edited by
Tsai-Fa Cheng, Yafei Li, Hongming Zhang

GSIL
(Graduate Students in Linguistics)
University of Southern California
Table 1: Effects of Semantic Transparency

<table>
<thead>
<tr>
<th>Semantic Transparency</th>
<th>High</th>
<th>Low</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transparent</td>
<td>274.4</td>
<td>61.2</td>
</tr>
<tr>
<td>opaque</td>
<td>274.4</td>
<td>61.2</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Character Frequency</th>
<th>High</th>
<th>Low</th>
</tr>
</thead>
<tbody>
<tr>
<td>High</td>
<td>54.5</td>
<td>10.5</td>
</tr>
<tr>
<td>Low</td>
<td>54.5</td>
<td>10.5</td>
</tr>
</tbody>
</table>

| Number of Errors (%)  | 3.5  | 1.5  |

Note: ** = standard deviation; % Err = percentage of errors.

Table 2: Mean Reaction Times (in ms), Standard Deviations, and Error Percentages for Each Condition of Experiment 3 (VCCL)

<table>
<thead>
<tr>
<th>Condition</th>
<th>Transparent</th>
<th>Final-Queque</th>
<th>Initial-Queque</th>
<th>PL Words</th>
</tr>
</thead>
<tbody>
<tr>
<td>g</td>
<td>644.0</td>
<td>693.0</td>
<td>722.1</td>
<td>872.5</td>
</tr>
<tr>
<td>z</td>
<td>64.3</td>
<td>64.3</td>
<td>74.5</td>
<td>56.9</td>
</tr>
<tr>
<td>% Err</td>
<td>5.3</td>
<td>5.3</td>
<td>15.0</td>
<td>2.1</td>
</tr>
</tbody>
</table>

Note: ** = mean; s = standard deviation; % Err = percentage of errors.

**Table:**

<table>
<thead>
<tr>
<th>Physical Constraints</th>
</tr>
</thead>
<tbody>
<tr>
<td>Physical Constraints in the Phonology of Fuzhou*</td>
</tr>
<tr>
<td>Jane Tsay</td>
</tr>
<tr>
<td>National Cheng Cheng University</td>
</tr>
</tbody>
</table>

1. Introduction

One of the fundamental issues in phonology is where phonological parametric regularities come from. The assumption that phonological regularities come from Universal Grammar seems to be well accepted by generative phonologists. For example, feature theories like Feature Geometry (Clements 1985, Sage 1986, McCarthy 1988) claim that the phonological regularities, as captured by rules, lie in the universal representations of phonological features. This is most explicitly addressed in the following quotation from McCarthy (1988:34): "If the representations are right, then the rules will follow."

On the other hand, there is a so-called approach which argues that phonological regularities come from two sources: Universal Grammar (i.e. the linguistic faculty) and extralinguistic domains such as physiology, perception/psychostatistics, learnability, etc. (e.g. Anderson 1983, Hammond 1990, Tsay 1994). In such an approach, grammar alone cannot account for all the phonological patterns. Very often, the patterns have to be attributed to extraparametrical constraints as well.

In this paper I show that in the case of the phonology in Fuzhou Chinese, phonological representations alone are not sufficient to describe an interaction between tone and vowel height, requiring in addition indirect reference to the physics of speech. Therefore, Fuzhou tone and vowel height interaction supports the claim that phonological regularities come from Universal Grammar.

* The author wishes to thank James Myers, Jim Sands, and the participants of the 3rd Meeting of CCCL-2 and NACCL-2, especially C.C. Chong, Hansi Bliesch, and Samuel Wang.
Tsuy: Physical Constraints

both from Universal Grammar and extralinguistic domains (physiology, in this case).

Although the correlation between tone and vowel height in Fuzhou does have its physical bases, the physical-phonology connection is still in the grammar of Fuzhou phonology as a lexicalized pattern.

