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## Bootstrapping into Taiwanese Tone Sandhi

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## Abstract

In this paper, I review the literature and cite new data where necessary in order to demonstrate two key characteristics of Taiwanese tone sandhi, namely, that it is categorical and that it is sensitive to syntax. I then point out how these two characteristics, long recognized or assumed in the literature, lead to a functional paradox affecting the acquisition of tone sandhi that has hitherto been unacknowledged. The solution of this paradox will force us to examine acoustic phonetic properties of Taiwanese tone sandhi, which will in turn lead to us to conclude that phonological patterns like this cannot refer directly to syntax (as has also been claimed by Selkirk 1984, 1986 and Hsiao 1996).

The central concept in this solution is prosodic bootstrapping, the idea that language learners can use acoustic cues for prosodic structure in order to acquire information about syntactic structure (see, e.g. Gleitman and Wanner 1982, Peters 1983, Morgan 1986 and Morgan and Demuth 1996). In short, I argue that this concept from the language acquisition literature has important consequences for the understanding of Taiwanese tone sandhi and thus the theory of prosodic phonology in general.

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## 1. Introduction

Taiwanese tone sandhi has had an important place in the literature on the interaction between phonology and syntax. Indeed, Selkirk's (1986) influential theory of prosodic phonology was originally inspired by an earlier draft of Chen's (1987) analysis of Taiwanese tone sandhi. Missing from the analytical literature on Taiwanese tone sandhi, however, has been a discussion of how consideration of the function of this pattern, and of problems faced by Taiwanese infants in acquiring it, can lead to new insights into the structure of tone sandhi and other similar patterns of prosodic phonology.

In this paper I review the literature and cite new data where necessary in order to demonstrate two key characteristics of Taiwanese tone sandhi, namely, that it is categorical and that it is sensitive to syntax (in senses to be defined below). I then point out how these two characteristics, long recognized or assumed in the literature, lead to a functional paradox affecting the acquisition of tone sandhi that has hitherto been unacknowledged. The solution of this paradox will force us to examine acoustic phonetic properties of Taiwanese tone sandhi, which will in turn lead to us to conclude that phonological patterns like this cannot refer directly to syntax (as has also been claimed by Selkirk 1984, 1986 and Hsiao 1996).

The central concept in this solution is *prosodic bootstrapping*, the idea that language learners can use acoustic cues for prosodic structure in order to acquire information about syntactic structure (see, e.g. Gleitman and Wanner 1982, Peters 1983, Morgan 1986 and Morgan and Demuth 1996). In short, I will argue that this concept from the language acquisition literature has important consequences for the understanding of Taiwanese tone sandhi and thus the theory of prosodic phonology in general.

## 2. Characteristics of Taiwanese Tone Sandhi

Before we discuss the function of Taiwanese tone sandhi, it is necessary to give a brief description of the pattern of this tone alternation.

### 2.1 Background on Taiwanese Tone Sandhi<sup>2</sup>

All full-toned monosyllabic morphemes in Taiwanese show up in two forms: one with what may be called *junction tone*, the other with *context tone*.<sup>3</sup> The junction tone shows up when the morpheme is in isolation or is in a pre-juncture position, which is syntactically defined (see Section 2.3 below), while the context tone shows up elsewhere. This tone alternation has been described in the literature as being categorical (e.g. Bodman 1955, Wang 1967 and Cheng 1968), i.e. from one tone category to another tone category. For example, Cheng (1968:24) describes the sandhi pattern of long tones in Taiwanese as "3 > 2 > 1 > 5 > 3." That is, Tone 3 (in his notational system) changes to Tone 2, Tone 2 changes to Tone 1, Tone 1 changes to Tone 5, and Tone 5 changes to Tone 3, when tone sandhi takes place.

Examples from the Chiayi dialect of western Taiwan are given below where superscript digits denote pitches following IPA notation (based on Chao 1930).

