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CONSONANT TYPES, VOWEL HEIGHT AND TONE IN YORUBA*

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Consonant types perturbate pitch in Yoruba, as they have been shown to do in non-tone languages. Such perturbations may serve as one source of "tone-splitting" in languages which already have tone. Average fundamental frequency of a given tone in Yoruba varies according to vowel height. The fact that average pitch differences for vowels bearing low tone is smaller than for those bearing high tone is evidence against a simple-minded version of the "tongue pull" theory as an explanation for the correlation of tongue and pitch height. Tonogenesis and tone-splitting would not be expected to arise from the vowel height/fundamental frequency correlation since this "steady state" correlation lacks the perceptual saliency of the perturbations caused by consonant types.

1. Introduction

In this paper I shall address myself to three different issues: consonant types, vowel height, and distribution of tones. In the first part, it will be shown how a voiced vs. voiceless consonant can affect the fundamental frequency of the following vowel depending on the tone of this vowel. In the second part, the intrinsic pitch of vowels as a function of tone will be investigated; the relevance of these data for rejecting or accepting current theories of intrinsic pitch of vowels and theories of tonal developments will be examined. Finally, it will be suggested that it is often the case that other cues than steady state fundamental frequencies are used to identify tones. The so-called Yoruba low level tone which is realized as a low falling tone, at least in some environments, is a good example of this.

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2. Consonant Types

In an earlier study [Hombert 1976a], five American speakers were asked to read a word list consisting of ten tokens of each test word arranged in random order. These test words were 6 CV nonsense words using the consonants /p, t, k, b, d, g/. Only the vowel [i] was used since I was not interested in variations caused by vowel height in this experiment. With a reference point at the onset of the vowel, F_0 values were measured at the onset and 20, 40, 60, 80 and 100 msec after this onset. Under these conditions, data presented in Figure 1 were obtained. As to be expected, the largest differences between the two curves, obtained respectively after voiceless and voiced consonants, were found at the vowel onset, with these differences decreasing as time increases. A statistical analysis[1] of these data showed that these two curves were still significantly different[2] at 100 msec after vowel onset.

In the second part of this study using synthesized stimuli I showed that these intrinsic perturbations can be perceived even when they are only 60 msec long. In relating these perceptual data and the production data to each other, we can see that there is an overlap of at least 40 msec between the time we start hearing significant differences and the time these differences cease to be significant.

These experimental data validate and explain the well-attested development of tone due to the loss of some voicing distinction in prevocalic position [Brown 1965; Chang 1973, 1975; Haudricourt 1954, 1961; Hombert 1975, to appear; Hombert, Ohala and Ewan 1976; Matisoff 1973; Mazaudon forthcoming].

Tone systems are not static. A language can acquire tones and then increase the complexity of this tone system but it can also decrease the number of its tones and ultimately become non-tonal. These two processes, acquisition and recession of tones, have been termed *tonogenesis* [Matisoff 1970, 1973] and *tonoexodus* [Lea 1973]. Cases of tonoexodus are rare[3] and it is not clear what the intermediate historical stages between the tonal and non-tonal stages are.

[1]Analysis of variance followed by Duncan's test.

[2]With a 1% confidence level.

[3]Some cases can be found among Eastern Bantu languages.

