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Intrinsic F0 in Passamaquoddy Vowels

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INTRODUCTION

Fundamental frequency (F0), or "pitch", is the basic rate at which the vocal folds vibrate, giving speech its voiced sounds. This rate is determined by many factors, including subglottal air pressure, tension on the folds, and the resistive air pressure above the larynx. Speakers are accustomed to dealing with these factors, and exert a great deal of control over their F0. It is this ability to control F0, of course, which makes it possible for languages to use pitch distinctions to signal phonemic contrasts. Even in languages in which F0 is used phonemically, however, phonetic effects on F0 may occur as well. The present paper will focus on one phonetic factor that contributes to determining F0 in the vowels of Passamaquoddy, an Eastern Algonquian language of Maine, which also makes distinctive use of F0 in a pitch accent system (Goddard 1970; LeSourd 1993).[1]

One phonetic property of F0 that has been found for every language examined for it is intrinsic F0 (IF0), also called intrinsic pitch: high vowels such as /i/ and /u/ tend to have higher F0s than low vowels like /ɑ/ and /æ/. This effect was found for 31 languages for which measurements were available (Whalen and Levitt 1995). IF0 does not appear to depend on the size of the vowel inventory of a language, nor on whether a vowel is front or back. Various explanations have been proposed (Ohala and Eukel 1987; Sapir 1989; Vilkman, Aaltonen, Raimo, Arajärvi and Oksanen 1989; Fischer-Jørgensen 1990; Honda and Fujimura 1991); while none is fully satisfactory, most researchers agree that IF0 is an automatic consequence of successful vowel production.

Not all F0 modulations can be attributed to IF0, of course. In all languages, there are intonational effects on F0, whether or not the intona-

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tional repertoire is large. Some languages use approximately syllable-sized changes in F0 — that is, tones — to signal lexical differences. Tones are often dynamic, as are three of the four tones of Mandarin (Howie 1976). Level tones also occur, though the number of contrasts is limited, probably to four although there is one report of five (Chang 1953). Although most of the Algonquian languages do not make use of lexical tone, Cheyenne and Arapaho in the west have developed tone systems, and a band of languages in the east, including Maliseet, Passamaquoddy and Penobscot, make use of pitch accent.

Even languages that use tone contrastively still exhibit IF0 (Zee 1980; King, Ramming, Schiefer and Tillmann 1987; Ohala and Eukel 1987; Shi and Zhang 1987). That is, even in those languages where control of F0 is of immediate importance for distinguishing words, F0 changes with vowel height. Various such pieces of evidence — the universality of IF0, its presence in tone languages, and its presence even in babbling (Whalen, Levitt, Hsiao and Smorodinsky 1995) — argue for an automatic effect of vowel articulation on F0.

Interestingly, both intonation languages (Ladd and Silverman 1984) and tone languages (Zee 1980; Shi and Zhang 1987) lose IF0 when a speaker is at the bottom of his or her speaking range. At the end of a sentence with falling intonation, or in a low-toned vowel (and even the low part of high/low tones), IF0 disappears. This is further evidence of a difference between the way that F0 is raised and the way that it is lowered, one that affects the interaction of vowel articulation and F0. Again, the exact mechanism of this interaction is not worked out to everyone's satisfaction, but the existence of an automatic mechanism is not seriously in doubt (Whalen, Gick, Kumada and Honda 1998, 1999). Precisely because IF0 effects are automatic, they are typically not perceived as changes in pitch, but simply contribute to the perception of differences in vowel quality (Silverman 1987; Fowler and Brown 1997).

