic considerations. Jun (2004), following Malécot (1956), argues that the place contrast in nasals is obscured due to coarticulatory nasalization. Weaker perceptibility of place in nasals finds some evidence in previous psycholinguistic studies. A similarity judgement task shows that speakers judge nasal minimal pairs as more similar to each other than oral consonant minimal pairs (Mohr and Wang, 1968). Pols (1983) shows that Dutch speakers perceive the place contrast more accurately in oral consonants than in nasal consonants (though see the experiments reported below for complications).

Not only has the P-map hypothesis provided insights into cross-linguistic patterning of phonology, it has provided explanations of novel phonological patterns as well. The native phonology of Japanese does not allow voiced obstruent geminates. However, when Japanese speakers borrow words from other languages, mainly from English, they geminate (some) word-final consonants (Shirai, 2002), which resulted in voiced obstruent geminates (e.g. *doggu* ‘dog’ and *eggu* ‘egg’). Having borrowed these words, Japanese speakers have spontaneously started devoicing voiced geminates when they appear with another voiced consonant (Nishimura, 2003), as in (1).

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|---|---|
| <p>(1) Geminates can devoice if they co-occur with another voiced obstruent</p> <p>a. <i>baddo</i> → <i>batto</i> ‘bad’</p> <p>b. <i>baggu</i> → <i>bakku</i> ‘bag’</p> <p>c. <i>doggu</i> → <i>dokku</i> ‘dog’</p> | <p>(2) Singletons do not devoice in the same environment</p> <p>a. <i>gibu</i> → *<i>gipu</i> ‘give’</p> <p>b. <i>bagu</i> → *<i>baku</i> ‘bug’</p> <p>c. <i>dagu</i> → *<i>daku</i> ‘Doug’</p> |
|---|---|

The devoicing in (1) takes place due to a dissimilative constraint against two voiced obstruents within the same stem, a constraint known as Lyman’s Law in the native phonology of Japanese (Itô and Mester, 1986). However, two voiced singleton obstruents do not devoice in loanwords, as in (2).

Kawahara (2006) argues that this difference between singletons and geminates arises from the ranking IDENT(VOI)-SING ≫ OCP(VOI) ≫ IDENT(VOI)-GEM, where IDENT(VOI)-SING and IDENT(VOI)-GEM are faithfulness constraints for voicing for singletons and geminates, and OCP(VOI) is a constraint against two voiced obstruents within the same stem.⁶ Speakers would project the ranking IDENT(VOI)-SING ≫ IDENT(VOI)-GEM if a voicing contrast is less perceptible in geminates than in singletons. Kawahara (2006)

⁵Other proposals encode phonetic perceptibility in markedness constraints by prohibiting non-perceptible contrasts (Flemming, 1995). However, the maximization of perceptual similarity between two corresponding representations can be only formulated in terms of faithfulness constraints, because markedness constraints evaluate the wellformedness of a structure at one-level of representation (Kawahara and Shinohara, to appear).

⁶A markedness based approach is undesirable because the relevant markedness constraint would have to penalize voiced geminates only when they also violate OCP(VOI), a constraint like *[VOICEOBSGEM&OCP(VOI)]_{stem} (Nishimura, 2003) (see Kawahara 2006, sec. 3.3). Pater (to appear) develops a reanalysis of (1) and (2) using Harmonic Phonology with weighted, rather than ranked, constraints, which dispenses with such a complicated markedness constraint. See Tesar (2007) for a reply.

supports the premise about the perceptual asymmetry between voicing in singletons and voicing in geminates in acoustic and perception experiments. Voiced geminates in Japanese are semi-devoiced because of their aerodynamic difficulty (Ohala, 1983), and the semi-devoicing leads to a lower perceptibility of the voicing contrast in geminates. This case shows that the perceptibility of a phonological contrast can shape a novel phonological pattern.⁷ In summary, the principle of faithfulness provides a bridge between phonetic perceptibility and phonological grammar.⁸

4 Generalizing Correspondence theory

The principle of maximization of similarity has brought about the formulation of the P-map hypothesis, which has interesting—and controversial—consequences. Another way in which faithfulness constraints have opened up a new line of research is the study of verbal art including rhyming and puns.

Correspondence Theory in principle allows any two representations to stand in correspondence. In their original proposal, McCarthy and Prince (1995) argue that correspondence holds not only between inputs and outputs, but also between base and reduplicants. Ever since then, the correspondence relation has been argued to hold in many dimensions e.g. between based and derived words (Benua, 1997) (see de Lacy to appear for a recent review). This generality of Correspondence Theory has also resulted in the renewed interests in the study of verbal art (Holtman, 1996; Steriade, 2003).

