INTRINSIC VOWEL F_0 IN A CONTOUR TONE LANGUAGE

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ABSTRACT - Two contour tones on high and low vowels are measured at different duration points to examine intrinsic vowel Fo effects in Shanghai Chinese. T-test results show the intrinsic vowel Fo occurs on the earlier part of the falling tone and later part of the rising tone.

INTRODUCTION

It is generally acknowledged that the average fundamental frequency (Fo) varies with vowel height; a higher vowel is related to higher Fo, *ceteris paribus*. This assumed intrinsic vowel fundamental frequency (IFo) has been observed in many genetically unrelated languages such as English (Taylor 1933), Danish (Petersen 1978), German (Ladd & Silverman 1984), Itsekiri (Ladefoged 1964), Yoruba (Humbert 1977a), Thai (Gandour & Maddieson 1975), etc. IFo also occurs on short vowels as well as on long ones (Dyhr 1990:149). Larger IFo differences have been found in stressed vowels than in unstressed vowels (Petersen 1986). Although Umedo (1981) suspects the so-called IFo is an artifact of experiments based on carrier sentences, Ladd & Silverman (1984) show that IFo differences do occur in running speech.

Most of the detailed and comprehensive researches in this field have been carried out in non-tone languages. The investigations in the tone languages mentioned above involved only one (Itsekiri, Thai) or two (Yoruba) subjects. Speakers realise the same acoustic properties or linguistic signals by different strategies. So it appears necessary to do a multi-subjects study in a contour tone language to see if this positive correlation is idiosyncratic or statistically significant. Can IFo be found in complex tones as in level tones? If so, is it manifested only on the peak point of a glide tone or on the entire stretch of the Fo curve?

PROCEDURES

Shanghai Chinese (SH) was chosen for the investigation. There are five lexical tones in SH contrasting falling with rising, long with short (Rose 1990). This paper will be reporting the results obtained from the data of the high falling tone, T(one) 1, and the low rising tone, T(one) 3. In order to eliminate individual idiosyncrasies and to get statistically significant results, 11 informants, five female (referred to as F1 to F5) and six male (M1 to M6), were employed. The syllables used in testing were real words or morphemes in SH. Included in the corpus were: T1 *pì* "edge", *pù* "to sow", *pà* "dad", T3 *pí* "convenient", *pú* "step", *pá* "to fail". Each syllable was read in citation form and repeated six times by each speaker. Thus a total of 2 (tones) x 3 (vowels) x 6 (repeats) x 11 (informants) = 396 tokens were involved. All recordings were made under laboratory conditions. Spectrographic measurements for Fo tracings were made by hand. The voice onset was defined as the point where the first glottal striation of the second formant was clearly present. The offset of the falling T1 was decided at where regularly increasing intervals between Fo striations had ended. For T3, which was rising in contour with a dropping Fo perturbation caused by a syllable-final glottal stop, the convex inflection point was decided as the offset of the tone (Rose 1990). Tokens were sampled every 20 percentage point of the duration, of which an additional point at 5% was also measured. Moreover, for those with T3, the end of the dropping Fo perturbation, arbitrarily designated as 110%, has been measured.

RESULTS

First to be mentioned is that the speakers behave quite differently if we look into the acoustic details, although there is a general tendency which conforms with the results in the majority of previous studies. The mean measurements for individual speakers are demonstrated in Fig 1. Each panel contains one of the two tones, on all three vowels, of two speakers: one female, with upper curves, and the other male, lower curves, except diagrams f and l, which include only one male speaker. Each curve represents the mean values of six tokens. The mean Fo values were t-tested for significant differences between the high and low vowels. The results are given in Table 1. In the following summary of the results, when I say "*a* has lower Fo than *i,u*" or the equivalents, it means that at least two out of three statistics (ie, the *t* values of *i* vs *a*, *u* vs *a*, and pooled *i+u* vs *a*) are significant at the confidence level of 95% or higher.