#### (1) Examples of Taiwanese Tone Sandhi (Chiayi dialect)<sup>4</sup>

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2. The term "Taiwanese" refers to the South Min Chinese spoken in Taiwan. There are several varieties of Taiwanese. The one that will be discussed in this paper is genetically very close to Xiamen (also called Amoy) spoken in Xiamen, China.
  3. In this paper, junction tone and context tone are used, instead of basic/inherent/underlying tone(本調) and sandhi/changed/derived tone(變調) as more commonly used in the literature (e.g. Wang 1967, Cheng 1968, Yip 1980 and Ting 1982) to avoid presuppositions about the direction of this tone alternation which remains controversial among scholars.
  4. These seven tones correspond to the following tone categories in Chinese philology: Yinping 陰平, Yangping 陽平, Yinshang 陰上, Yinqu 陰去, Yangqu 陽去, Yinru 陰入, Yangru 陽入, respectively. Note that there is no Tone IV, which would

	<u>JUNCTURE</u>	<u>CONTEXT</u>
Tone I	詩 [si <sup>55</sup> ] "poem"	詩文 [si <sup>33</sup> ]-[bun <sup>24</sup> ] "poetry and prose"
Tone II	時 [si <sup>24</sup> ] "time"	時間 [si <sup>33</sup> ]-[kan <sup>55</sup> ] "time span; time"
Tone III	死 [si <sup>53</sup> ] "die"	死人 [si <sup>55</sup> ]-[lang <sup>24</sup> ] "dead people"
Tone V	四 [si <sup>11</sup> ] "four"	四點 [si <sup>53</sup> ]-[tiam <sup>53</sup> ] "four o'clock"
Tone VI	寺 [si <sup>33</sup> ] "temple"	寺僧 [si <sup>11</sup> ]-[tsing <sup>55</sup> ] "temple-monk; monk"
Tone VII	色 [sik <sup>3</sup> ] "color"	色彩 [sik <sup>5</sup> ]-[ts <sup>h</sup> ai <sup>53</sup> ] "color"
Tone VIII	熟 [sik <sup>5</sup> ] "cooked"	熟茶 [sik <sup>1</sup> ]-[te <sup>24</sup> ] "baked tea"

The tone alternation shown in (1) can be summarized as follows using a phonemic representation where H, M, and L denote high, mid, and low tones, respectively.

(2) Taiwanese Tone Sandhi (highlighted tones are short tones.)

<u>Juncture</u>		<u>Context</u>
H	↔	M
LM	↔	M
M	↔	L
L	↔	HL <sup>-</sup>
HL	↔	H
<u>H</u>	↔	<u>M</u>
<u>M</u>	↔	<u>H</u>

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correspond to Yangshang, due to a historical change which collapsed most Yangshang words into the Yangqu category (see, for example, Ho 1988 for details). Tone I through Tone VI are long tones which appear with syllables ending with a sonorant while Tone VII and Tone VIII are short tones which only appear with "checked" syllables, i.e. syllables ending with an unreleased /p/, /t/, /k/ or /ʔ/ (glottal stop).

Note that the set of juncture tones and the set of context tones overlap. For example, a juncture H is assumed to be identical to a context H according to the representation. Thus when  $si[H]$  is heard, one does not know if it is the juncture form of the morpheme 詩 "poem" or the context form of the morpheme 死 "die" unless he/she knows the context. That is, Taiwanese tone sandhi creates potential words. However, it should be kept in mind that this is based on the assumption that tone alternation in Taiwanese tone sandhi is an alternation between two tone categories. This ambiguity does not hold if this tone alternation does not involve complete neutralization. Therefore, it is crucial to examine the categoricity of Taiwanese tone sandhi.

## 2.2 The Categorical Nature of Taiwanese Tone Sandhi

As noted above, Taiwanese tone sandhi has been described in the literature as being categorical. Tsay, Charles-Luce and Guo (1999), observing that this description had never been supported by instrumental data, conducted a production experiment on Taiwanese tone sandhi.<sup>5</sup> One of the questions that we were asking was whether the alternation between the juncture tone and the context tone in Taiwanese tone sandhi is indeed categorical.

The methodology used in this experiment was as follows. First, monosyllabic target forms (i.e. phonetic segment strings with specific tones) were chosen. For each target syllable, a pair of sentences were created so that the target syllable showed up either in juncture position (i.e. as the juncture form of a morpheme A) or in context position (i.e. as the context form of a morpheme B). One pair of sentences is given below as examples.

### (3) Examples (from Tsay, Charles-Luce and Guo 1999)<sup>6</sup>

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5. Lin (1988) and Peng (1993) had also done acoustic phonetic work on Taiwanese Tone Sandhi, but they did not address the specific questions that we did.