This paper is organized as follows. The patterns of Fuzhou tone-vowel height interactions are presented in Section 2. In Section 3 I show why these interactions require an analysis where physiology plays an important role. In Section 4, I discuss the implications of these conclusions for the psychological processing of Fuzhou tone sandhi and associated vowel height changes. Finally, in Section 5 I conclude that only a phonological theory that has separate modules for both phonological representations and extralinguistic factors such as physiology can handle patterns like that seen in Fuzhou.

2. Fuzhou tone and vowel height interaction
2.1. Data
Fuzhou belongs to the North Min Family of Chinese. In this language, each monosyllabic morpheme has two forms: a pre-juncture (including isolation) form and a context form. Both tone and vowel are involved in the alternation between these two forms. Specifically, vowels cooccurring with nilow tones resulting from tone sandhi (as is the context position in an utterance) are raised one vowel height level. Thus the low-vowel diphthongs iu and iu become the mid-vowel diphthongs iu and iu, respectively, while the mid-vowel diphthongs ai, and ai become the high vowels /i, /ü and /ü, respectively. Examples are given in (1) from T. Wang (1969) and (2) from Chan (1985).1

(1) T. Wang (1969)

<table>
<thead>
<tr>
<th>Isolation</th>
<th>Context</th>
</tr>
</thead>
<tbody>
<tr>
<td>a. tiXLML</td>
<td>｛i XL ML - gen[M]</td>
</tr>
<tr>
<td>b. hghXLML</td>
<td>｛g ML - ny[M]</td>
</tr>
<tr>
<td>c. rghXLML</td>
<td>｛rg ML - yo[M]</td>
</tr>
<tr>
<td>d. rghXLML</td>
<td>｛r ML - mo[M]</td>
</tr>
</tbody>
</table>

(2) Chan (1985)

<table>
<thead>
<tr>
<th>Isolation</th>
<th>Context</th>
</tr>
</thead>
<tbody>
<tr>
<td>a. k-xlML</td>
<td>｛k ML - go[M]</td>
</tr>
<tr>
<td>b. tiXLML</td>
<td>｛t ML - g ML - go[M]</td>
</tr>
<tr>
<td>c. hghXLML</td>
<td>｛h ML - en ML</td>
</tr>
<tr>
<td>d. tiXLML</td>
<td>｛t ML - mo[M]</td>
</tr>
<tr>
<td>e. rghXLML</td>
<td>｛rg ML - yo[M]</td>
</tr>
<tr>
<td>f. rghXLML</td>
<td>｛rg ML - mo[M]</td>
</tr>
</tbody>
</table>

1For uniformity of presentation, the inscription of the tones is changed from Wang's original graphic system and Chan's original digit system.

These vowel height alternations can be summarized as follows.
Tsai: Physical Constraints

(3) Summary of vowel height alternations

<table>
<thead>
<tr>
<th></th>
<th>[H.L.]</th>
<th>[L.M.]</th>
</tr>
</thead>
<tbody>
<tr>
<td>el</td>
<td>i</td>
<td></td>
</tr>
<tr>
<td>ou</td>
<td>u</td>
<td></td>
</tr>
<tr>
<td>ary</td>
<td>y</td>
<td></td>
</tr>
<tr>
<td>ai</td>
<td>el</td>
<td></td>
</tr>
<tr>
<td>au</td>
<td>ou</td>
<td></td>
</tr>
</tbody>
</table>

The covariation between tone and vowel height can be analyzed as feature interaction, e.g. informally as 'if higher tone, then higher vowel.' The formalization of this interaction will be discussed later.

However, the analysis of this phenomenon is complicated by the fact that the tone and vowel quality changes also covary with changes in quantity; note that lower tones tend to be associated with diphthongs, while higher tones tend to be associated with monophthongs. Some proposals have been made taking a Prosodic approach (e.g. Wright 1984, Chan 1985) or a No-Direct-Interaction approach (Jiang-Kele 1994, 1995). The former treats the vowel alternation as fundamentally an alternation in vowel length, while the latter claims that direct interaction between tone and vowel height does not only not occur in Fushan, but is in fact universally ruled out by phonological theory. Before presenting my own analysis, therefore, I must first argue against these proposals.