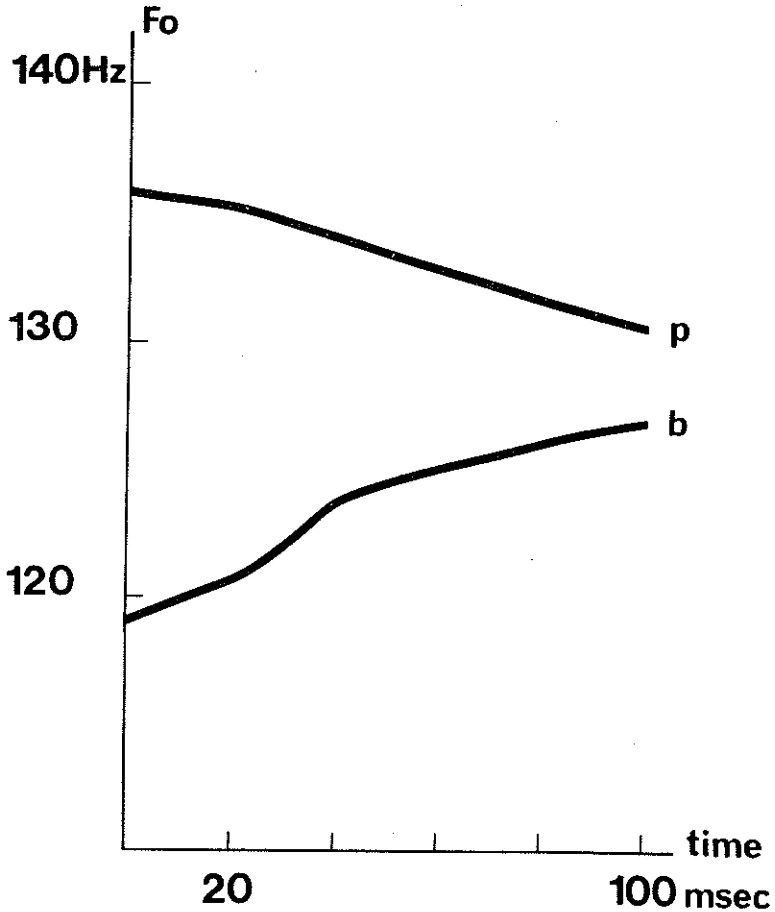

Figure 1: Averaged Fo of vowels after voiced and voiceless stops (from Hombert, 1976a) ([p] represents the voiceless stops and [b] represents the voiced stops)

In the case of tonogenesis, the complete "scenario" is well attested. The development of contrastive tones on vowels due to the loss of a voicing distinction on obstruents in prevocalic position is probably the most well-documented type of tonogenesis. When such a development occurs, a relatively lower pitch register develops on vowels following the previously voiced series and a relatively higher pitch is found after the previously voiceless or voiceless aspirated series. Phonetic studies by House and Fairbanks [1953], Lehiste and Peterson [1961], Mohr [1971], Lea [1972, 1973], Löfqvist [1975] and Hombert [1976a] show how a voicing distinction in prevocalic position can affect the fundamental frequency of the following vowel.

Unfortunately, all these phonetic studies are based on non-tonal languages. Thus, they can explain how a non-tonal language can acquire two tones from the loss of some voicing distinction in prevocalic position but we do not have any strong basis for believing that these data can be extended to languages which are already tonal. Namely we do not know what the behavior of voiced or voiceless consonants is going to be at different frequency registers. Is a voiced consonant still going to affect the onset frequency of a vowel with low tone? Is a voiceless consonant going to perturbate the frequency of a high tone?

In order to answer these questions, two Yoruba subjects were asked to read[4] a word list of 42 CV tokens (2 consonants[5] x 7 vowels x 3 tones) put in the frame: sō CV sókè[6] ('say CV louder'). Each token was read five times. The results are presented in Figure 2. On this graph each point represents the average of 70 measurements (7 vowels x 5 repetitions x 2

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[4]The recording was done at University of Ibadan, Nigeria, and the data analysis was done partly in the Phonology Laboratory, University of California, Berkeley and partly in the UCLA Phonetics Laboratory.

[5]Only two consonants [k] and [g] were used in this experiment to represent voiced and voiceless stops. Recent data seem to indicate that velar stops have a more important perturbatory effect on the F_0 of the following vowel than other stops [Hombert and Ladefoged 1976; Meyers 1976].

[6]The three Yoruba tones are represented as follows: High Tone ´
Mid Tone ¯
Low Tone `