6. Superscript letters indicate tones. Only tones of the relevant syllables are marked.

- a. 彼粒紅地球真值錢  
 hit-liap ang<sup>M</sup> te<sup>L</sup> - kiu<sup>LM</sup> # tsin tat tsi~  
 that CL red earth ball really worth money  
 "That red earth (globe) is very valuable."
- b. 彼個皇帝球真多  
 hit-e hong<sup>M</sup>-te<sup>L</sup> # kiu<sup>LM</sup> tsin tse  
 that CL emperor ball really many  
 "That emperor has many balls."

Note that the target syllable [te<sup>L</sup>] appears in both sentences. In the first sentence the target syllable is the context form of 地 "ground", while in the second sentence the target syllable is the juncture form of 帝 "emperor". The syllables immediately preceding and following the target syllable are controlled for tone, so that in each pair of sentences the target syllable had the same preceding tone and the same following tone. Therefore, the influence of neighboring tones (e.g. coarticulation) is excluded. Fourteen pairs of sentences (i.e. twenty-eight sentences) together with twenty-eight filler sentences made up the reading list.<sup>7</sup> Seventeen native speakers of the southern variety of Taiwanese were asked to read the sentences in randomized order. Each speaker repeated the whole list five times. In order to exclude the possible interference of the writing system, which works in favor of the Mandarin reading because Mandarin is the official language, the first of the five repetitions was not measured.

The F<sub>0</sub>'s of the target syllables were measured at three points of the syllable, i.e. beginning, middle, and end. The results showed that overall the tone in juncture position was not significantly different from the same tone in context position. That is, H, M, L, and HL in juncture position were not distinct from H, M, L, and HL in context position. The context M that alternates with the juncture H was also identical to the context M that alternates with the juncture LM, that is, there was

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CL = classifier.

7. After recording and before the measurements, some sentences were judged by the experimenter as having different pronunciations due to dialect variation and were excluded from measurements. Some subjects were excluded for the same reason. For details, see Tsay, Charles-Luce and Guo (1999).

complete neutralization of these two tones in context position. For example, the following table shows the means of F0's at three points one of the paired target syllables; differences are not significant ( $p > .05$ ).

(4) Mean F0's (in Hz) of context H vs. juncture H

	Beginning	Middle	End
Context	193.3	195.9	198.9
Juncture	189.2	191.9	197.4
difference	4.1	4.0	1.5

These findings confirm the assumption in the literature that Taiwanese tone sandhi is categorical. In other words, the context form of 地 "ground" (as in 地球 [te-kiu]) is identical to the juncture form of 帝 "emperor" (as in 皇帝 [hong-te]). (For more details of the experiment, see Tsay, Charles-Luce and Guo 1999.)

We can conclude that Taiwanese tone sandhi does create potential words. Assuming that there is only segmental and tonal information available, a language learner does not know if what she hears is the juncture form of morpheme A or the context form of morpheme B unless she already knows the meaning of the morphemes.

## 2.3 TTS and Syntax

Taiwanese tone sandhi applies in a domain called the tone group. Within a tone group, only the last syllable carries a juncture tone; all other syllables carry a context tone. Tone Group Formation rules in Chen (1987) and Lin (1994) are given below in (5) and (6), respectively.

(5) Tone Group Formation (Chen 1987, summarized by Lin 1994)

Mark the right edge of every XP with #, except where XP is an adjunct c-commanding its head.