IF0 appears, then, to be a automatic phonetic feature of vowel production which does not need to be specified phonologically. Such redundant features are sometimes used to reinforce segmental distinctions, raising the possibility that IF0 is available for such reinforcements. The sound systems of Algonquian languages provide other examples of redundant features that serve to enhance segmental contrasts. For example, the Western Abenaki vowel /ɔ/ is nasalized, even though it is also distinct in vowel quality from the other vowels of the language (Goddard 1979; Whalen and Beddor 1989). Processes of tonogenesis in which voicing distinctions in stops are replaced by tonal distinctions in vowels (Hombert 1978; Hombert, Ohala and Ewan 1979; Maddieson 1984) provide another class of cases in which (initially) redundant phonetic features are used to enhance segmental contrasts. The development of distinctive tones in cases of this kind appears to begin when changes in F0 that result automatically from stop voicing are redundantly enhanced. Tonal distinctions appear when these originally redundant features of vowel pronunciation are reinterpreted as the carriers of contrast, and the underlying voicing distinctions that once determined them are abandoned. Since reconstructing such processes requires postulating phonetic features that are often not well preserved in the written record, accounts of such changes remain controversial. Nonetheless, the phonetic mechanism that appears to initiate change in such cases is an interesting one that should be explored when possible.

A possible case of the phonetic enhancement of vowel contrasts through pitch differences has come to our attention through the work of Joseph Nicholas and David Francis, two Passamaquoddy elders who have long been active in work on documenting and maintaining their ancestral language at Pleasant Point, Maine. They report pitch differences among the vowels of the Passamaquoddy language in the following terms: "The (a-ah) vowel will always be in no. 3 (low pitch). The vowels (e-eh), (o-oh) and (u-uh) will always be in no. 2 (middle pitch). The vowel (i-ih) will always be in no. 1 (high pitch)" (Nicholas and Francis 1988, Introduction, tape 1, side 2). As a true system of tonal distinctions, the pitch differences among vowels that Nicholas and Francis describe would be extremely unusual, to say the least. In fact, however, the differences that they note precisely mirror IF0 effects that have been identified in languages throughout the world. Thus an investigation of the role of IF0 in Passamaquoddy is clearly in order. Such an investigation may serve a practical purpose as well: if the tonal differences that Nicholas and Francis identify can in fact be attributed to IF0, then they do not need to be explicitly taught, as is done in Nicholas and Francis (1988), since IF0 effects are automatic consequences of normal processes of vowel production.

DATA AND MEASUREMENTS

We tested the typical F0 from two speakers on the Passamaquoddy language tapes published by Audio Forum (Nicholas, Francis and Nicholas 1988). Although not identified on the tape, the speakers were known to the third author of the present paper as a young female and an elderly man. 264 vowels were measured for F0 from each speaker.

F0 was measured near the midpoint of these vowels. If there was a pitch plateau somewhat off the midpoint, that plateau was measured. F0 was calculated by HADES (Rubin 1995) using an autocorrelation function.

Vowels were identified in two ways. First, they were classified by the orthographic representation given in the reference text (Nicholas et al. 1988) with some corrections in phonemicization made by the third author. Second, they were further identified for length and pitch accent. Vowels were classified as "long" or "short" based on known allophonic rules (Sherwood 1983; Teeter and LeSourd 1983; Nicholas and Francis 1988; LeSourd 1993) and by comparing vowel quality. Pitch accents were assigned by the third author by listening to the productions and marking distinctively accented vowels on the basis of a phonological analysis of the language (LeSourd 1993).

It is possible that differences among vowels described here in terms of length may better be described in terms of vowel quality, since the vowel quality changes are quite apparent and duration differences are not as noticeable, but the present results do not allow us to decide the issue and the term "length" will be used for convenience. Pitch accents are listed as High, Low and None. The "None" category includes vowels that are interpreted as bearing no distinctive tonal specification, their tonal properties instead being determined by other phonological or phonetic processes. The number of tokens of each vowel are given in Table 1.

The uneven distribution of tokens is to be expected, since languages do not use their vowels evenly, especially when suprasegmentals such as tone and length are involved: if we were eliciting new material, we could try to balance it more evenly. Still, this causes some difficulties for statistical analysis of the F0s of these vowels. Since the two speakers had different patterns of missing vowels, it was not possible to do an analysis that included both pitch accent and length. Further, Speaker 2 had no /u/s with low pitch, so /u/ was excluded from his analysis.