2.2. Arguments for the existence of tone-vowel height interaction

There are several arguments for the existence of tone-vowel height interaction. First, in the case of Fushan, whether or not we call the diphthongization primary, the fact remains that there is still an alternation in vowel height as well. Moreover, in some examples, diphthongization does not occur at all (e.g. [u]-[ou], [ou]-[ou]). Hence, a purely prosodic approach cannot account for all the data.

Second, tone-vowel height interactions have also been confirmed by production experiments on other languages, for example, Taiwanese (See

Tsai: Physical Constraints

1980) and Mandarin (Tsai and Sawusch 1994). In the case of Mandarin, words with same phonemes but different tones have slightly different vowel heights. This has been observed by Chao (1948) and Pan (1965). An example is given below showing F1 (i.e. vowel height) variations among four Mandarin words which differ only in tones. As can be seen, Mandarin Tone 1 (H) and Tone 2 (LH) correlate with lower F1 (i.e. higher u=ou), while Tone 3 (L) and Tone 4 (HL) correlate with higher F1 (i.e. lower vowel). This pattern is gradient. That is, the F1 values do not match those of other vowel phonemes (e.g. /i/).

(4) F1 variations in Mandarin (Tsai and Sawusch 1994)

Finally, tone-vowel height interactions are physically based, and so it is not obvious why or how phonological systems could ignore it. The coupling between vowel height and fundamental frequency observed in phonetic studies of many languages has been accounted for by the hypothesis that there is a mechanical and/or neural coupling between the oral and laryngeal articulatory systems. For example, Ohala (1973, 1977) and Ohala and Ekbal (1978) propose that the correlation between higher vowels and higher F0 could be due to an indirect pull of the tissues.
Tsuy: Physical Constraints

connecting the tongue dorsum with the aryepiglottic folds on the ventricular and true vocal folds, which increases the tension of the vocal folds and thus raises F0. Honda (1983) and Honda, Hirai, and Dang (1994) have also shown that pitch can be raised by raising the whole larynx, which is linked to the base of the tongue via the hyoid bone. Now that we have established the existence of both phonetic and phonological tone-vowel height interaction, the next question is how it can be described formally in phonology. That is, how do we represent such a feature interaction?

3. The formal analysis of Fuzhou

3.1. Phonological representation of tone-vowel height interaction

There are three logical ways of formally capturing tone-vowel height interactions. One is to have the same features for both tone and vowel height. This seems highly implausible, since as is well known, tone most commonly interacts with laryngeal properties like voicing: tone-vowel height interactions do exist, but they are rather rare. Thus a single feature for both tone and vowel height would imply that such interactions are much more common than they are.

The second way to describe tone-vowel height interactions would be to link tone feature(s) and vowel height feature(s) in some universal hierarchical organization, as in Feature Geometry. The features could continue to have their own separate existence, but the representation would claim that they could interact. However, this approach faces the same problem as the first one. Since relationships between features in theories of phonological representations are universal and discrete, representations alone still cannot explain why tone-voicing interactions are so common but tone-vowel height interactions are rare but not unattested.

The third way to describe tone-vowel height interactions is to allow any pair of features to be linked in the phonology, but the pairings are phonetically evaluated for physical motivation. Though formally somewhat more complex, this approach has the advantage that an explicit claim has to be made in the phonological representation about how phonetically plausible the connection is. The evaluation of plausibility would be made outside of phonology entirely, in an independent phonetic (physical) module. In the case of tone-vowel height versus tone-voicing interactions, the evaluation would make reference to the following. The articulation of pitch has physical connections with the articulation of laryngeal features like voicing, since both involve manipulation of the vocal folds (e.g. Zemlin 1968, Halle and Stevens 1971), but it also has physical connections with the articulation of vowel height, since pitch can be raised by raising the whole larynx, which is linked to the base of the tongue via the hyoid bone (e.g. Honda 1983, Honda, Hirai, and Dang 1994). Tone-voicing interactions are much more common than tone-vowel height interactions because the former involves physically stronger connections between articulations: almost identical articulators in the case of tone-voicing, but distinct weakly coupled articulators in the case of tone-vowel height.

