The effect of aspiration on the fundamental frequency of the following vowel

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In this paper we will be concerned with the effect of aspiration on the fundamental frequency of the following vowel. More precisely we will be interested in comparing the Fo values after voiceless aspirated vs. voiceless unaspirated stops. This study will hopefully bring new insights into issues such as the timing of the articulatory gestures involved in the production of these stops and the development of contrastive tones from consonant mergers.

1. Introduction

The process by which a language can develop two tones (or multiply by two the number of its tones if it already has a tone system) from the loss of a voicing distinction in prevocalic position is rather well understood (Haudricourt, 1961; Hombert, 1975; Hyman, forthcoming; Matisoff, 1973). When such a development occurs, the intrinsic differences in the onset fundamental frequency of vowels following voiced vs. voiceless stops are reinterpreted and used extrinsically; that is they become contrastive after the loss of the voicing contrast as shown in (1):

(1)

Stage 1		Stage 2		Stage 3
pa	>	pa [‾]	>	pa [‾]
ba	>	ba [_]	>	pa [_]

It should be pointed out that the reinterpretation of the Fo shapes from stage 2 to stage 3 is not fully understood. When three series of stops (voiced, voiceless unaspirated and voiceless aspirated) are involved in a tone development, the picture is not clear, although there may be a tendency for the voiceless aspirated series to develop a higher tone as attested, for example, in the Siamese dialect of the Trang Province (Egerod, 1961; Haudricourt, 1961). If it is in fact the case that historically higher tones develop after voiceless aspirated stops rather than after voiceless non aspirated stops, we should be able to see and quantify this effect by looking at languages in which these two series of stops (voiceless aspirated and voiceless aspirated) have not merged.

2. Phonetic Data

In an earlier study (Hombert, 1975), Korean data were used to illustrate the fact that intrinsically voiceless aspirated stops lead to a higher Fo onset of the following vowel. Korean has a three way contrast of voiceless stops in word initial position: aspirated, unaspirated and "strong" series. This "strong" series will not be considered for the moment since it involves an extramuscular activity irrelevant for our present discussion. The following two tables show the voice onset time (v.o.t) and the Fo onset of the following vowel associated with these two series of Korean stops.

Table 1. Voice onset time associated with unaspirated and aspirated stops in Korean (in msec)

		p	t	k	p^h	t^h	k^h
Lisker and Abramson (1964)		7	11	19	91	94	126
Han (1967)	S1	27	33	62	129	133	148
	S2	20	23	42	105	107	136
	S3	17	21	27	66	73	71

Table 2. Onset values of fundamental frequency of vowels following unaspirated and aspirted stops in Korean (in Hz)

		p	t	k	p^h	t^h	k^h
Han (1967)	S1	144	161	162	185	205	201
	S2	266	312	309	341	334	300
Kim K. (1968)		277	282	282	300	304	300

From these data it is clear that, other things being equal, a longer v.o.t (corresponding to the aspirated series) lead to a higher Fo onset. These data suggest that if a tone development occurs in a language as a result of the merging of the voiceless aspirated and the voiceless unaspirated series, there will be a tendency for higher tone to develop after historical voiceless aspirated stops rather than after their unaspirated counterparts. Unfortunately other data from Korean do not give full support to this hypothesis. Kagaya (1974) found that one of the two Korean subjects he used had an average Fo onset about 8% higher (162 Hz vs. 150 Hz) after the voiceless unaspirated series than after the aspirated series (data based on 12 tokens for each series). A similar situation is found in other languages besides Korean.

Hindi has a contrast between four series of stops (voiced, breathy voiced, voiceless unaspirated and voiceless aspirated. Kagaya and Hirose (1975) found an average Fo onset about 5% higher (188 Hz vs. 178 Hz) after the unaspirated series (data based on 1 speaker, 12 tokens per series).

Danish has two series of stops, both voiceless, in word-initial position. One series is aspirated, the other is unaspirated; that is a situation very similar to English stops.

Eli Fischer-Jørgensen reports that the differential effect of these two series of stops on the Fo of the following vowel is very small (1968a) or non-existent (1968b). The situation is not clearer in Standard Thai (Bangkok dialect). Ewan's data (forthcoming) indicate that Fo is higher after the aspirated series by about 5% (131 Hz vs. 124 Hz) (data based on 1 speaker, 90 tokens per series). However, Gandour's data (1974) show the opposite pattern; he found that the unaspirated stops led to a Fo onset 8% higher than the unaspirated series. These data were also based on 1 subject and 90 tokens/series. Out of a sample of 11 speakers, Erickson (1975) found that 7 of them produced higher Fo after voiceless aspirated stops than after voiceless unaspirated. The other 4 speakers exhibited the opposite pattern[1]. It is not clear from these three studies on Thai whether these differences in the effect of voiceless aspirated vs. voiceless unaspirated can be attributed to slight dialect differences or should be considered speaker specific.