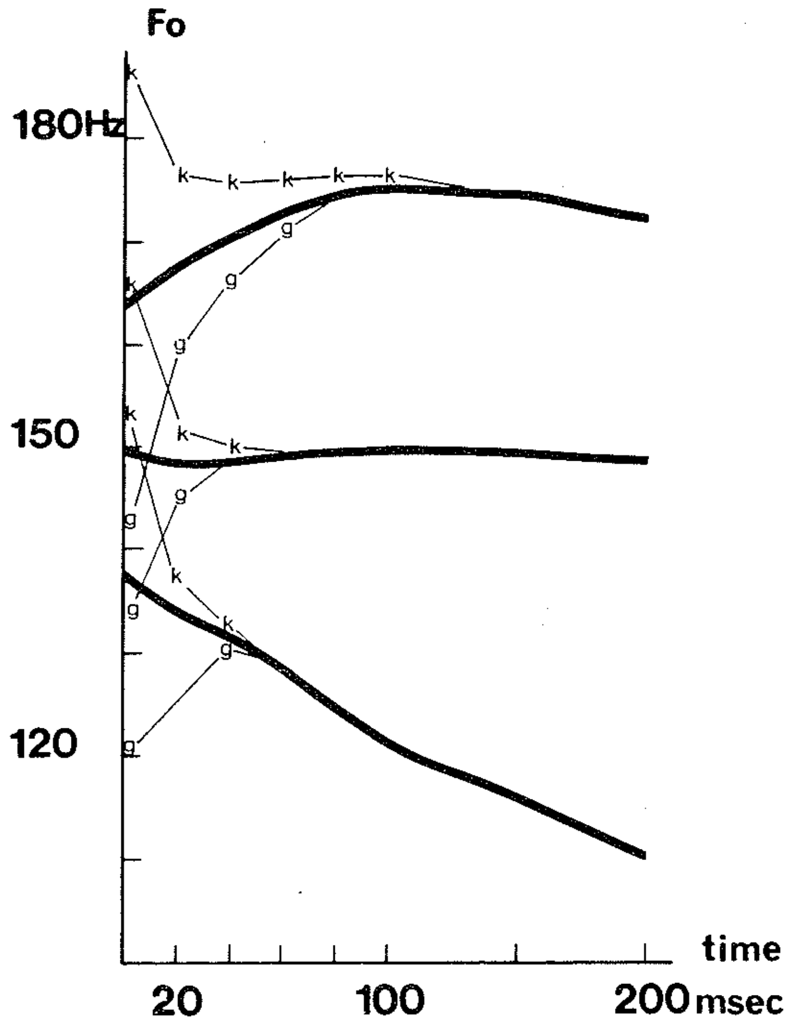

Figure 2: **Influence of prevocalic voiced and voiceless stops on the fundamental frequency of the three Yoruba tones (2 subjects)**

subjects). The thin lines represent the fundamental frequency of vowels after [k] or [g]. The wide lines represent the average F_0 after voiced and voiceless velar stops for the three Yoruba tones.[7]

My purpose was to compare the effect of voicing contrast at different frequency registers. From the data presented in Figure 2, three points should be emphasized:

1. The perturbation caused by a voiced consonant on a following high tone or by a voiceless consonant on a following low tone is greater than the effect of these two series of consonants on a mid tone.

2. The effect of a voiced consonant on a high tone is greater than the effect of a voiceless consonant on a following low tone.

3. The duration of the perturbations caused by prevocalic consonants on the fundamental frequency of vowels is shorter in a tone language (Yoruba) than in a non-tonal language (see Figure 1).

It is interesting to point out that these results are in agreement with Gandour's (1974) findings in his investigation of "Consonant types and tone in Siamese." Gandour found that a shorter part of the vowel was affected by the preceding vowel (about 30 msec for voiceless consonants and about 50 msec for voiced consonants). It seems that there is a tendency in tone languages (which does not exist in non-tonal languages) to actively minimize the intrinsic effect of prevocalic consonants probably in order to keep the different tones maximally different perceptually.

3. <u>Intrinsic Fundamental Frequency of Vowels</u>

In the second part of this paper, I shall address myself to the issue of intrinsic fundamental frequency of vowels. Essentially, four theories have been proposed to explain why high[8] vowels have a higher intrinsic fundamental frequency than lower vowels.[9]

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[7]When the F_0 values after voiced or voiceless stops were too close to the average value (wide line), they were not represented on Figure 2.

[8]High refers to the tongue-height parameter (or more accurately low first formant value).

[9]See Atkinson [1973] and Ohala [1973a] for a more detailed review of these different theories.

The first theory, proposed by Taylor [1933] and adopted by House and Fairbanks [1953] is called the "dynamo-genetic" theory. Taylor claims that the muscular tension of the tongue, required for the realization of high vowels, is transferred to the muscles of the larynx "via a kind of sympathetic resonance or radiation." This is not a viable theory anymore, since we know that electrical insulation in muscles and nerves is good enough to prevent serial contraction of adjacent muscles triggered by osmotic spread of excitability [Atkinson 1973].

The second theory presented by Mohr [1971] relates width of the pharynx and pressure build-up behind the point of constriction to explain the fundamental frequency differences between low and high vowels. Since the width of the pharynx is about one-fourth as big for low back vowels as for corresponding high vowels, Mohr tries to relate smaller cavity and constriction further back with higher supraglottal pressure, leading to smaller pressure drop across the glottis and consequently lower fundamental frequency. Unfortunately Mohr's data do not support his theory. In any case, as Ohala [1973a] mentions

> "... the air flow during vowels is rapid enough and the magnitude of the pressure small enough that whatever back pressure is caused by the vowel constriction will be manifested equally rapidly for all vowels."