I now turn to a more detailed examination of this third approach, which I claim is the one necessary to analyze Fuzhou tone-vowel height interactions.

3.2. How physics affects phonology

The relation between Universal Grammar and extra-linguistic factors (including the physiological factors that motivate tone-vowel height interactions) can be represented schematically as below. This figure shows that the innate principles of UIG allow more theoretically possible languages that can actually be used, given the constraints of learnability, perception and physiology. The bolded oval represents languages that are theoretically possible according to UIG, while the lighter oval represents languages that are ruled out due to learnability, perception and physiology. For example, the "physiology" oval contains all phonologically impossible things, including phonological systems that are physiologically totally unmotivated or even disallowed. The shaded area then represents the set of languages that are actually possible in the real world.
Tsay: Physical Constraints

(5) The interaction between grammar and extralinguistic domains (Tsay 1994; see also Anderson 1981; Hammond 1996)

Universal Grammar

Perception

Physiology

Learnability

Although tone and vowel height have connections in the physical world, the physical connections are weak, and so languages rarely invoke them and instantiate them in the grammar. In the case of Fushou, the feature interaction between tone and vowel height has happened to have been put into the grammar of the language. In other words, the physical connection has been phonologized (or even lexiconized as will be discussed in next section) and become part of the grammar of the language.

The relevance of the relative strength of physical connections can be made clearer in the following figure, where we see that the edge of the "physiology" set is "fuzzy", that is, some interactions are more physiologically disallowed than others. The core of this set contains physiologically totally impossible elements, while as one moves out towards the edge, the physiological constraints weaken until the elements become quite strongly physiologically motivated. A stronger physical connection means a greater likelihood of phonological interaction, and a weaker physical connection means a lesser likelihood of phonological interaction (Archangeli and Pulleyblank 1994).

Tsay: Physical Constraints

(6) The interaction between grammar and physiology

It is important to observe that the set of "possible languages" predicted by the innate principles of UG (the bold oval) is categorical: either a language (e.g. phonological system) is allowed by UG or it is not. Thus phonological systems with tone-voicing height interactions and systems with tone-vowel height interactions are both equally valid according to UG.

The gradient difference between the two types, i.e. the fact that the former is very common while the latter is quite rare, follows not from the nature of UG but from the gradience differences in physical motivation. It is this gradience that proves that an independent phonetic module must play a role in phonology. As we saw above, a formal phonological model of tone-vowel height interactions could not explain by itself why such interactions are rarer than tone-voicing interactions. Instead, it would have to incorrectly predict either that tone-vowel height interactions never occur, or that both kinds of interactions are equally common.
Tsuy: Physical Constraints

3.3. From physics to phonology
The gradient nature of the physics-phonology interface can be seen in the fact that there is no clear jump from a purely physical, non-phonological interaction to one that is purely phonological. Instead, cross-linguistic study shows that languages go through a series of stages, where the physical influence is mostly non-phonological to where it is truly phonological and even lexicalized.

As an example of the first stage, consider the effect of pitch on vowel height in languages without distinctive tone categories. Honda (1983) and Honda, Hiki, and Dong (1994) have examined this phenomenon in Japanese, and Tsuy and Sawashe (1994) looked at it in English. In Japanese there is a very small but real effect of pitch on vowel height, while in English the effect is smaller than predicted by the physical models, suggesting that the effect is being actively suppressed. The English results imply in particular that it may be naive to think of a "purely physical" stage of phonologization. Instead, it appears that speakers are always reacting to the physical nature of speech in some way or other. In this case, by attempting to preserve vowel categories by protecting them from distortions caused by phonologically irrelevant pitch. In any case, at this stage the tone-vowel height interactions are clearly not phonological, presumably because tone plays no role in the phonological system and so its effects may be ignored (e.g. Japanese), or suppressed (e.g. English).