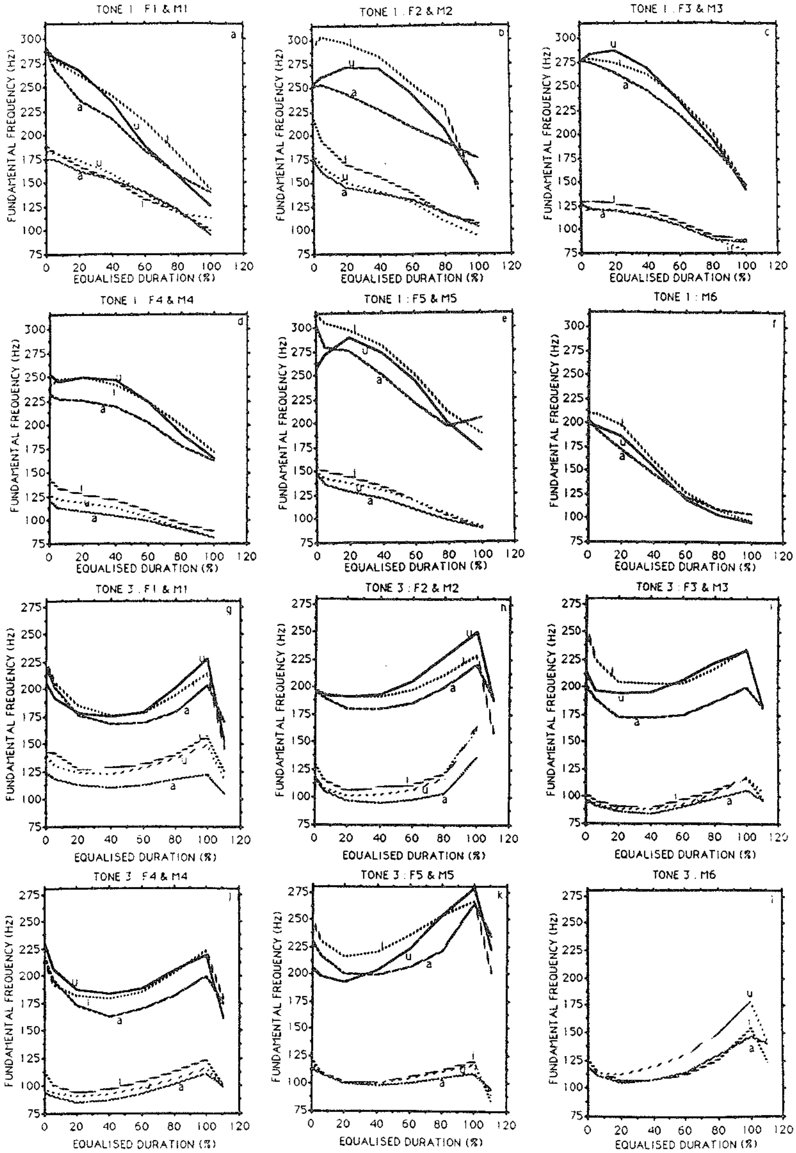

Figure 1. Average Fo curves of Tone1 and Tone 3 on three vowels for 11 Shanghai speakers.