To discuss an example that relates to the previous discussion on place assimilation, Kawahara (2007) and Kawahara and Shinohara (2009) found that when Japanese speakers pair two consonants in rap rhyming and punning, they are far more likely to pair [m]-[n] than [p]-[t]. Thus there exists an interesting parallel between this observation and the phonological pattern discussed in section 3. Correspondence Theory allows us to capture the parallel in a straightforward manner: both in input-output correspondence and word-word correspondence in rhyming and puns, speakers are more comfortable having the [m]-[n] pair in correspondence than the [p]-[t] pair in correspondence, because the former pair involves more perceptually similar consonants.

We find another interesting parallel between phonology and verbal art. Recall that Steriade (2001/2008) has argued that a voicing contrast is least perceptible among those contrasts made by spectral continuity; that is, speakers neutralize the voicing contrast more than any other contrasts, because minimal pairs differing in voicing are most perceptually similar to each other. This hypothesis finds independent support from rhyme and pun patterns in Japanese; speakers are most willing to pair consonants that differ only in voicing, arguably because they are perceptually similar.

Yet another way in which Correspondence Theory reveals an interesting parallel between verbal art and phonology is positional effects. In phonology speakers avoid making changes in initial syllables (Beckman, 1998), perhaps because initial syllables are psycholinguistically prominent, and such changes would consequently make lexical access difficult (Hawkins and Cutler, 1988). For example in Sino-Japanese, initial syllables allow many consonants but non-initial syllables allow only [t] and [k] (Tateishi, 1990). Assuming

⁷One debate concerning the general issue of phonetic naturalness in phonology is whether such perceptibility effects are encoded in synchronic grammar or result from diachronic changes. The first position, which has been implicitly assumed here, asserts that speakers possess knowledge of perceptibility and have the principle of minimization of perceptual disparity between the corresponding segments. An alternative is to say that listeners simply misperceive contrasts that are not perceptible, which result in a sound change (Blevins, 2004; Myers, 2002). In this theory speakers do not need to have explicit knowledge of perceptibility. However, some studies have argued that when speakers innovate novel phonological patterns, they show phonetically natural patterns, even when historical misperceptions are not at issue (Kawahara, 2006; Wilson, 2006; Zuraw, 2007). To the extent that historical changes can bring about unnatural phonological patterns, it would be crucial to look at novel, emergent phonological patterns which speakers spontaneously create in order to support the thesis of phonetic naturalness in phonology.

⁸There is potentially a chicken-and-egg problem here, because our linguistic knowledge affects our speech perception as well (Massaro and Cohen, 1983; Moreton, 2002): Does speech perception affect phonology first? Or does phonology affect speech perception first? The answer would probably be that the influence is bi-directional. The challenge therefore is how to model this bi-directionality (Boersma, 2006; Hume and Johnson, 2001).

the Richness of the Base (Prince and Smolensky, 1993/2004), speakers need to map an input like /sasul/ to [satu] in Sino-Japanese, as in (3a).

(3) The parallel between phonological mapping and pun pairing

a. Phonological input-output mapping

Input	/	s_i	a_j	s_k	u_l	/
Output	[	s_i	a_j	t_k	u_l]

b. Pun pairing

Word 1	[	s_i	a_j	s_k	u_l]
Word 2	[	s_i	a_j	t_k	u_l]

Kawahara and Shinohara (to appear) have shown via a wellformedness judgment experiment that the same pattern—the avoidance of disparity in initial segments—is observed in puns. We have found that speakers judge a pun involving an initial mismatch (e.g. *sasetsu-ni zasetsu* ‘I gave up turning left’) as less wellformed than a pun involving an internal mismatch (e.g. *hisashi-ni hizashi* ‘Sunlight on the sun roof’). Correspondence Theory allows us to generalize the two observations, as in (3): speakers avoid having a mismatched correspondence pair in initial positions, more so than having a mismatched pair in internal positions. In other words, Correspondence Theory models two separate patterns—resistance of initial syllables being changed in phonology and the wellformedness judgment pattern in puns—using a single principle.

To summarize, Correspondence Theory formalizes the parallel between phonology and verbal art.⁹ Furthermore, this finding has given rise to a new research program: to the extent that the same principle governs both phonology and verbal art, we can investigate our phonological knowledge through verbal art. See Kawahara and Shinohara (2009) for references, and Kawahara (2009) as well as the author’s website for suggestions for future research regarding Japanese puns.