The next theory, known as the source/tract coupling theory, was first proposed by Flanagan and Landgraf [1968]. This theory assumes a possible coupling between the vocal cords and the vocal tract so that a low first formant (characteristic of high vowels) would attract and consequently raise the fundamental frequency. This sucking effect does not occur when the first formant is further away from the fundamental frequency (as it is in the case of low vowels). The intrinsic pitch difference between low and high vowels would then be explained. Unfortunately, predictions made by this theory do not receive empirical support. It would predict, for instance, that the difference in pitch between high and low vowels would be reduced when speaking with a helium-air mixture (since a property of helium or other light gases is to raise formants and consequently to increase the distance between F_0 and F_1). Beil [1962] showed that this was not the case.

The tongue pull theory [Ladefoged 1964; Lehiste 1970] is based on the assumption that when the tongue is in high position for the realization of high vowels, it exerts an extra tension transmitted to the larynx via the hyoid bone. This vertical pull increases the tension of the vocal cords [Ohala 1972] and gives rise to a higher pitch for these high vowels. This theory ran into great difficulty when Ladefoged et al. [1972] provided data showing that tongue height and hyoid bone height were inversely proportional. Ohala [1973a] admits that such findings show that the pulling is not done through the hyoid bone but he maintains that the tongue pull theory is still a viable theory provided that the pulling is done through other tissues.

I would like to show in this paragraph that tone languages such as Yoruba can bring some very useful data in this controversy. If we assume a correlation between larynx height and F_0 [Ohala and Ewan 1973; Ewan and Krones 1974], it seems that the tongue pull theory would predict that the F_0 difference would be smaller with vowels realized with high tones as opposed to vowels realized with low tones. Since the larynx is in higher position for high tones than for low tones, we expect that the tension exerted by the tongue will be less. This assumes a linear relationship between tension and larynx elevation (which would have to be tested). Figure 3 displays the averaged fundamental frequency values of the 7 Yoruba vowels depending on the tone under which they were realized. The measurements were made 100 msec after vowel onset. Each point is an average of 20 tokens (2 consonants x 5 repetitions x 2 subjects). From these data it is clear that the prediction made by the tongue pull theory is not verified; in fact the opposite is found, namely that the fundamental frequency difference between high and low vowels is more pronounced with high tone than with low tone. The same type of data were obtained from American English speakers [Hombert 1976d] who were asked to produce vowels at three different F_0 levels.

Although it is obvious that more data are needed before refuting either the tongue pull theory or accepting the source/tract coupling theory, the data I just presented seems to be difficult to account for by the tongue pull theory.

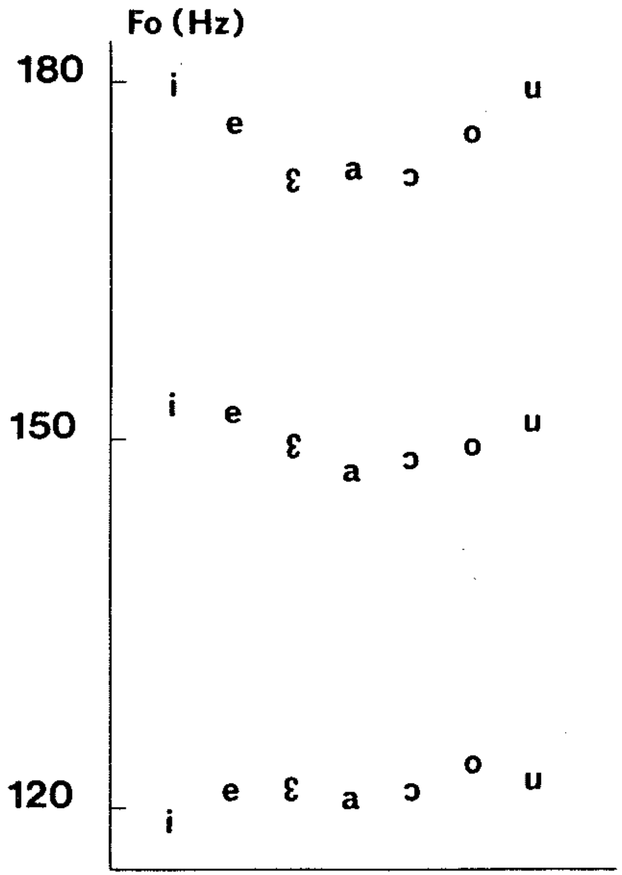

Figure 3: Intrinsic Fo of vowels for the three Yoruba tones (High, Mid and Low) (2 subjects)

