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Cantonese tonal behaviour in compatible and conflicting tonal environments.

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1 Prediction

In Flynn (2001) we saw the results of our investigation of the phonetic variation of the six individual tones when undergoing tonal coarticulation in two-tone sequences. The carryover effect is greater than the anticipatory effect and the modification of the slope is concentrated in the area of tonal transition. In respect of slope, in the domain of timing, there is a transition period which covers a quarter of the duration of the preceding tone and 25 percent of the duration of the following tone. A tone ends as an offset transition modified towards the following tone, and a tone begins with an onset transition built on the foundation of the preceding tone. The section of the tonal body not adjacent to another tone has found the right place to settle and is not much affected.

One would like to know what the tonal contour would become if it had adjacent tones at both ends. If a tone is modified at each end of its contour to about a quarter of its duration, can it maintain its distinct identity? The present experiment attempts to examine tonal behaviour when the tone is in the middle position of three-tone sequences where the contexts are 'conflicting' and 'compatible'.

1.1 Defining compatible and conflicting tonal environments

In the case of three-tone sequences, we expect that the target tone in the middle syllable of the three tones has its onset modified by the preceding tone and its offset modified towards the following tone. We expect the target tone to be modified more when it is in a conflicting tonal environment than in a compatible tonal environment, as discrepancies of the F_0 value between the tones coming into contact is greater in a conflicting context than in a compatible context. The terms 'conflicting' and 'compatible' tonal environment are adopted from Xu (1994: 2241): "A 'compatible' context is an environment in which adjacent phonetic units have identical or similar values along the phonetic dimension under scrutiny. A 'conflicting' context is an environment in which adjacent phonetic units have very different values along that phonetic dimension." We treat the item, /tʰi:n^1 ji:n^4 wa:n^1/ (a natural bay), for example, as being in a conflicting tonal environment, where the tonal boundaries between the first and the second syllable, and between the second and the third syllable are the boundaries between a high offset tone and a low onset tone, and between a low offset tone and a high onset tone, respectively. The F_0 values of those onsets and offsets are very different. In contrast, the item /tɕʰɐw^1 ji:n^1 joŋ^1/ (an old man smoking), for example, we treat as being in a compatible tonal environment, where the tonal boundaries between the first and the second syllable, and between the second and the third syllable are boundaries between onsets and offsets whose F_0 values are very close.

Fig. 1. Examples of tones in the middle syllable of compatible tonal environments.

	Compatible	
_ / ‾		‾ ‾ ‾
/m^4 ji:n^2 ŋa:m^1/		/tɕʰɐw^1 ji:n^1 joŋ^1/
(not perform correctly)		(an old man smoking)

Fig. 2. Examples of tones in the middle syllable in conflicting tonal environments.

Conflicting	
¯ / _	_ ¯ _
/tɔː[1] jiːn[2] jyːn[4]/	/fɔːŋ[4] jiːn[1] muːn[4]/
(lots of performers)	(smoke preventing door)

When a tone occurs in a compatible tonal environment, we expect its canonical tonal shape to be able to stretch fully. Therefore, in the case of /tɕʰɐw[1] jiːn[1] joŋ[1]/ (an old man smoking), we expect the tonal contour of /jiːn[1]/ to keep a fairly level shape at a high F_0 level. In contrast, when a tone occurs in a conflicting tonal environment, we expect its canonical form to change at both ends. Therefore, in the case of /tʰiːn[1] jiːn[4] waːn[1]/ (a natural bay), we expect the tonal contour of /jiːn[4]/ to become concave where both its low ends are pulled up by the high pitch of the adjacent tones; and in the case of /fɔːŋ[4] jiːn[1] muːn[4]/ (smoke preventing door), we expect the tonal contour of /jiːn[1]/ to become convex where both its high ends are pulled down by the low pitch of the adjacent tones.

1.2 Coarticulation in compatible and conflicting tonal environments

As discussed in Flynn (2001), we believe that the articulators never move from one static state to another, and never finish one sound completely before producing the next in connected speech. Instead, they create an area which is not completely characterised as the preceding sound nor the following sound, but is a transition which allows the articulators to move from one state to another. This transition, where the gestures may overlap in time, is called coarticulation. But in a string of tones in speech, the duration of one syllable can be very short and it may have a few vocal pulses only. The crucial question is whether, in such a short time, the articulators responsible for F_0 control - the vocal folds - can increase (or decrease) the rate of vibration from one tone to another without losing the phonetic characteristic of the tone which the speaker is supposed to convey - i.e., which the articulators actually intend to articulate.