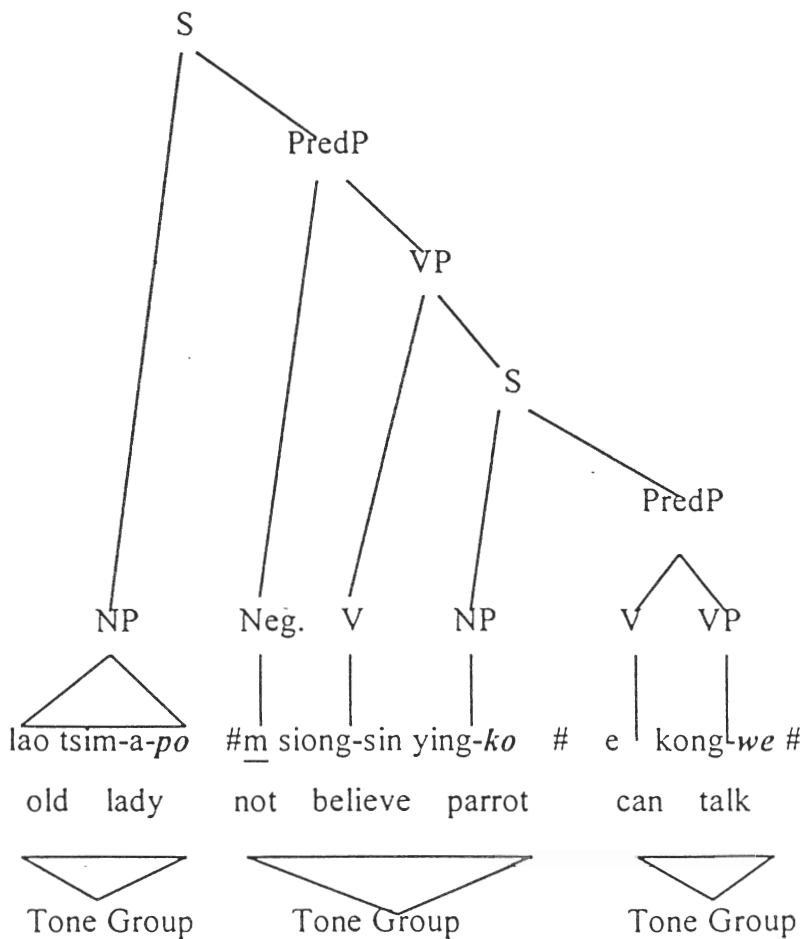


(6) Xiamen Chinese Phrasing Parameter (Lin 1994:248)

$]_{X_{max}}, X^{max}$  not lexically governed

I will not discuss these rules any further since it is beyond the scope of this paper; the point is merely to illustrate the dependence of tone group formation on syntax. An example from Chen (1987:114) demonstrates the relation between syntactic constituents and tone groups in Taiwanese tone sandhi. (The indication of tone groups is added by the author.)

(7) Syntax and Tone Groups in Taiwanese (Chen 1987)



There are three tone groups in this sentence which are separated by #. The right edge of each tone group, i.e. the syllable right before a #, corresponds to the right edge of a syntactic constituent. Specifically, the right edge of a Taiwanese tone sandhi group corresponds to the right edge of a maximal projection as long as it is not lexically governed (according to Lin 1994; see also Chen 1987, Hsiao 1991). Syllables in the right edge position, i.e. [po], [ko], and [we] in this example, carry a juncture tone. All other syllables carry a context tone.

So far, we have discussed two characteristics of Taiwanese tone sandhi. One is that tone alternation in Taiwanese tone sandhi is categorical; the juncture tone of word A might be identical to the context tone of word B. The other characteristic is that Taiwanese tone sandhi is dependent on syntactic structure. These two characteristics are important for our discussion to come on the function of Taiwanese tone sandhi.

### 3. The Function of Taiwanese Tone Sandhi

The discussion of Taiwanese tone sandhi so far should bring no surprises. However, as I will argue in this section, when one considers a plausible function of this pattern for users of the language, it immediately becomes clear that there is a logical problem that must be faced. This logical problem will be seen to lead to an empirical prediction that is then tested in later sections. In this way, we will see that consideration of linguistic function brings us to a deeper understanding of linguistic structure (see e.g. Givon 1995 and Biq, Tai and Thompson 1996 for further arguments along these lines).

#### 3.1 Taiwanese Tone Sandhi, Syntax and Functionalism

The fact that the tone groups used in Taiwanese tone sandhi are predictable from syntactic structure (see Section 2.3 above) has an important implication for native speaker-hearers of Taiwanese: they can

use the phonological changes brought on by tone sandhi as an aid in locating syntactic boundaries. For example, in a sentence like the one in Figure (7) above, listeners can use the fact that the second syllable in *ying-ko* (parrot) is in its juncture form to determine that it is at the right edge of a tone group, and thus of an XP. This sort of information is likely to be quite useful to the listener, and we may therefore suggest that one of the functions of Taiwanese tone sandhi is to help listeners in parsing syntactic structure.<sup>8</sup>

The suggestion that Taiwanese tone sandhi has a function, and is not merely an arbitrary element of Taiwanese grammar, gains plausibility from the fact that Taiwanese tone sandhi puts a heavy burden on speakers and listeners of the language. After all, Taiwanese tone sandhi involves all full-toned monosyllabic morphemes in every utterance spoken or heard. Every such morpheme has two distinct forms, **which** do not necessarily have a phonologically elegant relationship with each other (see, e.g. Tsay and Myers 1996). The computational effort needed to learn and execute this complex system is surely **not** trivial. If we recognize that Taiwanese tone sandhi **pays** users of the language back for its costs, by helping them **determine** syntactic structure, we can perhaps understand a bit better how such a complex system could have developed.