Table 1. Number of tokens of each vowel type for the two speakers.

Vowel	Length	Pitch	Phonetic transcription	Speaker 1 (female)	Speaker 2 (male)
A	short	None	ʌ	4	3
	short	Low		8	1
	short	High		2	7
	long	None	ɑ	12	10
	long	Low		6	2
	long	High		4	4
E	short	None	ɛ	18	6
	short	Low		2	0
	short	High		6	5
	long	None	æ	9	11
	long	Low		2	4
	long	High		8	7
I	short	None	ɪ	22	18
	short	Low		16	1
	short	High		12	15
	long	None	i	28	21
	long	Low		2	0
	long	High		12	12
O	short	None	ə, ʊ, o	50	67
	short	Low		10	1
	short	High		1	15
	long	None	o	4	9
	long	Low		2	0
	long	High		0	3
U	short	None	ʊ	4	12
	short	Low		0	0
	short	High		2	9
	long	None	ụ	10	10
	long	Low		2	0
	long	High		6	11

RESULTS

The measured F0s for the tokens selected were put into an analysis of variance with the grouping factors of Vowel, Length and Pitch accent. For both speakers, an analysis that used just the first two factors could be completed, since there were no empty cells (see Table 1). To analyze Pitch accent, length was ignored and, for Speaker 2, the vowel /u/ was omitted.

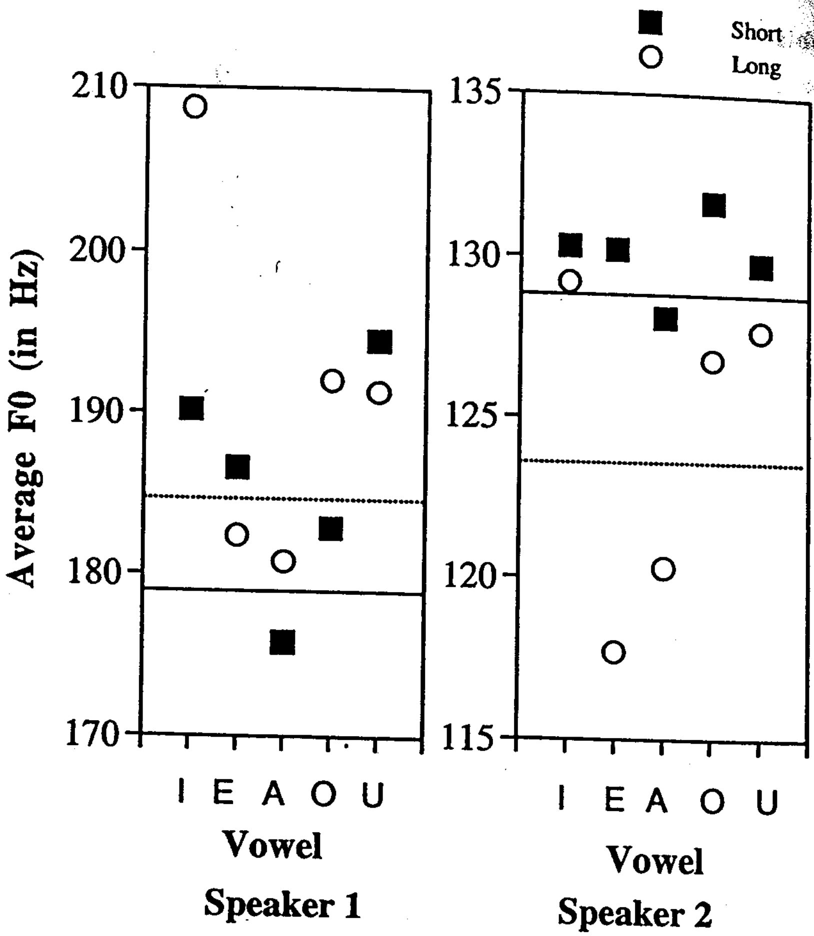

Figure 1. Average F0 values for Speaker 1 (female) and Speaker 2 (male). The separation between the lower and the higher F0s is shown in each panel by a solid line for the short vowels, and a dotted line for the long vowels.