2 Procedures

2.1 Material

The selected target syllable is /jiːn/, which has special advantages in terms of: (a) voicing through the whole syllable in order to realise the tonal contour throughout the syllable from beginning to end; (b) like formants between /j/ and /iː/ avoiding fluctuation in tonal contours caused by different formants from different vowels; (c) being one of the few syllables which not only can carry six tones but also have the possibility of combinations of three-tone sequences as actual expressions. Sonorants are chosen for the first and the third syllables at the syllable boundaries with the target syllable in order to ensure that voicing continues throughout the syllable boundaries.

Only the onset of T1 satisfies as the maximum high onset at the tonal boundary and only the offsets of T1 and T2 satisfy as the maximum high offset at the tonal boundary. T4 serves as a low onset and low offset at the tonal boundaries. (In order to pair up the low-high-low combination for the target T1, T5 is used as the substitute for T4 serving as the low tone onset. The offset of T6 is the penultimate lowest and the offset of T4 is the lowest, thus both T4 and T6 are used for the first syllable in three-tone sequences.) Therefore, only T1, T2 and T4 are used as target words in the conflicting tonal environments. The combinations of three-tone sequences chosen in conflicting tonal environments are listed as below.

Fig. 3. Examples of T1, T2 and T4 in conflicting tonal environments.

Tone 1	Tone 2	Tone 4
T4-T1-T4 (_ ¯ _)	T2-T2-T4 (/ / _)	T1-T4-T1 (¯ _ ¯)
T4-T1-T5 (_ ¯ /)	T1-T2-T4 (¯ / _)	T2-T4-T1 (/ _ ¯)

For their compatible counterparts, T1 and T4 can be put in identical-tone sequences of trisyllables, i.e., T1-T1-T1 (¯ ¯ ¯) and T4-T4-T4 (_ _ _). T2 is placed adjacent to the high onset T1 and the low offsets T4 and T6 (i.e., T4/T6-T2-T1, (_ / ¯)). Apart from these, we also investigate T2, T3, T5 and T6 as the middle syllable of identical tone trisyllables, i.e., T2-T2-T2, T3-T3-T3, T5-T5-T5 and T6-T6-T6, as a by product of the experiment. Placing the target tone in the middle syllable of a three-tone sequence is believed to be optimal for showing coarticulatory effects since tonal coarticulations appear to be restricted to contiguous tones only (Potisuk *et al* 1997 and Shen 1990).

2.2 Speakers and recording

The trisyllables used in this investigation are actual expressions (i.e., make sense to native speakers) and are isolated from other neighbouring items. The informants JCCF, JHDG and LTHJ, all native speakers of Cantonese born in Hong Kong and students at SOAS, read the designed item lists, with three repetitions, in a sound proofed booth at SOAS.

The recording was made with a laryngograph device. The laryngograph recordings can be displayed as waveforms and spectrograms in both PCLx SPG and the Speech Workstation (SW) software packages; F_0 contour, Lx waveform and closed quotient contour (Qx) can be derived from the laryngograph trace and displayed simultaneously in the SPG. All tokens are digitised at a 10 kHz sampling rate. The method for segmentation is conventional. All six tones were used in the investigation. F_0 values are taken from five points in the target tones: the onset point, the mid point, the offset point, and the points at a quarter and three quarters of the total duration. 378 tokens in total were involved (42 syllables x 3 repetitions x 3 informants) and a total of 1890 F_0 values (5 measurement locations x 378 tokens) were taken into computation.

Each syllable is normalised for duration on a percentage scale and all raw F_0 data are normalised. By such normalisation, F_0 contours may be compared across speakers. F_0 contours were smoothed by curve-fitting for display purposes only.

3 Results and Discussion

3.1 T1, T2 and T4 in conflicting and compatible tonal environments

The following figures 4-8 illustrate T1, T2 and T4 in conflicting and compatible tonal environments. Figures 4–6 are arranged by tones and figures 7–8 are arranged by tonal contexts.