TONE 1

Speaker	Source of variation	0%	5%	20%	40%	60%	80%	100%
F1	i+u : a	-0.017	1.406	3.648**	3.536**	2.337*	1.447	-0.578
	i : a	0	0.905	2.928**	3.521**	5.314***	3.238**	0.198
	u : a	-0.039	1.546	3.199**	2.517*	0.797	-0.086	-1.138
	i : u	0.028	-0.327	-0.518	0.973	3.946**	3.977**	1.557
F2	i+u : a	2.173*	2.708**	4.802***	6.683***	4.941***	2.433*	-4.826
	i : a	5.069***	7.001***	6.264***	6.315***	4.371***	2.778**	-4.191
	u : a	0.375	1.106	3.681**	5.4***	4.412***	2.359*	-4.086
	i : u	8.704***	9.859***	4.273**	1.78	1.227	1.86	-0.606
F3	i+u : a	-0.25	1.084	2.37*	3.169**	3.372**	3.006**	-0.396
	i : a	-0.165	0.548	1.187	2.06*	3.015**	5.504***	-1.171
	u : a	-0.273	1.282	3.341**	3.977**	2.965**	1.772	-0.495
	i : u	0.065	-0.708	-1.854	-1.096	0.617	1.283	0.354
F4	i+u : a	2.088*	3.673**	4.097***	4.241***	4.517***	2.806**	0.802
	i : a	1.059	2.884**	3.26**	3.315**	4.183***	3.386**	1.059
	u : a	2.505*	2.911**	3.574**	4.086**	4.212***	2.056*	0.328
	i : u	-1.331	0.479	-0.142	-0.614	-0.024	0.964	0.705
F5	i+u : a	-1.189	0.741	2.341*	4.544***	5.26***	1.442	-3.856
	i : a	3.929**	1.724	3.631**	6.132***	5.661***	2.149*	-2.577
	u : a	-7.538	-0.429	1.36	3.048**	3.972**	0.404	-4.488
	i : u	10.046***	5.349***	0.857	0.898	1.135	2.001	3.607**
M1	i+u : a	1.568	1.194	1.483	0.589	-0.756	-0.558	1.75*
	i : a	1.472	1.147	0.802	0.079	-0.902	-0.401	0.776
	u : a	1.022	0.908	2.443*	1.311	-0.353	-0.631	2.374*
	i : u	0.612	0.356	-0.668	-0.755	-0.738	0.043	-1.714
M2	i+u : a	2.583*	2.753***	2.65***	2.141*	0.532	-1.445	-0.509
	i : a	6.201***	5.153***	4.599***	3.714**	1.353	-0.425	0.745
	u : a	1.018	1.287	1.028	0.557	-0.867	-1.944	-2.039
	i : u	5.12***	5.567***	7.402***	6.275***	2.18*	2.333*	2.545*
M3	i+u : a	-0.292	0.837	1.247	0.993	0.526	0.141	-0.548
	i : a	0.655	1.808	2.093*	1.555	0.787	0.475	0.588
	u : a	-1.318	-0.402	0.348	0.164	0.036	-0.25	-2.973
	i : u	2.908*	2.235*	1.48	1.434	0.878	0.706	2.229*
M4	i+u : a	2.294	2.823**	3.504**	3.699***	2.798**	1.771*	0.546
	i : a	3.746**	3.888**	4.108**	4.496***	4.285***	2.97**	1.405
	u : a	1.061	1.921*	2.915**	2.549*	1.427	0.504	-0.382
	i : u	2.714*	2.126	1.649	1.874	2.582*	2.64*	1.869
M5	i+u : a	0.986	2.594**	3.303**	4.738***	6.424***	3.146**	0.35
	i : a	1.108	3.12**	3.288**	4.221***	5.116***	2.407*	0.038
	u : a	0.347	1.466	2.561*	3.896**	4.66***	2.692*	0.526
	i : u	1.564	2.241*	1.629	1.46	0.379	-0.257	-0.62
M6	i+u : a	0.262	1.047	1.995*	1.359	0.326	-0.895	-2.015
	i : a	1.63	3.549**	6.564***	3.065**	1.008	-0.329	-1.378
	u : a	-0.387	0.279	1.04	0.696	-0.285	-1.121	-1.775
	i : u	1.272	0.992	0.776	0.581	1.086	0.962	0.302
Female	i+u : a	0.628	2.777**	5.226***	6.544***	5.352***	3.128**	-2.198
	i : a	1.645	3.262***	4.574***	5.889***	6.123***	4.24***	-1.214
	u : a	-0.755	1.335	4.344***	5.657***	3.758***	1.492	-2.471
	i : u	2.721**	2.58*	0.529	0.52	1.703	2.645*	1.416
Male	i+u : a	1.37	1.634	2.237*	2.087*	0.919	-0.177	0.048
	i : a	2.074*	2.237*	2.621**	2.437**	1.261	0.395	0.661
	u : a	0.309	0.64	1.374	1.231	0.288	-0.702	-0.527
	i : u	1.759	1.555	1.099	1.101	1.056	1.228	1.151
All	i+u : a	0.722	1.298'	1.881*	1.906*	1.507'	0.884	-0.956
	i : a	1.307'	1.691*	1.911*	1.9*	1.664*	1.272	-0.381
	u : a	-0.084	0.557	1.4'	1.486'	1.017	0.267	-1.233
	i : u	1.348	1.027	0.35	0.244	0.498	0.875	0.866
			p<0.001(***)			p<0.01(**)		