High vowels did indeed have higher F0s than the low vowels, as described by Nicholas and Francis (1988) — 199 Hz for /i/ and 187 for /u/ vs. 178 for /ɑ/ for Speaker 1; 130 Hz for /i/ and 129 for /u/ vs. 124 for /ɑ/ for Speaker 2. These differences were significant in the ANOVA ($F(4,254) = 6.90$, $p < .0001$ for Speaker 1; $F(4,254) = 3.40$, $p < .01$ for Speaker 2). This was true when we divide the vowels into short and long as well (see Figure 1). The solid lines in that figure divide the low short vowel from the other short vowels; the dotted lines divide the low long vowels from the

Table 2. Average F0 near the midpoint of the vowels (standard deviation in parentheses), in Hz, analyzed by length. The "range" is the difference between the highest value and the lowest value for each speaker.

Vowel	Length	Transcription	Speaker 1 (female)	Speaker 2 (male)
A	short	ʌ	175.8 (23.4)	128.1 (4.6)
	long	ɑ	180.8 (23.2)	120.3 (9.0)
E	short	ɛ	186.6 (25.7)	130.2 (7.0)
	long	æ	182.4 (27.7)	117.7 (9.7)
I	short	ɪ	190.2 (22.4)	130.3 (8.2)
	long	i	208.8 (17.1)	129.2 (7.7)
O	short	ə, ʊ, o	182.9 (22.8)	131.7 (9.5)
	long	o	172.3 (8.6)	130.1 (5.7)
U	short	ʊ	194.6 (22.1)	129.8 (9.7)
	long	u̟	191.4 (24.3)	127.7 (9.2)
Range			33.0	14.0

other long vowels. Note that it is only the low vowel /ɑ/ that is lower for the short vowels, but both /ɑ/ and /e/ for the long vowels. This effect was marginal for Speaker 1 ($F(4,254) = 2.15$, $p = .075$ for the interaction of Vowel and Length) and significant for Speaker 2 ($F(4,254) = 3.33$, $p < .05$). Phonetically, long /e/ surfaces as [æ], another low vowel that has been shown to pattern with /ɑ/ in terms of IF0 (Vilkman et al. 1989; Honda and Fujimura 1991). The values for the mid height vowels are often intermediate in F0 value, but the sample size is too small to show this consistently; we can expect from other studies that this height relationship will appear with sufficient measurements.

Long and short vowels did not differ in F0 for Speaker 1 ($F(1,254) = 2.31$, n.s.), but did so for Speaker 2 ($F(1,254) = 19.36$, $p < .0001$), as shown in Table 2. To the extent that Speaker 1 had any trend at all in this respect (higher F0 for long vowels rather than short ones), it was in the opposite direction from that of Speaker 2. Since the Passamaquoddy length difference is often indistinguishable from vowel quality differences, changes in vowel height would lead to different expectations about what the F0 would do. For /ɑ/ and /e/, for example, the allophone for the long version is also lower in height, while the opposite is true for /i/ and /u/. For /o/, the allophones are too variable to make a prediction. If we look at the data with these facts in mind, only two vowels for each speaker (that is, exactly

Table 3. Average F0 of the center of the vowels (standard deviation in parentheses), in Hz, analyzed by pitch accent. The range in this case is the largest difference between any two pitch accents within one vowel.