### 3.2 A Functional Paradox

We have seen why Taiwanese tone sandhi may help adult listeners parse sentences, therefore helping us to understand why infants are required to learn this complex system. However, the utility of Taiwanese tone sandhi for infants appears to be undermined **by the** fact

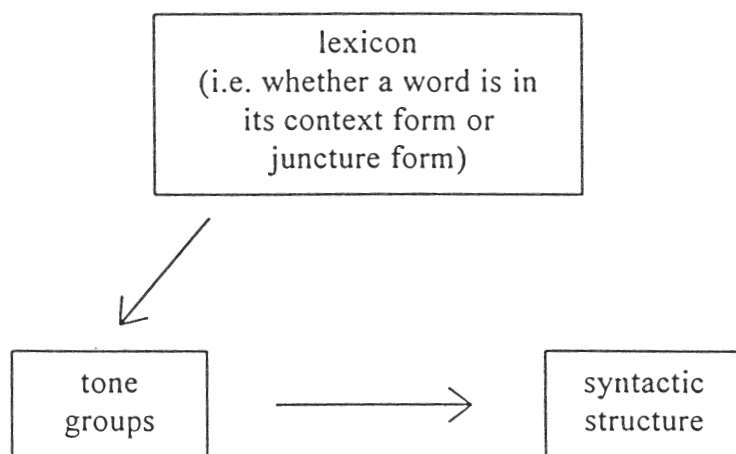
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8. Notice a contrast between standard linguistic analyses and processing models of language comprehension and acquisition. In linguistic analyses, e.g. when defining tone groups, tone sandhi is described as "taking place after" syntactic parsing. However, for adults perceiving speech or for children learning the language, the order is reversed; what is available for them is the acoustic signal which includes tonal information for potential syntactic boundaries. That is, listeners have to go from the speech signal to the grammar (e.g. syntactic structure).

that Taiwanese tone sandhi is categorical in nature.

The categoricity of Taiwanese tone sandhi means that both juncture and context forms of a morpheme are potentially real, independent morphemes. There is apparently no acoustic evidence that one form is merely derived from the other. Thus the juncture form of a word A may be identical to the context form of a word B. For the adult, who presumably has memorized the juncture and context forms for thousands of morphemes, this need not pose any problem. If the listener already knows the words, she would know whether the words are in a juncture or a context position. Then, she could find the tone groups, and thus learn the syntactic structure, as schematized in the following figure.

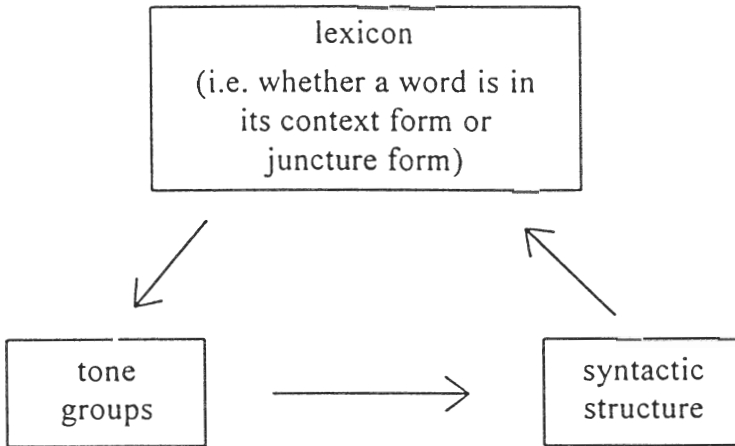
(8) From knowing the words to knowing the syntactic structure



The problem is that the infant acquiring Taiwanese will know neither the words nor the syntactic structure. On the one hand, a child learning Taiwanese will have to find the syntactic boundaries (or at least the tone groups) in order to decide whether a syllable is the juncture form of morpheme A or the context form of morpheme B. Otherwise, the child cannot learn the words. On the other hand, in order to find the syntactic boundaries, a child first has to know something

about the semantics and syntax of these morphemes, which means she already has to know whether she is hearing morpheme A or B (i.e. she has to know the words already). This situation can be illustrated as in the following figure.