5 Testing some premises: Experiment 1

The maximization principle of similarity incorporates the effect of perceptibility in phonology. The generality of Correspondence Theory captures the parallel between phonology and verbal art. In addition to some open questions that I outlined in the preceding footnotes, one important line for future research is to test hypotheses about perceptual grounding of phonology by experiments. There have been several studies that specifically test such hypotheses (see Kawahara, to appear, for a review), but there are several hypotheses that remain to be tested. For example, Winter (2003) points out that the evidence for lower perceptibility of [place] in nasal is weak, and he himself did not find convincing evidence for a perceptibility difference between nasal [place] and oral [place] in a difference magnitude estimation task or an AX discrimination task. This debate shows that it is important to test the premises for perception-based explanations of phonological patterns. To this end I report (admittedly preliminary) similarity judgment experiments that attempt to test the assumptions about perceptual similarity discussed in the preceding sections.

5.1 Method

The first experiment was a paper-based forced-choice similarity judgment task. The experiment addressed two hypotheses: (i) nasal minimal pairs are more similar to each other than oral consonant minimal pairs (Jun, 2004) (ii) pairs differing in voicing are more similar than pairs differing in other manner features (Kawahara, 2007; Kawahara and Shinohara, 2009; Kenstowicz, 2003; Steriade, 2001/2008). The stimuli

⁹The observation about the parallel between phonology and verbal art is not new, explicitly noticed at least as early as Kiparsky (1973) and Zwicky (1976) (in fact, the origin of literary linguistics dates back to even older time: Fabb 1997). However, Correspondence Theory has provided a tool with which to formulate the parallel explicitly. Another point that is worth mentioning is that some proposals have claimed for a return to Containment Theory (e.g. van Oostendorp, 2008). As far as I can see, it is impossible to capture the parallel between phonology and verbal art in this theory, because Containment Theory does not provide a general mechanism to relate two representations.

consisted of two pairs of consonants (e.g. [ba]-[pa] vs. [ba]-[ma]) to allow participants to judge which pair involved more similar consonants. The task of the participants was thus analogous to comparing (the similarity of) two input-output pairs. The list of the stimuli is given in (4). In addition to these 8 target comparisons, 12 filler dummy comparisons were added. The order of two pairs was counterbalanced by preparing two types of questionnaire.

- (4) The stimuli used to address the two hypotheses
- The weaker perceptibility of nasal [place]: [ma]-[na] vs. [ba]-[da], [ma]-[na] vs. [pa]-[ta]
 - The weaker perceptibility of [voice]: [ba]-[pa] vs. [ba]-[va], [ba]-[pa] vs. [ba]-[ma], [da]-[ta] vs. [da]-[za], [da]-[ta] vs. [da]-[na], [za]-[sa] vs. [za]-[na], [za]-[sa] vs. [za]-[da]

The participants were students taking an introductory psychology class at Rutgers University and two graduate students in the linguistics department. None of them were familiar with the related P-map hypotheses tested in this study. They were encouraged to read the stimuli silently before responding to each question and base their judgment on auditory quality rather than orthographic similarity. The entire process took about 20 minutes. No compensation was given to the participants. Excluding non-native speakers of English, the data from 34 speakers entered into the subsequent statistical analysis. To statistically assess the obtained data, after excluding non-responses, a binomial test was run against the null hypothesis that the participants' responses were random (that is, the probability of one particular pair to be chosen as more similar is .5). The alpha-level was adjusted to $0.05/8=0.006$ by a Bonferroni adjustment.

5.2 Result

Table 1 tallies the results. "Expected responses" are those that are expected from the two hypotheses being tested: nasal minimal pairs are more similar to each other than oral consonant minimal pairs, and minimal pairs differing in voicing are more similar to minimal pairs differing in other manner features (nasality and continuancy). Statistical significance is signaled by an asterisk.

Table 1: The number of expected, unexpected, and no-responses in Experiment 1.