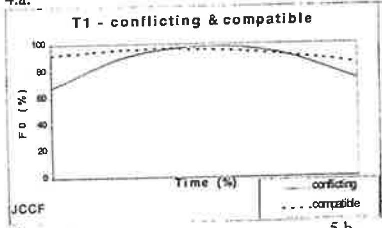
As expected, a tone is modified at both ends by its preceding and following adjacent tones. This confirms that anticipatory and carryover effects are both present in the tonal contour when a tone is in the middle syllable of a three-tone sequence.

3.1.1 Gravity
In terms of slope, T1 becomes a big arch, T4 a big fall-rise shape and T2 a right-oriented slantwise "ʃ" shape in conflicting contexts; T1 keeps its canonical level shape, T4 becomes a fairly gentle curve and T2 a bending " / " line in compatible contexts. Recall that in two-tone sequences (see Flynn 2001), the tonal boundary of T1-T1 always exhibits a dip, the tonal boundary of T4-T4 is always higher than the valley of the first T4 and the offset of the second T4. All three tones maintain their identity in around the central portion (i.e., in the area of the second and third quarters of the tonal duration) of their tonal contour (the central point area for T1, left of centre for T4 and right of centre for T2) while they allow a quarter of the duration from the onset and a quarter of the duration back from the offset to alter their heights or directions in favour of assimilation from/to their adjacent preceding and following tones. The central portion of the contour, where tones keep their identity, is the least affected by accommodation from/to the preceding or the following adjacent tones in terms of height or slope. We call it the gravity of the tone. Every tone has its own gravity which has a strong power to resist modification from any direction and to maintain its characteristic height and slope.

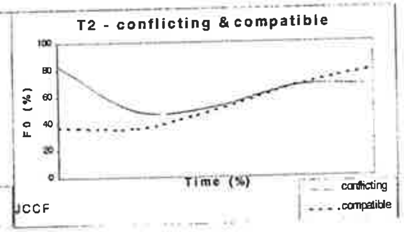
Fig. 4(a-c). Mean F_0 contours of T1 in the middle syllable of 3-tone sequences produced by JCCF, JHDG and LTHJ, respectively.

Fig. 5(a-c). Mean F_0 contours of T2 in the middle syllable of 3-tone sequences produced by JCCF, JHDG and LTHJ, respectively.

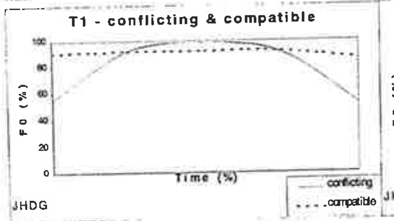
4.a.



5.a.



4.b.



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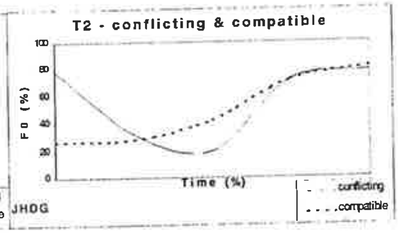
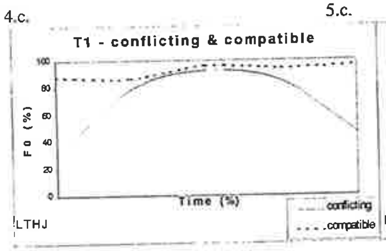


4.c.



5.c.

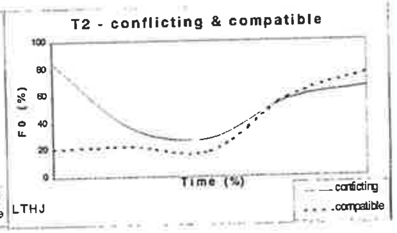
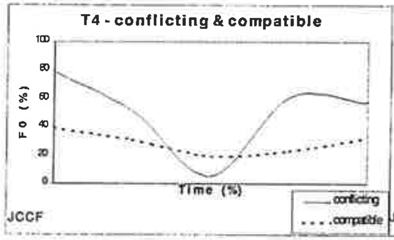
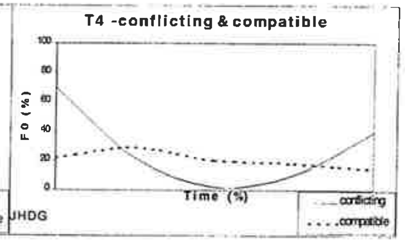


Fig. 6(a-c). Mean F_0 contours of T4 in the middle syllable of 3-tone sequences produced by JCCF, JHDG and LTHJ, respectively.