(9) A Vicious Circle



This is a vicious circle, and it is not immediately obvious how a language-learner can break into it. A solution to this paradox will be proposed in the section to follow.

#### 4. A Solution to the Paradox: The Prosodic Bootstrapping Hypothesis

Since this functional paradox of Taiwanese tone sandhi is caused by a vicious circle formed by tone alternation and syntax depending on each other, the solution to this paradox has to be nontonal and nonsyntactic, i.e. additional cue(s) to syntactic structure other than tone sandhi. The most plausible candidate for nonsyntactic, nontonal cues to syntactic structure is prosody. Hence I propose to solve the functional paradox of Taiwanese tone sandhi by means of what has been called *prosodic bootstrapping* (Gleitman and Wanner 1982, Peters 1983,

Morgan 1986 and Morgan and Demuth 1996).

#### 4.1 Bootstrapping in Language Acquisition

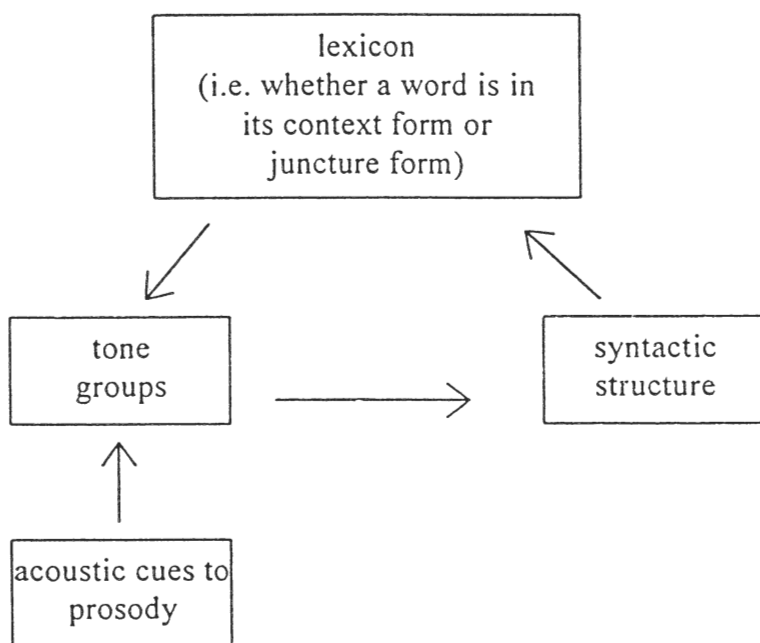
The idea of bootstrapping in language acquisition first came from semantic bootstrapping, the process whereby children use semantics to infer syntax (Bowerman 1974, Pinker 1987). Thus, for example, if an English-acquiring child learns that "water" is a substance, not an object, and that one cannot say "a water," then she can infer that if "wood" is a substance, then she cannot say "a wood" either. Gleitman (1990) later proposed a similar idea, called syntactic bootstrapping, whereby children infer semantics from syntactic structure. Hence if a child hears adults referring to "a xylophone," she can infer that it must name an object, not a substance. In both cases, the child is "lifting itself by the bootstraps" from one linguistic subsystem into another.

According to the prosodic bootstrapping hypothesis (Gleitman and Wanner 1982, Peters 1983, Morgan 1986 and Morgan and Demuth 1996), the child uses suprasegmental information (e.g. stress, pitch contour, and vowel lengthening) to infer something about syntactic structure. Prosodic constituents like intonational phrases, though not identical to syntactic constituents, are predictable from syntactic structure (Selkirk 1984, 1986, Nespor and Vogel 1986). For example, as we saw in Taiwanese, the edge of a prosodic constituent typically coincides with the edge of a syntactic constituent. Moreover, unlike syntactic structure, prosodic structure should be directly perceivable from the physical signal. Pitch contours and variations in segmental duration can be picked up without knowing anything else about the grammar of a language. Thus if a child can determine the prosodic constituents in a sentence, she should have some useful information about the syntactic structure of the sentence.