Vowel	Pitch accent	Speaker 1 (female)	Speaker 2 (male)
A	low	167.0 (15.4)	116.8 (3.9)
	none	180.5 (23.8)	122.4 (10.7)
	high	202.4 (18.5)	126.5 (4.4)
E	low	158.8 (9.0)	111.6 (5.9)
	none	189.6 (27.6)	121.3 (11.9)
	high	183.1 (23.4)	127.1 (8.8)
I	low	165.9 (8.4)	136.0 (0)
	none	207.9 (16.7)	129.3 (7.3)
	high	204.0 (15.4)	130.1 (8.9)
O	low	166.0 (8.5)	132.4 (0)
	none	189.3 (24.5)	130.4 (10.8)
	high	168.1 (0)	134.0 (7.6)
U	low	161.4 (7.4)	—
	none	187.4 (17.6)	—
	high	191.8 (22.9)	—
Within-Vowel Range		42.0	15.5

half of the cases) behave as expected — /i/ and /e/ for Speaker 1, /e/ and /ɑ/ for Speaker 2. Thus while vowel height corresponds significantly with F0 in Passamaquoddy, the relationship of vowel length to F0 is not clear from this data.

As mentioned above, the analysis of the pitch accent results is necessarily limited by the missing cells in our distribution of vowel tokens if vowel length is included, so an analysis using only the factors of Vowel and Pitch accent was performed (see Table 3). For Speaker 1, the vowels were again different in F0 as they had been in the previous analysis ($F(4,249) = 4.34$, $p < .01$), and Pitch accent also corresponded significantly with F0 differences ($F(2,249) = 19.66$, $p < .0001$). The pitch accent values were 190.9 for the unspecified accent, 163.8 for the low, and 189.9 for the high. The interaction of the two factors (Vowel and Pitch accent) was nearly significant ($F(8,249) = 1.97$, $p = .051$). For Speaker 2, the vowel /u/ had to be excluded, due to an absence of low pitch vowels. The remaining vowels were again different in their F0s ($F(3,210) = 5.79$, $p < .001$), and the effect of Pitch accent was marginal ($F(2,210) = 2.89$, $p = .058$). The pitch

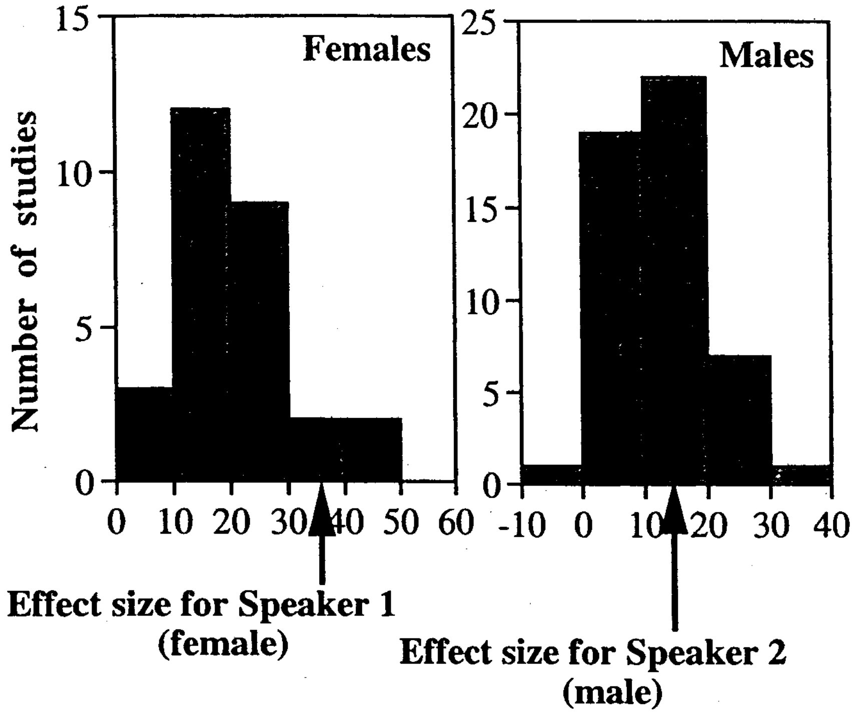

Figure 2. Size of the IF0 differences in 31 languages (from Whalen and Levitt 1995). The speakers from the current study are indicated by the arrows on the x-axis.

accent values were 125.9 for the unspecified accent, 124.2 for the low, and 129.4 for the high. The interaction of the two factors was not significant ($F(6,210) < 1$, n.s.). For these utterances, the unspecified pitch accent is equivalent in F0 to the high pitch for Speaker 1, and the low pitch for Speaker 2.