	Pairs	Expected responses	Unexpected responses	No responses	<i>p</i>
a.	[ma]-[na] vs. [pa]-[ta]	25 (74%)	9	0	= .003*
b.	[ma]-[na] vs. [ba]-[da]	26 (79%)	7	1	< .001*
c.	[ba]-[pa] vs. [ba]-[ma]	27 (79%)	7	0	< .001*
d.	[da]-[ta] vs. [da]-[na]	22 (65%)	12	0	<i>n.s.</i>
e.	[za]-[sa] vs. [za]-[na]	30 (88%)	4	0	< .001*
f.	[ba]-[pa] vs. [ba]-[va]	24 (71%)	10	0	<i>n.s.</i>
g.	[da]-[ta] vs. [da]-[za]	25 (74%)	9	0	= .003*
h.	[za]-[sa] vs. [za]-[da]	29 (85%)	5	0	< .001*

5.3 Discussion

As observed in the first two rows in Table 1, the first hypothesis is statistically confirmed—participants judged the nasal minimal pair more similar to each other than oral consonant minimal pairs at a more than chance frequency. The rows (c, e) statistically show that speaker judge the minimal pair differing in voicing

more similar than the minimal pair differing in nasality, and the comparison (d) shows the same tendency ($p = .03$). Finally, the rows (f, g, h) show that speakers tend to judge the minimal pair differing in voicing more similar than the minimal pair differing in continuancy, although the comparison in (f) did not reach significance ($p = .007$).

6 Experiment 2

6.1 Introduction

Although Experiment 1 supports the two hypotheses about the phonetic grounding of phonological patterns— weaker perceptibility of [place] in nasal and weaker perceptibility of [voice]—the results could have been affected by orthographic similarity, although the participants were encouraged to use auditory impression. Furthermore, the phonological alternations under question—nasal place assimilation and coda devoicing— occur in coda, and therefore we should test the hypotheses about perceptibility in coda as well. Therefore the second experiment tested these hypotheses both in onset and coda using auditory stimuli.

In addition to the two hypotheses tested in Experiment 1, this experiment tested two more hypotheses, summarized in (5).

- (5) The four hypotheses tested in Experiment 2
 - a. The [place] contrast is weaker in nasals than oral consonants.
 - b. The [voice] contrast is weaker than [nas] contrast.¹⁰
 - c. The redundant [+voice] feature in sonorants promote their similarity with voiced obstruents.
 - d. Glides and [h] are not highly audible and hence similar to ϕ whereas a strident like [s] is highly audible and not similar to ϕ .

The hypothesis in (5c) was proposed to explain the observation that in languages that avoid similar consonants in adjacent positions, sonorants are considered to be more similar to voiced obstruents than to voiceless obstruents (Frisch et al., 2004; Kawahara and Shinohara, 2009). Hypothesis (5d) explains why languages prefer to use glottal consonants and glides for epenthesis while no languages epenthesize [s]: speakers prefer consonants that are most similar to ϕ for epenthesis, and [s] is too different from ϕ (Kawahara and Shinohara, 2009; Steriade, 2001a). The hypothesis (5d) also explains why [s] is unlikely to be deleted in loanword adaptation (Steriade, 2001a), again because [s] is too different from ϕ . The high audibility of [s] also explains why [s] can violate the sonority sequencing requirement in English onset clusters (Wright, 2004). The format of the experiment is the same as Experiment 1; speakers were presented with two pairs of sounds within each comparison and asked to judge which pair involved more similar consonants.

6.2 Method

The stimuli consist of 12 pairs to test the four hypotheses in (6).

- (6) The stimuli in Experiment 2
 - a. Hypothesis (5a): [ma]-[na] vs. [pa]-[ta], [ma]-[na] vs. [ba]-[da], [am]-[an] vs. [ap]-[at], [am]-[an] vs. [ab]-[ad]
 - b. Hypothesis (5b): [ba]-[pa] vs. [ba]-[ma], [da]-[ta] vs. [da]-[na], [ab]-[ap] vs. [ab]-[am], [ad]-[at] vs. [ad]-[an]
 - c. Hypothesis (5c): [ba]-[ma] vs. [pa]-[ma], [da]-[na] vs. [ta]-[na],

¹⁰Experiment 2 did not compare [voice] and [cont], because this comparison is not relevant to the P-map hypothesis. Recall that the hypothesis addresses why languages only resort to devoicing to resolve coda voiced obstruents; however, spirantization would not eliminate coda voiced obstruents, because voiced fricatives are still voiced obstruents.