The prosodic bootstrapping hypothesis thus appears to be just what is needed to deal with the problems posed by Taiwanese tone sandhi. This hypothesis claims that there must be prosodic cues

available for the child learning the language to help her locate the boundaries of tone groups. Then, since tone groups are consistent with syntactic constituents, the child can find the boundaries of these constituents too, information necessary for deciding which morphemes are in juncture form and which are in context form. This in turn allows the child to learn the words. This solution is illustrated in the following figure.

(10) Breaking into the Vicious Circle



## 4.2 Prosody in Perceptual Development

In other languages, empirical support for the prosodic bootstrapping hypothesis comes from a large body of experimental research on infant speech perception. First of all, infants are sensitive to the prosodic features of language from a very early age (DeCasper and Fifer 1980, Fernald 1984, Jusczyk and Thompson 1978 and Mehler et al. 1988). Moreover, infants appear to be able to use suprasegmental cues to locate the boundaries of prosodic constituents (Fernald 1985, Hirsh-Pasek, Kemler Nelson, Jusczyk, Wright Cassidy, Druss and

Kennedy 1987, Kemler Nelson et al. 1989, Jusczyk, Hirsh-Pasek, Kemler Nelson, Kennedy, Woodward and Piwoz 1992, Gerken, Jusczyk and Mandel 1994). It is particularly significant that infants are sensitive to prosodic markers of syntactic units such as clauses and phrases (Hirsh-Pasek et al. 1987, Jusczyk 1989, Jusczyk, Hirsh-Pasek, Kemler Nelson, Kennedy, Woodward and Piwoz 1992, Kemler Nelson 1989, Jusczyk, Hirsh-Pasek, Kemler Nelson, Kennedy, Woodward and Piwoz 1992). In short, although it may not be possible to demonstrate the validity of the prosodic bootstrapping hypothesis directly (as suggested by Fernald and McRoberts 1996), there is good reason to suppose that it is substantially correct.

Given this conclusion, it seems reasonable to ask whether suprasegmental acoustic cues might also play a role in the acquisition of Taiwanese tone sandhi.

### 4.3 Evidence for Acoustic Cues to Taiwanese Tone Sandhi

In order to argue that infants use suprasegmental acoustic cues to break into the vicious circle of Taiwanese tone sandhi, the lexicon, and syntax, one crucial point that must be demonstrated is that such acoustic cues in fact exist. That is what I will show in this section.<sup>9</sup>

In the production experiment on Taiwanese tone sandhi by Tsay, Charles-Luce and Guo (1999) mentioned above, there was another question that we were concerned about, in addition to the categoricity of tone sandhi. The question was whether there were other cues for the domain of application of Taiwanese tone sandhi other than the tone sandhi alternation itself.

The duration of the target syllables in the pairs of sentences described in Section 2.2 above were measured. For each target syllable, three measurements were taken: (i)  $C_1$ - $C_2$ : from the beginning of the onset consonant of the target syllable to the beginning of the onset

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9. Evidence that infants really use these cues must be left to further research.



consonant of the following syllable; (ii) S: from the beginning of the onset consonant of the target syllable to the end of periodicity of the target syllable and (iii) V: from the beginning to the end of the periodicity of the target syllable.

The results showed that the vowel duration of the target syllable in juncture position was significantly longer than the vowel duration of the same form in context position. That is, the vowel duration of [te<sup>h</sup>] 帝 "emperor" in 皇帝 [hong-te] was longer than the vowel duration of [te<sup>h</sup>] 地 "ground" in 地球 [te-kiu].

(11) Mean duration (in msec.) of the target syllables

	C <sub>1</sub> -C <sub>2</sub>	S	V
Context	265.1	190.0	147.0
Juncture	442.6	239.7	194.1
Difference	-177.5*	-49.7*	-47.1*

\* p < .01

(Again, for details of the experiment, see Tsay, Charles-Luce and Guo 1999.)