In the next stage, a physical connection between two articulators becomes part of the grammar and shows up in allophonic (i.e. gradient) alternations. For the first time we may think of the connection as being part of the speaker's knowledge of their language, but at this stage it takes place at the level of speech production or motor control (e.g. at the level called "phonetic speech", in the processing model of Levelt 1989). The Mandarin vowel height alternative discussed above appears to be of this sort; the effect of tone on vowel height, though merely allophonic, appears to be exaggerated beyond what would be predicted if it resulted purely from physics. That is, speakers seem to be actively changing their vowel height with different tones. The difference between this stage and the earlier one seems to result from differences in the functions of the articulations. In Mandarin, unlike English, pitch is used to make lexical contrasts. Thus the fact that pitch changes vowel quality can be made to serve a useful function, namely to exaggerate differences in the articulation of tone categories, thereby making them more distinct to listeners.

In a still later stage, such an allophonic change can be further phonologized and become a (morpho)phonemic (i.e. categorical) alternation. Vowel height alternation in Fushan appears to be an example of this. Since at this stage the interaction is occurring totally between abstract phonological features, it is not clear if physics can play a direct role in maintaining it. Instead, it may be better to think of the role of physics at this stage as historical; as Lehtinen (1970: 79) notes about the categorical vowel changes in Fushan: "...one is led to assume, however, a stage (in Fushan) with allophonic raising of the vowels under high tones may have preceded the present stage."

Summarizing, the three stages are shown in the figure below.

(7) Stage I
- gradient physics
- Japanese (Japanese/English) (Mandarin)
- physical constraints
- all phonetics
- gradient/phonemic
- physics active/off-line

Stage II
- gradient physics
- phonetics > phonology
- gradient constraints
- gradient/allophonic
- active/on-line

Stage III
- phonetics > phonology
- gradient/allophonic
- allomorph selection (lexicalized)
lexicalized phraseology applies on-line with the construction of syntactic structure, or off-line, like standard lexicalized patterns of allomorphy? Hayes (1990) solves the problem by analyzing such cases as precompiled phraseology. That is, they are true lexical rules that happen to include some sketchy information about the syntactic structure in their descriptions. The way speakers actually use such rules, though, involves only the on-line selection of lexical allomorph for insertion into syntactic frames. In other words, lexicalized phraseology is off-line in its generation of the allomorph, but on-line in its morphophonological selection.

This situation seems to be common with tone sandhi. For example, Taiwanese. They point out that Taiwanese tone sandhi shows all the signs of being a lexical rule, from the fact that it is categorical (Tsay and Charles-Luce, in prep.) and only semi-productive (Hsieh 1970, 1975, 1976, Wang 1995) to the existence of lexical isomorphs in its application. It does refer to information beyond the word, of course, but as Chen (1987) and Liu (1994) have shown, this information is specifically syntactic, precisely the information that is needed for lexical insertion.

There are three points of view. First, tone sandhi in Fuhouo is notoriously complex and "phonetically unnatural," characteristics typical of lexical rules (Yip 1991, Wright 1983, Chen 1985, Jiang-King 1994, among others). More important, both the tone alterations of tone sandhi and the vowel height alternations that tone sandhi triggers have been shown to be categorical (Tsay and Sawusch 1994). As can be seen in the figure below on the left, the F0 (i.e. pitch) contour for the pre-juncture [H] tone ( labeled 'k'-underlying) is phonetically identical to the context [H] tone (labelled 'k'-derived), while both are clearly distinct from the [ML] tone. The same holds for the vowel height alternations. In the figure on the right, we see that the F1 (i.e. vowel height) contours for the pre-juncture [i] and context [i] are again identical, while again both are distinct from that of [e]. Together, these results indicate that not only Fuhouo tone sandhi, but also the vowel height alternations that cooccur with it, are categorical, and thus quite likely
Tsay: Physical Constraints

lexicalized.