In historical data on one Wu dialect (Wufang), Ballard (1975) reports that aspiration caused a tone lowering resulting in a merger. In another Wu dialect (Wuchiang), the voiceless aspirated and voiceless unaspirated have split phonemically in certain tones, the aspirated initial syllables having generally lower tones than the unaspirated initial syllables (Ballard, personal communication). All these data from Korean, Hindi, Danish, Thai and Wu do not support the hypothesis of a clear direct relationship between v.o.t. and Fo onset of the following vowel. The explanation generally provided to support this theory is based on the interaction between rate of airflow and width of glottal opening upon stop release. Other things being equal a higher rate of airflow will lead to a higher rate of vibration of the vocal folds. Considering the number of contradictory examples from different languages this explanation has to be reconsidered. In order to bring new data which hopefully will help clarify this issue, we decided to investigate the two series of stops in French and in English. The major reason which dictated our choice of these two languages is the well-known difference in the nature of the contrast between the two series of stops in these two languages. The main difference between the two English series is, in word-initial position at least, an aspiration difference, the voiceless series is voiceless aspirated and the so-called voiced series is often voiceless un-aspirated. In French, the contrast between the two series of stops is

[1] These data are based on 8 repetitions of CV utterances with C=[u]. The number of tones used in this experiment is not mentioned.

an actual voicing contrast; the voiced series is generally fully voiced during stop closure and the voiceless series has a very small v.o.t (that is, almost no aspiration). Fischer-Jørgensen's data (1968a,b) indicate higher Fo after French voiceless unaspirated stops than after French voiced stops. A number of studies (Hanson, 1975, Hombert, 1975; House and Fairbanks, 1952; Lehiste and Peterson, 1961) indicate that in American English, voiceless aspirated stops lead to a higher Fo onset than the so-called voiced series. What we are interested in here is comparing the French voiceless unaspirated series with the American English voiceless aspirated series. Since these two series differ only in aspiration, we will be able to isolate and quantify the effect of aspiration. We mentioned earlier that the two series of American English stops often differ only in aspiration; however since the CV test words read by our speakers (see next paragraph) were put within a frame, the voiced series was in fact sometimes voiced. We decided to keep our test-words within a frame in order to get a more natural intonation pattern and consequently a more natural laryngeal behavior. Our study will involve Fo measurements of vowels following orthographic "p, t, k" and "b, d, g" in American English and in French as well as glottal width and airflow measurements; we will report here only on the first stage of our investigation.

3. Experimental procedure

Two American English speakers (1 Female and 1 Male) and two French speakers (1 Female and 1 Male) were used in this experiment. They spoke 6 CV nonsense words where C= [p,t,k,b,d,g] and V= [i]. The word list consisted of 10 tokens of each test word arranged in random order. Each test word was uttered in the frame "Say ___ louder". No special instructions were given with respect to the speed of reading. The recording was done in a sound treated room. The speech waveform was sampled at an effective rate of 20000 Hz . Since most Fo extractor methods perform poorly in determining the Fo during the first few cycles and since these measurements were crucial in our study, we decided to make our measurements directly on the digitized waveform. In order to get maximum accuracy in locating similar points on each consecutive period, high frequencies were filtered out (above 1 KHz).

4. Results and discussion

The v.o.t. and Fo values are presented in Table 1 and Figure 1.

Table 1. Voice Onset Time values(in msec) in French and English (10 tokens/consonant/subject)

		p		t		k	
		Av.	S.D.	Av.	S.D.	Av.	S.D.
French	F	18	4	29	6	51	8
	M	13	8	34	6	53	14
English	F	57	6	66	6	87	10
	M	35	4	64	9	85	6