The second point I would like to discuss with respect to intrinsic pitch of vowels has to do with tonogenesis. Phonetic studies indicate that the intrinsic perturbations caused by prevocalic consonants on the pitch of the following vowel are of about the same order of magnitude as the intrinsic differences depending on vowel height. Lehiste [1970] mentions

> "the influence of an initial consonant could counterbalance the influence of intrinsic pitch: the average for /kɐ/ sequences was 171 Hz while that of /gi/ sequences amounted to 170 Hz."

Pilszczikowa-Chodak [1972] suggests that tone assignment of verbs and noun plurals in Hausa is largely predictable from the height of the final vowel: a high (vs. low) final vowel predicting a high (vs. low) tone. This analysis, however, has been criticized by Hausa scholars [Newman 1975; Leben and Schuh, personal communications]. It seems that Middle Chinese words with checked tones, i.e. p, t, k endings, and voiceless initial consonants developed a relatively lower tone when the vowel nucleus was [a] than when it was [ə] [Baron, in preparation; Pulleyblank 1970-1]. In some Cantonese dialects, this tone development has sometimes been analyzed as originating from a length contrast. In the Omei dialect of Mandarin, two tones rearranged themselves depending on vowel height, the "new" high tone regrouping high vowels [Baron, in preparation; Cheung 1973]. In Ngizim [Schuh 1971] and in Bade, the tone patterns of verbs are partially predictable from the vowel of the first syllable; if the vowel is [a], the verb will have a high tone. These historical data do not suggest that the development of contrastive tones from vowel height is a widely attested process; furthermore, the reverse direction of interaction (i.e. low vowels giving rise to high tones) as observed in Ngizim and Bade seems inexplicable phonetically. It would seem reasonable then to find an explanation for the infrequency of this type of effect.

First I want to show that different loudness levels cannot explain this asymmetry between the two potential possibilities of tonal developments:

We know that low vowels are perceived as louder than higher vowels [Fant 1960] and we also know that loudness can affect our perception of pitch. If we can show that the *produced* intrinsic differences between high and low vowels are not *perceived* because of factors (such as loudness) affecting our perception of pitch, then we would have an explanation to the question of why languages do not develop tone from these intrinsic fundamental frequency differences.

Although the magnitude of the effect of loudness on pitch differs from one study to the other [Zurmühl 1930; Stevens 1935; Snow 1936; Cohen 1961], it is generally accepted that the effect of increased loudness (if any) (see Cohen [1961]) will be to lower the pitch (at least within this frequency region). Thus, this effect will lead to an *increase* in the pitch difference between high and low vowels and would make it more difficult to explain why tone developments based on these differences did not occur historically. In fact, instead of comparing the overall amplitude values of vowels just by stating that low vowels are louder than high vowels, it would be more appropriate to compare the amplitude values of different vowels within the frequency region relevant for pitch discrimination. It has been shown [Plomp 1967] that the frequency region around the fourth harmonic is more important for pitch perception than the fundamental frequency region. Under the best conditions (around 300 Hz), high vowels are 10 dB louder than low vowels [Fant 1960]. This amplitude difference is not enough to cancel out the intrinsic differences obtained in production. Thus, this explanation based on loudness is not satisfactory.

The second suggestion I want to propose is based on the well-known fact that whatever the sensory modality, our auditory mechanism is more sensitive to a signal varying from state 1 to state 2 (with a variation $\Delta S = S_2 - S_1$) than to a static difference between the same two steady states S_1 and S_2 [Whitfield and Evans 1965; Møller 1973]. If we apply this principle to pitch perception we can understand why tones develop from prevocalic consonants (where the intrinsic effects are realized as either rising or falling contours) but not from vowel height differences (where the intrinsic differences are in terms of steady state differences).

A third possibility is that our perception of pitch of vowels is affected by vowel quality. Since intrinsic pitch and vowel quality are always associated for a given vowel (as opposed to the case of consonantal perturbation where the consonant can be removed) it is possible that the pitch of a high (vs. low) vowel is lower (vs. higher) than its intrinsic fundamental frequency as a result of a process of normalization done by our auditory system. If this is the case, the pitch differences between low and high vowels would be smaller than their fundamental frequency differences and this would account partially at least for the lack of development from vowel height. This last hypothesis was proven to be correct in a recent study [Hombert 1977] in which it was shown using synthesized stimuli that listeners consistently judged the high vowels [i] and [u] to be lower in pitch than the low vowel [a] although their actual fundamental frequencies were identical.