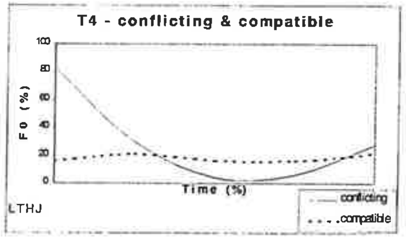
6.a.



6.b.



6.c.



3.1.2 Tone 1
There are similarities in the central portions of the two contours of T1 when occurring in conflicting and in compatible contexts. First, T1 keeps its fairly level contour in the central portions both in conflicting and compatible contexts. Second, the height of the central portion of T1 in compatible contexts is very close to that in conflicting contexts. The two contours almost overlap. This suggests that their tonal identifications are maintained in the central portion of their tonal bodies, regardless of the considerable modifications in the two quarters at each end.

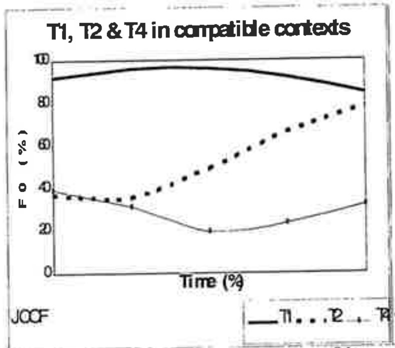
In conflicting contexts, T1 bows down its head in order to connect to the low offset of the preceding tone and bends its tail in order to link up with the low onset of the following tone. Therefore, the slope appears as a convex as predicted. However, the degree of the 'bending' at both ends is not equal. The offset does not have to be lower than the onset, as one might have predicted in view of the declination effect. In fact, the offset is higher than the onset, i.e., the onset is modified more than the offset. This may be due to the fact that the height of the offset of the preceding T4 is much lower than that of the onset of the following T4, as a result of coming at the end of a fall. Thus, the target T1 has to drop its onset more than its offset.

In compatible contexts, T1 appears as a fairly straight level line. Its offset is lower than its onset for informants JCCF and JHDG. This coincides with the tonal behaviour of T1 in the two-tone sequence - the end (i.e., either the head or the tail) of the tonal contour dips a little when it comes in contact with another preceding or following T1 (see Flynn 2001). Comparing the pitch range of the onsets and the offsets between the compatible and the conflicting contexts, the pitch range of the onsets is obviously wider than that of the offsets. The onsets are modified more than

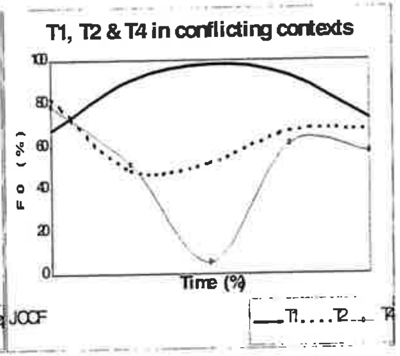
Fig. 7(a-c). Mean F_0 contours of T1, T2 and T4 in the middle syllable of 3-tone sequences of compatible tonal contexts produced by JCCF, JHDG and LTHJ, respectively.

Fig. 8(a-c). Mean F_0 contours of T1, T2 and T4 in the middle syllable of 3-tone sequences of conflicting tonal contexts produced by JCCF, JHDG and LTHJ, respectively.

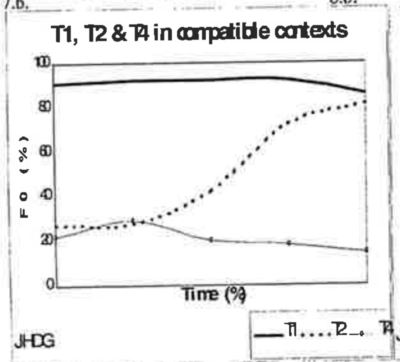
7.a.



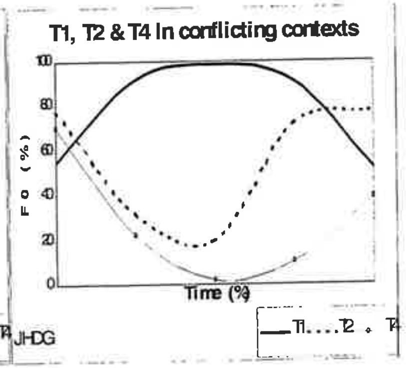
8.a.