TONE 3

0%	5%	20%	40%	60%	80%	100%	110%	Statistics
-0.891	-0.316	1.163	2.175*	2.179*	3.884***	3.281**	-1.919	t (1-tail)
0.578	1.083	1.525	1.867*	2.277*	3.8**	2.206*	-1.644	t (1-tail)
-2.478	-1.788	0.312	1.736	1.632	3.538*	4.415***	-1.615	t (1-tail)
3.232**	3.592**	2.044	0.336	-0.125	-0.936	-1.764	-0.555	t (2-tail)
-0.043	0.715	2.929**	3.45**	3.639**	3.229**	3.282**	-1.297	t (1-tail)
0.028	0.971	2.96**	3.142**	3.645**	2.646*	2.671*	-2.554	t (1-tail)
-0.084	0.36	2.285*	3.124**	3.618**	4.498***	6.202***	-0.073	t (1-tail)
0.121	0.402	0	-0.666	-1.448	-2.295*	-3.634**	-2.522*	t (2-tail)
3.416**	2.987**	6.024***	5.882***	4.933***	5.601***	6.38***	0.215	t (1-tail)
10.015***	6.93***	6.024***	5.578***	3.74**	4.11**	5.74***	0.244	t (1-tail)
2.785**	1.968*	4.802***	4.791***	5.546***	6.276***	5.075***	0.137	t (1-tail)
8.042***	5.571***	2.338*	1.335	-0.429	-0.635	0.026	0.134	t (2-tail)
0.44	0.496	2.882**	5.365***	5.886***	5.919***	5.862***	-0.412	t (1-tail)
-0.547	-0.906	2.019*	4.227***	4.033**	5.489***	7.443***	0.478	t (1-tail)
1.156	1.577	3.128**	5.867***	5.868***	4.998***	3.982**	-1.172	t (1-tail)
-2.413*	-2.69*	-1.55	-1.05	-0.881	-0.466	1.161	1.262	t (2-tail)
-0.27	-0.402	0.722	2.935**	4.661***	7.303***	1.084	-2.858	t (1-tail)
4.851***	3.612**	4.956***	6.805***	7.438***	8.411***	0.216	-3.952	t (1-tail)
-6.473	-6.765	-2.195	1.357	3.103**	5.26***	1.535	-2.008	t (1-tail)
10.282***	9.104***	6.945***	5.659***	2.524*	-0.092	-1.644	-2.489*	t (2-tail)
2.502*	3.444**	4.23***	5.399***	6.366***	6.946***	6.61***	3.095**	t (1-tail)
2.721*	4.695***	4.974***	7.971***	7.728***	8.119***	8.866***	4.218***	t (1-tail)
1.757	2.037*	2.938**	3.648**	4.367***	4.8***	4.633***	2.006*	t (1-tail)
0.611	2.389*	0.863	1.306	1.322	0.869	1.364	0.92	t (2-tail)
0.884	1.616	2.631**	4.153***	4.184***	3.694**	5.388***		t (1-tail)
1.876*	2.917*	3.497**	7.177***	5.982***	6.789***	5.061***		t (1-tail)
-0.319	0.41	1.687	2.581*	2.261*	2.268*	4.414***		t (1-tail)
4.258**	2.304	1.252	2.199	1.629	0.9	-0.556		t (2-tail)
2.015*	1.397	2.261*	2.936**	2.33*	2.613**	4.057***	1.149	t (1-tail)
3.073**	2.108*	2.638*	2.719*	2.989**	2.509*	3.02**	0.218	t (1-tail)
0.894	0.572	1.383	2.456*	1.416	2.205*	4.342***	2.727*	t (1-tail)
1.92	1.239	1.095	0.445	1.936	0.91	-0.231	-1.43	t (2-tail)
2.231*	2.757**	2.65**	3.475**	3.065**	1.995*	2.004*	0.478	t (1-tail)