We can conclude that there indeed exist prosodic cues (duration and perhaps other cues) for marking Taiwanese tone sandhi groups.<sup>10</sup> This acoustic cue can then potentially be used by infants to locate the boundaries of prosodic constituents (i.e. the tone groups). After the child finds the tone groups, she can then use this information to learn about syntactic structure and also about Taiwanese tone sandhi. Once acquisition of both of these domains has begun, the task of learning words, with their alternating context and juncture forms, becomes possible. The key is that the acoustic cues like duration that begin this process are gradient rather than categorical. Thus their use by the child

10. Stress is another candidate for such cues. However, this experiment found that amplitude measurements vary drastically even within the same subject. This is consistent with the findings in the literature about the unreliability of amplitude as a prosodic cue in tone languages (e.g. Shen 1993).

does not depend on any prior knowledge of language-specific constructs such as tone groups, tone categories, or syntactic constituents.<sup>11</sup>

Not only are we able to solve the functional paradox of Taiwanese tone sandhi, but in the course of solving it we have posited and then proven an empirical claim, namely, that there must be acoustic cues for tone groups. In other words, functional considerations have led us to new insights into the structural description of Taiwanese.

## 5. Implications for the Phonology-Syntax Interface

There are also implications for theoretical phonology of this solution to the functional paradox. One important debate in the literature on the phonology-syntax interface concerns whether these two modules interact directly or not. While supporters of the Direct Reference Hypothesis (e.g. Kaisse 1985, 1990) claim that phonological patterns like Taiwanese tone sandhi are directly sensitive to syntactic structure, supporters of the Indirect Reference Hypothesis (e.g. Selkirk 1984, Odden 1990 and Hsiao 1996) suggest that an intervening medium is required, namely prosodic structure. That is, phonological rules are sensitive to prosodic constituents, not to syntax directly; it is this intervening prosodic structure that is built on the syntactic foundation.

In this paper I have been assuming a point of view more consistent with that of the Indirect Reference Hypothesis, since I have described Taiwanese tone sandhi as applying within tone groups, which are prosodic constituents. But the solution to the functional paradox discussed above now allows us to provide further support for this position.

The claim that phonology can be directly sensitive to syntax, which is made by the Direct Reference Hypothesis, is only plausible if

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11. How adults actually represent such prosodic cues (as purely phonetic side-effects of prosodic structure or as phonologically manipulated representations) is irrelevant to the problem faced by the language learners.

we restrict our attention to categorical phonology, as Kaisse (1985, 1990) does (what she calls P1 rules); discrete allomorphs can then be thought of as appearing in discretely defined syntactic contexts. Noncategorical, gradient phenomena such as phrase-final lengthening are assumed by Kaisse (1985) and other supporters of similar positions to be sensitive to prosodic constituents (these are her P2 rules). Hence if we find that the domain within which a phrase-level categorical phonological pattern occurs also has gradient acoustic correlates, then that domain must be prosodic, not syntactic. That is of course precisely what we have found with Taiwanese tone sandhi: phrase-final lengthening is a form of gradient phonology, not categorical phonology.

The logical paradox we have discussed, however, allows us to go further. The paradox faced by Taiwanese infants faces any language learner attempting to acquire phrase-level categorical phonology (what Kaisse 1985, 1990 calls the P1 rules, and what Tsay and Myers 1996 call lexicalized phrasal phonology). The categoricity of the pattern will mean that each alternate form of a morpheme or word is itself a possible lexical item. Hence there will be no way for the infant to break into the vicious circle formed by phonology and syntax unless there are independent acoustic cues for some intervening prosodic level. Thus like Taiwanese tone sandhi, all rules of lexicalized phrasal phonology must refer to prosodic constituents in order to allow infants to bootstrap into the system. The Direct Reference Hypothesis can therefore be rejected because it posits an adult system that is unlearnable by real children.

## 6. Conclusion

In summary, I have pointed out a functional paradox caused by the two properties of Taiwanese tone sandhi, i.e. the facts that Taiwanese tone sandhi is categorical and that tone groups are syntactically defined. Since Taiwanese tone sandhi cannot help the language learner find syntactic constituents directly, it must be a prosodic cue, e.g. duration,

that is used to bootstrap into syntax and Taiwanese tone sandhi.

This application of the prosodic bootstrapping hypothesis is supported by the results of Tsay, Charles-Luce and Guo's (1999) production experiment on Taiwanese tone sandhi which found that the prosodic cue of vowel duration is indeed available for finding syntactic constituents and tone groups. The functional paradox for language learning is then solved, with interesting implications for the debate between the Direct and Indirect Reference Hypotheses. Finally, along the way, I have also illustrated another example of how functional considerations lead to deeper insights into linguistic structure.

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