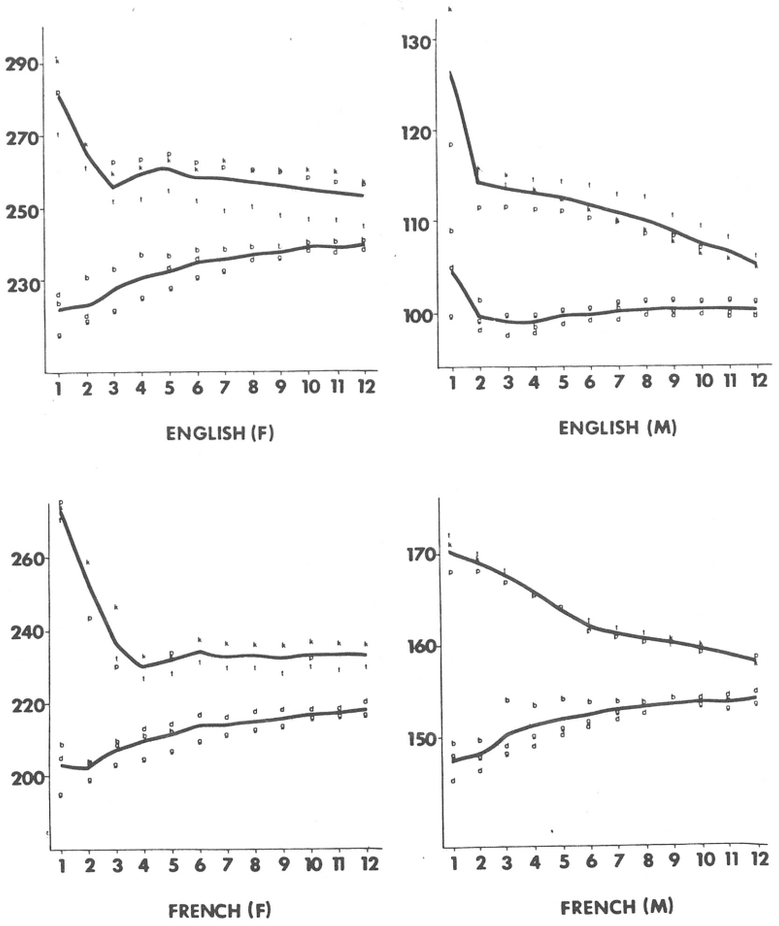

Fig. 1. Fundamental frequency measurements (vertical axis) of vowels following ptk and bdg (orthographic) as a function of glottal period (horizontal axis) for two American English speakers (1 female and 1 male) and two French Speakers (1 female and 1 male). The upper curve represents average Fo measurements after ptk, the lower curve represents average Fo measurements after bdg.

In Figure 1, Fundamental frequency (vertical axis) is plotted as a function of successive vocal folds cycles (horizontal axis). The upper line represents the average Fo after voiceless aspirated stops in American English and after voiceless unaspirated in French; the lower line corresponds to the two other series (voiceless unaspirated or "voiced" in American English and voiced in French). Values corresponding to each individual stop (p,t,k,b, d,g) are represented by corresponding letters on the graph (with the usual orthographic convention).

By comparing the two upper curves from the French Female and from the American English Female, it becomes clear that there is no direct correlation between longer v.o.t and higher Fo onset since the two curves are very similar despite the fact that one curve represents the Fo of a vowel after a voiceless aspirated series and the other after a voiceless unaspirated series. However, by comparing the upper and the lower curve from the American Male who was producing devoiced bdg (probably because of a short pause before the test-word), it is also clear that v.o.t does play a role since the only difference between these two series is a longer v.o.t for the aspirated series.

From these data is seems reasonable to conclude that longer v.o.t does affect Fo onset but not in a direct fashion. Other factors such as glottal width, rate of airflow and muscular tension interact and affect the determinant factor of Fo onset. Looking back at the Korean data now, it is possible that the differences in Fo onset were not only due to different v.o.t. In fact, E.M.G. data (Hirose et al, 1974) indicate that the muscular activity involved in producing the unaspirated stops is lower than in producing the aspirated ones; this difference in muscular activity could account for part of the Fo onset differences.

5. Conclusions

In summary, the data presented here disconfirms the simple but naive view claiming a direct correlation between longer v.o.t (aspirated series) and higher Fo onset. This position was mainly based on a too hasty interpretation of the Korean data. On the other hand, these data help us understand the untidy patterns observed in a number of languages with respect to the non-systematic effect of aspiration on the Fo onset of the following vowel. In other words, these data are disappointing in the sense that they show that intrinsic Fo effects and consequently phonetically motivated tonal changes cannot be predicted from a vague phonetic characterization of the segments involved such as aspirated or unaspirated. But one can also take the following optimistic view, that these data show that some of the tonal developments that we consider unexpected or unexplainable may just be the result of our lack of knowledge of the accurate phonetic characteristics of the segments involved in these historical developments.

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