- d. Hypothesis (5d): [wa]-[a] vs. [sa]-[a], [ha]-[a] vs. [sa]-[a]

In order to create the stimuli, a native speaker of English pronounced all the stimulus syllables in a frame sentence ‘Please say the word X again’. Each syllable was written on a separate index card, and the order was randomized. His speech was recorded through an AT4040 Cardioid Capacitor microphone with a pop filter in a sound-attenuated recording booth and amplified through an ART TubeMP microphone pre-amplifier (JVC RX 554V). The speech was digitized with 44k sampling rate upon recording using GoldWave. After the recording, the syllables were extracted from the frame sentence at zero crossing. Since the speaker did not assign a uniform pitch contour to all syllables, the pitch contour was artificially made uniform by imposing a flat contour at 110Hz using PSOLA in Praat (Boersma and Weenink, 1999-2009). Their amplitude was also made uniform at the peak of 0.6. The syllables were then windowed with on- and off-ramps of 0.005 ms. The resynthesized syllables were then combined to form pairs with 100 ms of silence in between. Two pairs were finally combined with 500 ms in between. The ordering of pairs was controlled by preparing two orderings.

The participants were students of introductory linguistics classes at Rutgers University. The stimuli were played through HK 195 multimedia speaker systems from a Macintosh computer in quiet rooms, and they were asked to choose which pair sounded more similar to each other. The inter trial interval was 5 seconds, although the participants were encouraged to use their first auditory impression. In order to avoid the effect of orthography, the answer sheet did not provide the orthographic representations of the stimuli. The overall experiment took about 15 minutes. They were paid one dollar for their time.

The data from non-native speakers of English were excluded from the analysis. Also, data from two participants who chose the first pair as more similar in all but one comparison were excluded. As a result, data from 36 participants entered into the statistical analysis. The statistical significance of the results was assessed via a binomial test. The alpha-level was set at .01 for the following reason; some results were expected from Experiment 1, so that a drastic Bonferroni correction would increase Type 2 error (Myers and Well, 2003, p.243-244); on the other hand, since there were 12 comparisons, not adjusting the alpha-level may result in the inflation of Type 1 error.

6.3 Results

Table 2 tallies responses that are expected from the hypotheses in (5). Unlike Experiment 1 there were no non-responses. Again asterisks signal statistical significance. The asterisks in parentheses show significant results that are opposite from expectation.

6.4 Discussion

The first hypothesis, the weaker perceptibility of [place] in nasal, is not supported by the results. Only the onset comparison (a) supports it, but the other three pairs (c-d) did not support the hypothesis. Surprisingly, given the comparison (d) in coda, English speakers judged the oral consonant pair as more similar than the nasal consonant pair. The second hypothesis, the weaker perceptibility of [voice] compared to [nasal], is observed only in coda pairs. The onset results (e, f) are not compatible with the results in Experiment 1 or with Japanese pun or rhyme patterns (Kawahara, 2007; Kawahara and Shinohara, 2009). However, the coda results (g, h) are consistent with the idea that speakers prefer coda devoicing to coda nasalization because the former involves smaller perceptual changes (Steriade, 2001/2008). The third hypothesis that voicing in sonorant promotes their similarity with voiced obstruents was not supported—neither pairs showed statistically significant skew. The fourth hypothesis that glides and [h] are closer to ϕ than [s] is supported.

In summary, the experiment supported only a subset of phonetically-based hypotheses about phonological patterns. The results, however, were not conclusive and further experimentation is warranted. First, since one comparison ([A]-[B] vs. [C]-[D]) was presented only once, the listeners may have had difficulty

Table 2: The number of expected and unexpected responses in Experiment 2.

Pairs			Expected responses	Unexpected responses	<i>p</i>
a.	[ma]-[na]	vs. [ba]-[da]	29 (81%)	7	< .001*
b.	[ma]-[na]	vs. [pa]-[ta]	19 (53%)	17	<i>n.s.</i>
c.	[am]-[an]	vs. [ab]-[ad]	16 (44%)	20	<i>n.s.</i>
d.	[am]-[an]	vs. [ap]-[at]	8 (22%)	28	< .001(*)
e.	[ba]-[pa]	vs. [ba]-[ma]	11 (31%)	25	< .01(*)
f.	[da]-[ta]	vs. [da]-[na]	15 (42%)	21	<i>n.s.</i>
g.	[ab]-[ap]	vs. [ab]-[am]	29 (81%)	7	< .001*
h.	[ad]-[at]	vs. [ad]-[an]	26 (72%)	10	< .01*
i.	[ba]-[ma]	vs. [pa]-[ma]	23 (64%)	13	<i>n.s.</i>
j.	[da]-[na]	vs. [ta]-[na]	15 (42%)	21	<i>n.s.</i>
k.	[wa]-[a]	vs. [sa]-[a]	30 (83%)	6	< .001*
l.	[wa]-[a]	vs. [sa]-[a]	31 (86%)	5	< .001*

in remembering the first pair by the time they heard the second pair. Therefore, a follow-up experiment is planned in which the same comparison will be repeated multiple times.