4.21***	3.693**	2.427*	3.593**	3.435**	2.592*	2.814**	0.51	t (1-tail)
0.787	1.694	2.569*	2.779**	2.359*	0.902	0.969	0.263	t (1-tail)
3.633**	2.153	0.916	1.387	1.816	2.06	1.613	0.266	t (2-tail)
2.034*	0.418	0.537	1.056	1.475	1.614	1.949*	-1.618	t (1-tail)
2.165*	0.666	0.698	0.889	1.24	1.538*	1.863*	-1.725	t (1-tail)
1.401	0	0.191	0.989	1.387	1.224	1.524	-1.154	t (1-tail)
1.188	0.668	0.554	0.133	0.277	0.315	0.394	-0.923	t (2-tail)
0.631	0.742	1.148	1.223	1.239	1.123	1.972*	-0.906	t (1-tail)
1.114	0.588	0.468	-0.065	-0.333	-0.443	0.632	-1.736	t (1-tail)
-0.154	0.791	1.986*	3.223**	3.402**	3.613**	5.391***	0.191	t (1-tail)
1.352	0.032	-0.849	-2.411*	-3.299**	-3.142*	-2.145	-1.761	t (2-tail)
1.189	1.384	4.144***	4.653***	4.572***	5.482***	3.834***	-1.938	t (1-tail)
2.649**	2.712**	4.216***	4.415***	3.842***	4.355***	2.715**	-2.253	t (1-tail)
-0.748	-0.593	2.88**	4.03***	4.367***	5.532***	3.703***	-1.145	t (1-tail)
3.366**	3.437**	2.137*	0.839	-0.095	-1.047	-1.414	-1.034	t (2-tail)
2.389**	2.153*	2.411**	3.123**	3.346***	3.392***	3.858***	0.366	t (1-tail)
3.36***	2.65**	2.427**	2.958**	3.306***	3.304***	3.57***	-0.146	t (1-tail)
0.948	1.189	1.882*	2.645**	2.755**	2.876**	3.505***	0.779	t (1-tail)
2.272*	1.467	0.53	0.221	0.159	-0.191	-0.325	-0.903	t (2-tail)
0.813	0.743	1.293	1.728*	1.954*	2.255*	2.33*	-0.782	t (1-tail)
1.332'	1.121	1.361'	1.623'	1.732*	1.856*	1.817*	-1.052	t (1-tail)
0.047	0.141	0.891	1.409'	1.719*	2.144*	2.228*	-0.281	t (1-tail)
1.324	1.013	0.494	0.24	0.007	-0.334	-0.494	-0.806	t (2-tail)
p<0.05(*)			p<0.1(')					

Table 1. *T*-scores and probabilities at 95% confidence level or higher as tested between vowels. For reference, I marked with a prime (') those figures in the "all speakers" group at 90% level.

The direction of the Fo at the vowel onset is said to vary with tone types (Petersen 1986) as well as the voicing state of preceding obstruents (Hombert 1977a). In SH, the Fo of T3 starts from the mid or low-mid part of the Fo range, assumed corresponding to the neutral, rest position of vocal cords, then goes down to the lowest part before rising to mid or upper-mid. As for T1, the Fo onsets for different speakers do not move identically; they fall down straightforwardly in most of the male cases, but go up before falling in some female cases, especially F2 and F3.