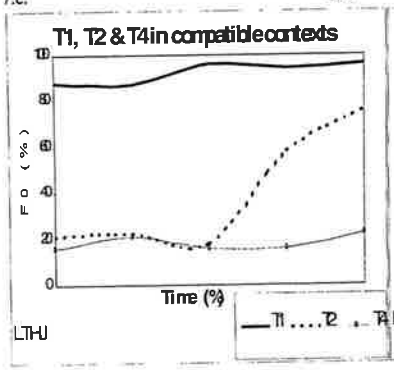
7.b.



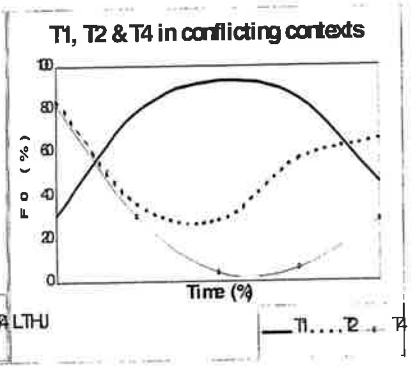
8.b.



7.c.



8.c.



the offsets. The same is true of T2 and T4. This finding strongly supports the claim in Flynn (2001) that the carryover effect is greater than the anticipatory effect in tonal coarticulation.

3.1.3 Tone 2

In both the tonal contexts (i.e., compatible and conflicting) T2 maintains its rising shape in the third quarter of the tonal duration. This part is called the gravity, as the tone's characteristics are concentrated here. The slopes from its onsets, extending to over a quarter of the duration, differ in direction as between the two contexts. In conflicting contexts, the onset starts from high then heads down to the lowest point of the contour at the second quarter of the duration. From the lowest point, the contour starts rising and more or less overlaps with the third quarter of the duration of the compatible-context contour. When it reaches the last quarter of the duration, the slope ceases its continuous rise and assumes a fairly level shape in order to link up with the low onset of the following tone.

In contrast, in compatible contexts the first quarter of the duration of the contour has a fairly level shape because the onset is in contact with a low offset tone. In the last quarter of the duration the contour is a continuous gentle rise until the offset which is in contact with a high onset tone. Again, the preceding tone exerts greater influence on the target tone than does the following tone. The difference of F_0 value and slope is greater in the first quarter of the duration than in the last quarter of the duration in both conflicting and compatible contexts. The offsets of the two contours in the two contexts are close in F_0 value while the onsets of the contours are far apart. This indicates that the tone's preservative power is greater at the offset than at the onset.

In conflicting contexts, the F_0 value is higher at the onset. In fact, the peak F_0 after rising is below the F_0 value of the onset. This is also attributed to the preservative power at the high offset of the preceding tone, which lifts up the onset of the target tone to a considerable extent. This is very different from the pictures shown in Flynn (2001) in respect of tonal behaviour in two-tone sequences or in monosyllables. In those circumstances, its F_0 maximum always coincides with the rising peak and is always at (or very near) the offset whether it is the preceding tone or the following tone or is isolated, and whether it is adjacent to a high or a low tone.

We note two characteristics of T2 when occurring in a conflicting context. One is that the rising peak can occur much earlier (about 25% of the duration before the offset) when followed by a tone which has a falling movement at the beginning. Another is that the F_0 value of the onset can be higher than that of the rising peak. If we take the tonal environment into account, we need not be surprised at this new phenomenon. When a T2 is in a conflicting environment, its low onset is pulled up by the preceding tone. However, it has to struggle to preserve its rising feature - rising from low to high. Therefore, it quickly falls down to a low position to prepare for a pre-rise. The level of this fall differs across the informants, but the level of the rise reached is uniform across informants. After the rise, the two contours (i.e., in conflicting and in compatible contexts) intersect at around the end of the third quarter of the tonal duration. The contour successfully keeps its rise at the third quarter of the tonal duration, but the rising peak is comparatively earlier due to the fact that its offset is pulled down by the oncoming fall from the following tone. It seems that the shape of a contour is triggered by the forces from both directions - from left to right and from right to left.