Second, the current experiment is based on one token of each comparison, and in order to further verify the generality of the results, it would be desirable to prepare multiple tokens of the same contrast pairs pronounced by multiple speakers. In particular, the speaker recorded for the current experiment did not release the word-final stops. The lack of release may be responsible for low perceptibility of oral [place] contrasts, because release bursts convey place distinctions (Stevens and Blumstein, 1978). The result is in fact compatible with what Winter (2003) found—when speakers were asked to estimate differences of minimal pairs, if stop minimal pairs do not have audible release, they were considered as similar as nasal pairs. It would therefore be interesting to test the perceptibility of both released and unreleased oral consonants.

Third, since place assimilation takes place in preconsonantal positions rather than in word-final positions, it would be interesting to include comparisons like [amka]-[anka] vs. [abka]-[adka]. However, since English has nasal place assimilation, and since this property affects English speakers’ speech perception patterns (Darcy et al., 2009), this comparison needs to be tested in languages which do not show any place assimilation.

More generally, the studies reported here are admittedly preliminary, and we need to test listeners from other languages to investigate the robustness of the perceptual asymmetries under question. We also need to test the hypotheses about perceptibility of different contrasts in other experimental methods such as identification/discrimination experiments under noise and magnitude estimation tasks. In summary, the experiments support only a subset of proposed hypotheses but open up possibilities for further experimentation.

7 Conclusion

Optimality Theory has allowed us to address issues that have been hitherto impossible to ask. The principle of faithfulness has opened up the possibility that phonology may encode phonetic perceptibility in phonology. Correspondence Theory’s formalization of faithfulness captures both our quotidian speech behavior and verbal art patterns. While these research programs have produced interesting results, the hypotheses on the phonetic grounding of phonological patterns should be tested experimentally.

References

- Beckman, J. (1998) *Positional Faithfulness*. Doctoral dissertation, University of Massachusetts, Amherst.
- Benua, L. (1997) *Transderivational Identity: Phonological Relations between Words*. Doctoral dissertation, University of Massachusetts, Amherst.
- Blevins, J. (2004) *Evolutionary Phonology: The Emergence of Sound Patterns*. Cambridge: Cambridge University Press.
- Blumenfeld, L. (2006) *Constraints on Phonological Interactions*. Doctoral dissertation, Stanford University.
- Boersma, P. (2006) "A programme for bidirectional phonology and phonetic and their acquisition and evolution." Ms. University of Amsterdam.
- Boersma, P. and Weenink, D. (1999-2009) "Praat: doing phonetics by computer." A software.
- Chomsky, N. (1995) *The Minimalist Program*. Cambridge, MA: MIT Press.
- Darcy, I., Ramus, F., Christophe, A., Kinzler, K. and Dupoux, E. (2009) "Phonological knowledge in compensation for native and non-native assimilation." In Frank, K., Féry, C. and van de Vijver, R. (eds.) *Variation and Gradience in Phonetics and Phonology*. Berlin & New York: Mouton de Gruyter.
- de Lacy, P. (to appear) "Markendess and faithfulness constraints." In van Oostendorp, M., Ewen, C. J., Hume, E. and Rice, K. (eds.) *The Blackwell companion to phonological theory*. Oxford: Blackwell-Weiley.
- Fabb, N. (1997) *Linguistics and Literature: Language in the Verbal Arts of the World*. Oxford: Basil Blackwell.
- Flemming, E. (1995) *Auditory Representations in Phonology*. Doctoral dissertation, UCLA.
- Frisch, S., Pierrehumbert, J. and Broe, M. (2004) "Similarity avoidance and the OCP." *Natural Language and Linguistic Theory* 22, pp. 179–228.
- Goldsmith, J. (1976) *Autosegmental Phonology*. Doctoral dissertation, MIT. Published by Garland Press, New York, 1979.
- Halle, M. (1995) "Letter commenting on Burzio's "the rise of optimality theory"." *Glott International* 1(9/10), pp. 27–28.
- Hawkins, J. and Cutler, A. (1988) "Psycholinguistic factors in morphological asymmetry." In Hawkins, J. A. (ed.) *Explaining Language Universals*, (pp. 280–317). Oxford: Basil Blackwell.
- Hayes, B. and Steriade, D. (2004) "Introduction: The phonetic bases of phonological markedness." In Hayes, B., Kirchner, R. and Steriade, D. (eds.) *Phonetically Based Phonology*, (pp. 1–33). Cambridge: Cambridge University Press.
- Holtman, A. (1996) *A Generative Theory of Rhyme: An Optimality Approach*. Doctoral dissertation, Utrecht Institute of Linguistics.
- Hume, E. and Johnson, K. (2001) "A model of the interplay of speech perception and phonology." In Hume, E. and Johnson, K. (eds.) *The role of speech perception in phonology*. San Diego: Academic Press.
- Itô, J. and Mester, A. (1986) "The phonology of voicing in Japanese: Theoretical consequences for morphological accessibility." *Linguistic Inquiry* 17, pp. 49–73.
- Jun, J. (2004) "Place assimilation." In Hayes, B., Kirchner, R. and Steriade, D. (eds.) *Phonetically-based Phonology*, (pp. 58–86). Cambridge: Cambridge University Press.
- Kawahara, S. (2006) "A faithfulness ranking projected from a perceptibility scale: The case of voicing in Japanese." *Language* 82, pp. 536–574.
- Kawahara, S. (2007) "Half-rhymes in Japanese rap lyrics and knowledge of similarity." *Journal of East Asian Linguistics* 16, pp. 113–144.
- Kawahara, S. (2009) "Probing knowledge of similarity through puns." In Shinya, T. (ed.) *Proceedings of Sophia Linguistics Society*, volume 23, (pp. 110–137). Tokyo: Sophia University Linguistics Society.
- Kawahara, S. (to appear) "Experimental approaches in generative phonology." In van Oostendorp, M., Ewen, C. J., Hume, E. and Rice, K. (eds.) *The Blackwell companion to phonological theory*. Oxford: Blackwell-Weiley.