(8) Categoricity in tone sandhi and vowel height alternations

In other words, at this stage physics has left the phonology far behind. There is no way the physical connection between the tongue root and the larynx could produce the categorical effects seen here. Instead, the only way in which tone-vowel height interactions are psychologically real for modern Fuzhou speakers is that they must memorize allomorphs that reflect the phonetically-motivated tone-vowel height interactions. An example showing how this works is given below.

Tsay: Physical Constraints

(9) Allomorph selection

a. Both forms for each word are stored in memory.

For the word meaning "ground"
Form A: [\text{\textit{g}}}^{(H)}\text{ml}]
context position
Form B: [\text{\textit{g}}}^{(H)}\text{ml}]

b. Select the form that fits the proper syntactic environment.

The fact that the physical motivation for tone-vowel height interactions (i.e. the tongue-larynx coupling) is completely divorced from its psychological processing in modern Fuzhou (i.e. speakers merely choose non-derived, memorized allomorphs) is a powerful argument in favor of the modular approach to the role of physical constraints in phonology that has been advocated in this paper. In Fuzhou we see that separate modules for physics and phonology must be posited, or else we would be forced to make one of the following two absurd claims: either we must derive the categorical tone-vowel height interactions directly from physics in Fuzhou, or else we must claim that phonological constraints have nothing at all to do with physics, thereby falsely predicting that tone-vowel height interactions are as common as tone-voicing interactions (or are totally impossible).

5. Conclusion

In this paper, it has been argued that tone and vowel height interaction does exist, although it is rare, and that this interaction is physically based. The physical connections between two features are instantiated in the grammar of the language through phonologization. As to the psychological aspect of phonology, not all phonological patterns involve rule applications in processing. Fuzhou tone and vowel height interaction is a case where the physics-phonology connection is not active any more, but lexicalized.
Tsai: Physical Constraints

In order to deal with Fuzhou, then, we must posit separate modules for phonology and for physics. If we attempt to record all relevant physical properties solely in terms of phonological representations, then we cannot explain why certain interactions are much more common than others, nor why this gradience correlates perfectly with physical strength. If, however, we attempt to abstract all physically motivated phonological patterns to the active intervention of physics, then we cannot explain why Fuzhou tone-voiced height interactions are clearly lexicalized. In short, in a sense there are no physical constraints within the synchronic phonology of Fuzhou; rather, they are separate, outside of language altogether, but nevertheless too important for phonologists to ignore.

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Taiy: Physical Constraints

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Are Taiwanese Syllables Segmented into Phoeneme-Sized Units?

H. Samuel Wang
National Taiwan University, Taiwan

Traditional linguistic analyses have proceeded with the assumption that the speech stream is analyzable into phoneme-sized units. However, such an assumption has been seriously questioned in recent years. Experiments in segmentation have shown that such ability is acquired easily via training in orthography (see, for example, Morrocco et al 1979; Read et al 1985), that is, the claim that the ability to segment the speech stream into phoneme-sized units arises naturally as a consequence of phonological acquisition is dubious.

The phonetic analysis in even needed for a language such as Taiwanese. Taiwanese has about 800 distinct syllable types (not including the differences in tones). To principle, a language learner can remember at 800 syllables without further analyzing them. In this study we will explore the question and provide some possible explanations for the segmentation behaviors of native speakers.

1. The Phonemic Analysis

The common assumption of phonemic analysis is reflected in the following quote from Fries (1995: 170): According to one view, the alphabet was not invented, it was discovered. If language did not include discrete individual sounds, no one could have invented alphabetic letters to represent such sounds. When humans started to use one symbol for one phoneme, they had already brought their intuitions knowledge of the language sound systems to consciousness; they discovered what they already "knew." Furthermore, children (and adults) can learn an alphabetic system only if each separate sound has some psychological reality.