DISCUSSION

The differences found in this study are statistically reliable and thus could form the basis for a tone system. Although no such reinforcement of vowel height has been reported, we must always be willing to entertain the possibility that some language will do the unusual. However, the size of the effect is equivalent to that for IF0 in the world's languages (see Figure 2). For both of our speakers of Passamaquoddy, the values fall well within the range of typical IF0 for the world's languages. The differences in F0 between the high vowels and the low appear to be more on the order of IF0 than of tones. For example, if the language were Mandarin, we would expect the difference between the tones to be about 85 and 58 Hz, not the 33 and 14 Hz found (Howie 1976). If it were Yoruba, it would be about 69 and 47 Hz (Hombert 1978). Since F0 variation in Passamaquoddy also follows vowel height (as we would expect of a typical IF0 effect), it appears more likely that what was initially identified as a tone distinction is, instead, the presence of the universal phonetic effect of IF0.

Recall that tone languages still show IF0. This is true of languages that have both relative large (Thai, Mandarin) and small (Yoruba) differences in their tone qualities. Thus it would be surprising if we did not find the current differences in addition to any tone that might be present. Since the size of the effect we found was just that of IF0 in the world's languages, Passamaquoddy would have to be doubly unusual in using tone to reinforce vowel height and, at the same time, suppressing IF0, which has not been documented before. Finally, the F0 seems to follow the phonetic (allophonic) character of the vowel rather than its phonemic status. The clearest example is the long allophone of /e/, which is phonetically the low vowel [æ]. This vowel has the lowest F0 value of all for Speaker 2, and a lower value than for the short /e/ for Speaker 1 (see Table 2). If IF0 is, as assumed, an automatic consequence of vowel production, then this is what we would expect. Some of the smaller differences in vowel height do not appear to confirm this hypothesis, but the small number of tokens makes it difficult to be certain. Further, the effects of such small differences on IF0 are unclear since the difference, say, between /i/ and /ɪ/ is not always produced as a height difference (Fischer-Jørgensen 1990).

Independent of the IF0 issue, our initial measurements of the previously unmeasured Passamaquoddy pitch accent make it an appealing case for further work. It can be seen from Table 3 that the differences among the pitch accents are also small relative to cross-linguistic comparisons of the phonetic realization of tonal differences. The differences there were a maximum of 42 Hz for Speaker 1 and 15.5 Hz for Speaker 2. Again, this is smaller than would be expected for a tone system. However, the value for Speaker 1 is the equivalent of 3.90 semitones. This is above the three semitones that are apparently needed for a reliably discriminable difference ('t Hart 1981; 't Hart, Collier and Cohen 1990). For Speaker 2, however, the difference is only 2.25 semitones, below the usual cutoff; this is likely due to the limited nature of the data collected. Further work is clearly needed to elaborate on the phonetic nature of the pitch accent in Passamaquoddy.

CONCLUSION

It appears that Passamaquoddy does indeed have reliable F0 differences between high and low vowels, but the difference is attributable to the universal phonetic effect of IF0, rather than to the distinctive use of tone. Thus the difference does not need to be explicitly taught, since speakers of any language will introduce these differences automatically. Nicholas and Francis 1988 are to be commended for successfully describing these difficult-to-distinguish differences, which led to the postulation of a new pattern in language. It is to be hoped that more phonetic data will be collected, leading to better evaluations of the realization of human (especially Algonquian!) speech.

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