There are no Fo differences between high and low vowels at the first (0%) and last (100% for T1 and 110% for T3) measurement points of both tones except a few cases: the Fo on *a* is 12 Hz or more lower than that on *i* and *u* at the 0% points in M1's and F3's Tone 3. The *a*-curve even ends higher than the other two here and there, eg, T1 of F2, F3, F5, M6, and T3 of F1, F2, F5, M5. The Fo differences are distributed from 5% of the duration to 80% for T1, and to 100% for T3, but differing from speaker to speaker. In T1, the three Fo tracings are close to one another for M1 and M3. For M2, the *a*-curve is close to the *u*-curve on first half part and close to the *i*-curve on the second half. *a* has lower Fo than *i,u* at 20% and 40% for the remaining three male speakers, and at 60% for M5. Female speakers all have lower Fo with *a* than with *i,u* from 20% to 60%, and still at 80% for F2, F3, and F4. In other words the Fo differences do not occur in T1 for M1 and M3, and they merge from the 40% point for M6, 60% for M2, 80% for F1, F5, and at 100% for F2, F4, and M4. In T3, there are four speakers, F3, M1, M4, and M3 (except at the 5% point), who have lower Fo with *a* than with *i,u* throughout the tone. IFo differences occur from the 20% point up to the end for F2, F4, and M2, from 40% for F1 and F5, and only at 100% for M5 and M6.

Larger absolute amounts of Fo differences occur for female than for male speakers. This can be seen from the following two panels of Fig 2.

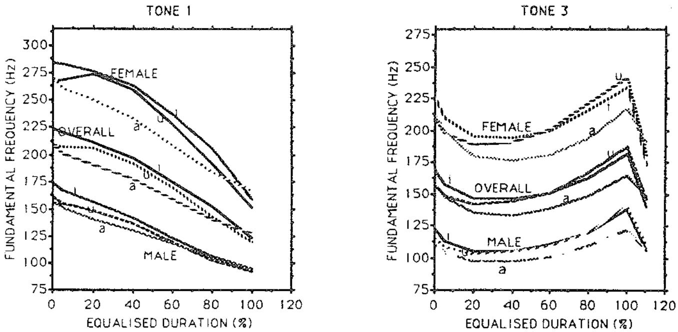

Figure 2. Average Fo curves of T1 and T3 on three vowels for female, male, and all speakers.

Female group - The Fo on *a* at 0% is between that on *i* and *u* in both tones. In T1, *a* runs lower than *i,u* from 5% (8Hz or more), maximises the difference at 40% (17Hz or more), then approaches *u* at 80% (7Hz or more), and even goes over both high vowels at the end. In T3, *a* remains in-between at 5%, and shows divergence from 20% (9Hz or more). The maximum difference occurs at 80% (22Hz or more). A slightly smaller difference remains at 100% (16Hz or more). *a* is also higher than *i,u* at the end of offshoot (110%).

Male group - In T1, although *a* is lower than *i* from 0-40%, it is very close to *u*. In fact *a* is not significant from *u* in the whole contour at 95% confidence level. Only at the 20 and 40% points *a* is lower than pooled *i+u*. Much more differences can be seen in T3; they exit in the whole stretch of the tone: 0-100%.

Overall - In T1, *a* is lower than *i* from 5% (19Hz) to 60% (16Hz), but not significantly different from *u* throughout the contour. It is only significantly lower than *u* at 20-40% points at 90% confidence level. *a* has lower Fo than pooled *i+u* again at 20 and 40%, the earlier part of the falling tone, ignoring the onset which is disturbed by the preceding consonant. In T3, *a* is lower than both *i* and *u* from 60-100% (and lower than *i+u* from 40%), the later part of the rising tone, ignoring the dropping offshoot.