4. Distribution of Tones

It has been shown that if we consider intensity and frequency as two independent parameters, about 350,000 different pure tones can be discriminated by the human ear over the whole auditory area [Stevens and Davis 1938; Wever 1949; Licklider 1956; Winckel 1968]. About 1500 of these tones are discriminated from pitch differences only. The fact that it is very rare to find tone languages with ten or more distinctive tones can be explained by the following reasons:

-- the amplitude parameter is not completely independent of the frequency parameter in speech [Hombert 1975];

-- the fundamental frequency range is a much smaller range than the auditory range;

--the most important point is the difference between discrimination and identification. In contrast with our amazing ability to decide if two tones presented successively are similar or not, our identification ability, i.e. our ability to identify and name sounds, is rather poor. For speech and music it has been estimated that a trained listener can identify about 50 sounds presented individually. Winckel [1938] indicates that fluctuations of less than 20 Hz are imperceptible, in noise, i.e. in everyday situations.[10] Figure 2 indicates that the three tones in Yoruba are from 20 to 30 Hz apart.

Pollack [1952] shows that a maximum of five level tones can be distinguished under laboratory conditions[11] (when loudness cues have been removed).

Few languages have been reported as having as many as five level tones [Longacre 1952]. In fact it seems that the more tones a language has the more likely this language will make use of other cues than steady state fundamental frequency to identify some of the tones.

It has been shown by Pollack and Ficks [1954] that our auditory system is more efficient, i.e. transmits more information, at processing a stimulus with multiple encoding, i.e. more than one cue is used, as opposed to the processing of the same amount of information using a more sophisticated coding of only one parameter. This finding can be applied to pitch perception indicating that secondary cues such as loudness, duration and direction and speed of change, and phonation types are likely to be used in order to facilitate our tone identification [Hombert 1976d]. From Figure 2, we can see that the so-called "low" tone in Yoruba is in fact a falling tone. The fact that the falling contour is a more important cue than the F_0 level has been shown by LaVelle [1974] and Hombert [1976c]. LaVelle argues that Yoruba has a rule which lowers a low tone in phrase final position. I propose that the "unmarked" realization of the Yoruba low tone is in fact a low falling tone and that the falling tone is realized as a low level tone when followed by a non-low tone, i.e. when followed by either a mid or a high tone. When a low tone occurs in isolation or in final position, it is realized with

[10] 20Hz is probably an overestimation considering on the one hand the richness of certain tone languages (in terms of number of tones) and on the other hand the maximum frequency range of vocal cord vibrations.

[11] Pollack's experiment was done using a 100-5000 Hz frequency range, but his data show that the number of identifiable tones is negligibly affected by a lowering of the upper limit of the frequency range.

its more distinctive perceptual characteristics; when it is followed by a higher tone, articulatory constraints (the complexity of going down for a falling tone and then up for the next tone) take over and the low falling tone is realized as a low level tone. But in this environment perception is made easier by the following tone which can be used as a reference for comparison. It has been shown by Han and Kim [1974] that "the pitch information in the neighbouring syllables serves as a basis on which the retrieval of the phonemic status of a tone is made."

5. Conclusion

In this paper, I have shown:

1. How the three Yoruba tones were affected by voiced/voiceless consonants in prevocalic positon. Voiced consonants have a greater effect on high tones and voiceless consonants on low tones. The duration of these perturbations is smaller in Yoruba than in a non-tonal language such as English.

These data show that an already existing tone system can multiply the number of its tones if the voicing contrast in prevocalic position is to disappear.

2. The fact that the intrinsic F_0 differences between high and low vowels are smaller when these vowels are realized with a low tone as opposed to a high tone seems to be a counter-argument to the tongue-pull theory generally proposed to account for these intrinsic F_0 differences between high and low vowels.

In the discussion it was also suggested that the fact that tones do not develop from intrinsic pitch of vowels as they do from intrinsic F_0 perturbations caused by prevocalic consonants cannot be explained by loudness but may be by the dynamic effect of prevocalic consonants as opposed to the static effect of vowel height.

3. It is often the case that other cues than steady state F_0 are used to identify tones. It seems that Yoruba "low" tone is in fact a low falling tone, but that this low falling tone is changed into a low level tone when followed by a non-low tone.

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