- Kawahara, S. and Shinohara, K. (2009) "The role of psychoacoustic similarity in Japanese puns: A corpus study." *Journal of Linguistics* 45, pp. 111–138.
- Kawahara, S. and Shinohara, K. (to appear) "Phonetic and psycholinguistic prominences in pun formation: Experimental evidence for positional faithfulness." In McClure, W. and den Dikken, M. (eds.) *Japanese/Korean Linguistics 18*. Stanford: CSLI.
- Kenstowicz, M. (2003) "Salience and similarity in loanword adaptation: A case study from Fijian." Ms. MIT.
- Kiparsky, P. (1973) "The role of linguistics in a theory of poetry." In Freeman, D. (ed.) *Essays in Modern Stylistics*, (pp. 9–23). London: Methuen.
- Lombardi, L. (2001) "Why place and voice are different: Constraint-specific alternations in Optimality Theory." In Lombardi, L. (ed.) *Segmental Phonology in Optimality Theory*, (pp. 13–45). Cambridge, UK: Cambridge University Press.
- Malécot, A. (1956) "Acoustic cues for nasal consonants: An experimental study involving a tape-splicing technique." *Language* 32, pp. 274–84.
- Massaro, D. and Cohen, M. (1983) "Phonological context in speech perception." *Perception & Psychophysics* 34, pp. 338–348.
- McCarthy, J. J. (2008a) *Doing Optimality Theory*. Oxford: Blackwell-Weiley.
- McCarthy, J. J. (2008b) "The serial interaction of stress and syncope." *Natural Language and Linguistic Theory* 26, pp. 499–546.
- McCarthy, J. J. and Prince, A. (1995) "Faithfulness and reduplicative identity." In Beckman, J., Walsh Dickey, L. and Urbanczyk, S. (eds.) *University of Massachusetts Occasional Papers in Linguistics 18*, (pp. 249–384). Amherst: GLSA.
- Mohanan, K. P. (1993) "Fields of attraction in phonology." In Goldsmith, J. (ed.) *The Last Phonological Rule: Reflections on Constraints and Derivations*, (pp. 61–116). Chicago: University of Chicago Press.
- Mohr, B. and Wang, W. S. (1968) "Perceptual distance and the specification of phonological features." *Phonetica* 18, pp. 31–45.
- Moreton, E. (2002) "Structural constraints in the perception of English stop-sonorant clusters." *Cognition* 84, pp. 55–71.
- Myers, J. and Well, A. (2003) *Research Design and Statistical Analysis*. Mahwah: Lawrence Erlbaum Associates Publishers. Mahwah.
- Myers, S. (1997) "Expressing phonetic naturalness in phonology." In Roca, I. (ed.) *Derivations and Constraints in Phonology*, (pp. 125–152). Oxford: Oxford University Press.
- Myers, S. (2002) "Gaps in factorial typology: The voicing in consonant clusters." Ms. University of Texas.
- Nishimura, K. (2003) *Lyman's Law in loanwords*. MA thesis, Nagoya University.
- Ohala, J. J. (1983) "The origin of sound patterns in vocal tract constraints." In MacNeilage, P. (ed.) *The Production of Speech*, (pp. 189–216). New York: Springer-Verlag.
- Pater, J. (1999) "Austronesian nasal substitution and other NC effects." In Kager, R., van der Hulst, H. and Zonneveld, W. (eds.) *The Prosody-Morphology Interface*, (pp. 310–343). Cambridge: Cambridge University Press.
- Pater, J. (to appear) "Weighted constraints in generative linguistics." *Cognitive Science*.
- Pols, L. (1983) "Three mode principle component analysis of confusion matrices, based on the identification of Dutch consonants, under various conditions of noise and reverberation." *Speech Communication* 2, pp. 275–293.
- Prince, A. (1997) "Elsewhere & otherwise." Ms. Rutgers University.
- Prince, A. and Smolensky, P. (1993/2004) *Optimality Theory: Constraint Interaction in Generative Grammar*. Malden and Oxford: Blackwell.
- Shirai, S. (2002) *Gemination in Loans from English to Japanese*. MA thesis, University of Washington.
- Steriade, D. (2001a) "Directional asymmetries in place assimilation: A perceptual account." In Hume, E. and Johnson, K. (eds.) *The Role of Speech Perception in Phonology*, (pp. 219–250). New York: Academic.