The results of measurements and statistics from the data of all speakers are not in agreement with what Gandour and Maddieson (1975:249) found from a Thai speaker, namely that the IFo differences are "...

with low tone." In short, Fo differences tend to diminish in the lowest Fo range. In the high falling tone (T1), Fo differences disappear in the later duration part, which is entering the lowest Fo range. In the low rising tone (T3), Fo differences are least on the lowest Fo points, 20 and 40% of the duration. The onset of both tones and the offshoot of T3, of course, are excluded from consideration.

DISCUSSION

Many competing hypotheses have been advanced to account for the IFo during the last three decades. These theories can be divided into two categories: 1) those articulatorily intrinsically related to vowel height, such as acoustic coupling (Atkinson 1960), vertical tongue pull and hyoid upward movement (Ladefoged 1964), oral constriction (Mohr 1971), tongue retraction (Ewan 1979), mandible position (Zawadzki & Gilbert 1989), 2) those not neccesarily articulatorily associated with the vowel height. The latter can be further divided into two sub-sets: 2a) articulatory activities, eg, (vertical tongue pull and) the tension of the soft tissues in larynx (Ohala 1977), (horizontal tongue pull and) cricothyroid activity (Honda 1983, Vilkman et al. 1989, Dyhr 1990), respiratory drive (Gandour & Weinberg 1980), and 2b) perceptual compensation (Hombert 1977a, Silverman 1984).

The data given above are unfavourable to set 1 theories since during producing a glide tone, no matter on high or low vowels, the oral tract and the tongue position remain unchanged, thus the formant pattern, assumed to result from supraglottal configuration, remains unchanged, but the Fo differences among vowels have changed. There should be other factors which induce these changed Fo differences. Our results, however, is compatible to set 2a theories, provided the tension of the muscles or membranes involved is not done through the vertical or horizontal tongue pull. The reason is that during the production of a glide tone, intrinsic or extrinsic laryngeal muscles or membranes can be changed in the tension, and subglottal air pressure (P_s) as well, if it really affects the IFo. These changes will certainly influence the Fo on either high or low vowels, thus affect the IFo differences.

It is still controversial whether P_s contributes to IFo. Vilkman et al (1989) claim that the role of P_s is negligible. Gandour & Weinberg (1980) take P_s as a principal factor. Hombert (1977b) considers it as a significant role working together with laryngeal muscles. Intensity does correlate positively with Fo (Humbert 1977b, Zee 1978), but that does not necessitate the conclusion that P_s is responsible for Fo. There may be an overall tension in all vocal tracts which simultaneously brings about the higher P_s and higher tension of laryngeal muscles, the former resulting in higher intensity, and the later higher Fo, both of which co-occur in the case with higher IFo differences. Or, as Ohala (1978) suggests, both P_s and Fo are heavily influenced by laryngeal activities.

Our data can be explained from the view of set 2b hypotheses. I speculate that the vowel Fo differences are due to active changes in vocal cord tension and P_s, and that it is not an intrinsic, automatic effect caused by vowel height, but is purposeful. This is superficially reasonable because the vowel Fo differences occur on the parts of the glide tones with both higher Fo and intensity. These parts are supposed to carry more important linguistic information than the other parts. The speaker intentionally raises the Fo on *i* and *u*, or lowers that on *a*, in order for the listener to get the impression of equal pitch level (Hombert 1977a). This speculation brings about two predictions: 1) Since the distinctive features of two contrastive glide tones of the same direction are located at the higher part of Fo range, two contrasting falling tones must have different onsets, eg, HL vs ML, or HM vs ML, but not HM vs HL, and two distinct rising tones must have differing offsets, eg, LM vs LH, or MH vs LM, but not LH vs MH, other phonation types keeping constant. 2) Vowel Fo differences should be present in all contrasting level tones since they all carry distinctive information. A brief survey of some hundred Chinese dialects reveals that the first prediction is tenable. Prediction 2 is testable in languages with two or more distinct level tones.

CONCLUSION

1) IFo is found in complex tones. 2) IFo occurs neither only on the peak point nor the entire stretch of the glide tones, but at the higher part of the Fo range. 3) IFo at that part is statistically significant. 4) These results are best explained in perception terms.

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