- Press.
- Steriade, D. (2001b) "What to expect from a phonological analysis." Talk presented at LSA 77, Washington, D.C.
- Steriade, D. (2001/2008) "The phonology of perceptibility effect: The p-map and its consequences for constraint organization." In Hanson, K. and Inkelas, S. (eds.) *The nature of the word*, (pp. 151–179). Cambridge: MIT Press. Originally circulated in 2001.
- Steriade, D. (2003) "Knowledge of similarity and narrow lexical override." In Nowak, P. M., Yoquelet, C. and Mortensen, D. (eds.) *Proceedings of the twenty-ninth annual meeting of the Berkeley Linguistics Society*, (pp. 583–598). Berkeley: BLS.
- Stevens, K. and Blumstein, S. (1978) "Invariant cues for place of articulation in stop consonants." *Journal of Acoustical Society of America* 64, pp. 1358–1368.
- Tateishi, K. (1990) "Phonology of Sino-Japanese morphemes." In Lamontagne, G. and Taub, A. (eds.) *University of Massachusetts Occasional Papers in Linguistics 13*, (pp. 209–235). Amherst: GLSA.
- Tesar, B. (2007) "A comparison of lexicographic and linear numeric optimization using violation difference ratios." Ms. Rutgers University.
- van Oostendorp, M. (2008) "Incomplete devoicing in formal phonology." *Lingua* 118, pp. 1362–1374.
- Wilson, C. (2001) "Consonant cluster neutralization and targeted constraints." *Phonology* 18, pp. 147–197.
- Wilson, C. (2006) "Learning phonology with substantive bias: An experimental and computational study of velar palatalization." *Cognitive Science* 30, pp. 945–980.
- Winter, S. (2003) *Empirical Investigations into the Perceptual and Articulatory Origins of Cross-Linguistic Asymmetries in Place Assimilation*. Doctoral dissertation, Ohio State University.
- Wright, R. (2004) "A review of perceptual cues and cue robustness." In Hayes, B., Kirchner, R. and Steriade, D. (eds.) *Phonetically Based Phonology*, (pp. 34–57). Cambridge: Cambridge University Press.
- Zuraw, K. (2007) "The role of phonetic knowledge in phonological patterning: Corpus and survey evidence from Tagalog reduplication." *Language* 83, pp. 277–316.
- Zuraw, K. and Lu, Y.-A. (2009) "Diverse repairs for multiple labial consonants." *Natural Language and Linguistic Theory* 27, pp. 197–224.
- Zwicky, A. (1976) "This rock-and-roll has got to stop: Junior's head is hard as a rock." In Mufwene, S., Walker, C. and Steever, S. (eds.) *Proceedings of Chicago Linguistic Society 12*, (pp. 676–697). Chicago: CLS.