In discussing the intonation phenomenon in Hausa, Inkelas & Leben (1990: 22) point out that "a primary low tone triggers the lowering of the pitch register in which all following tones in the phrase are realised" and this is called downdrift. In other words, the mechanism is that the left triggers the right. In discussing the assimilatory process in intonation in Hausa, they point out that a low tone can raise the preceding high tone, or it can raise itself if no high tone follows. The former is called high raising, the latter low raising. In other words, these mechanisms work from the right to the left. In discussing the timing of prenuclear high accents in English, Silverman and Pierrehumbert (1990: 102) describe how a high accent peak can be shifted earlier by the following low accent. This also implies that it triggers from right to left.

We argue (see Flynn 2001) that tonal assimilatory effects in Cantonese occur in both directions and an earlier tonal peak is likely to be pushed up by the oncoming fall. That the F_0 maximum within a T2 is not at the rising peak but at the onset in a conflicting context, is simply because the contour of a tone is affected from both directions. The left force pulls up its onset and the right force pulls down its offset. The left force is stronger as shown in its lifting the onset of the target T2 which is higher than the offset of the target T2 which is pulled down by the right force. Recall that the onset of a T2 is much lower than its offset in its canonical form (see Flynn 2001). If it did not persist in maintaining its rising characteristic, it would be straightened and become a falling contour. When it persists in rising, it is being pushed by the oncoming fall from the right force and anticipates by assimilation to the low onset of the following tone. As a result, the strength of the rise is too weak to extend to the offset and has to give way - the actual rising peak is realised much earlier before the offset.

3.1.4 Tone 4

For T4, the two contours (i.e., in conflicting and in compatible contexts) differ from each other greatly in respect of height and slope. However, in both their gravity keeps in the left centre and remains low. In compatible contexts, the contour falls slightly to the centre point before it rises gently towards the offset for informants JCCF and LTHJ. The tone cannot persist in falling all the way through for the two informants because its onset is pulled down by the preceding low offset and it has to anticipate in linking up the following tone (e.g., a T4) whose onset is somewhat higher than the inherent offset of T4. For informant JHDG, the tonal contour falls continuously after the centre point.

In the case of a string of low falling tones, i.e., in compatible contexts, we can expect that the onsets are successively lower in F_0, reflecting intonational declination or tonal coarticulation (the onset's absolute F_0 is dragged down by its preceding low offset tones). However, we cannot imagine that this could happen in a linear scale: for example, if a fall of a low falling tone is 80Hz starting at 200Hz, the end of the third low falling tone will end up below 0 Hz. Also, they do not seem to work like downdrift as in Hausa. They display a gentle concave contour in the central portion, therefore they leave lots of space in F_0 for the following low falling tones - they preserve their falling shape at the second quarter of the tonal body in spite of a low start before giving way to modification by the following tone. As a result of falling, the centre point of the target T4 is lower than the starting point of the second quarter of the duration - the inherent pitch pattern. The onset of the target T4 is lower than the onset of its preceding T4 as a result of triggering by the left force; the offset of the target T4 is lower than the offset of its preceding T4 because it falls from an already low start, followed by triggering by the right force. Apart from this, the gradual

downward trajectory in a string of low falling T4 can be seen as an effect of the universal declination phenomenon.

When T4 is in conflicting contexts, the contour falls steeply to the centre point of the tonal body before rising towards the offset, pulled up by the following high onset tone. The whole contour displays a big V shape or a hanging hammock with someone sitting right in the centre. The two contours (i.e., in conflicting and in compatible contexts) are similar in that their fall is bigger than their rise and their centre points are close in F_0 value.

3.1.5 Summary

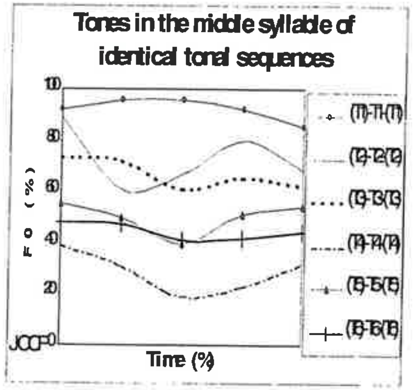
The first and the last quarter of the tonal duration are modified towards the adjacent tones both in conflicting and in compatible tonal contexts. The modification appears heavier at the first quarter of the tonal duration and in conflicting tonal contexts. The F_0 values at the central portion (centre area for T1, centre left for T4 and centre right for T2) of the two contours (i.e., in conflicting and in compatible contexts) of a tone are very close. That is where the core of the gravity of the tone sits. It is where the tone defines its identity.

3.2 Tones in the Middle Syllable of Identical-Tone Trisyllabic Utterances

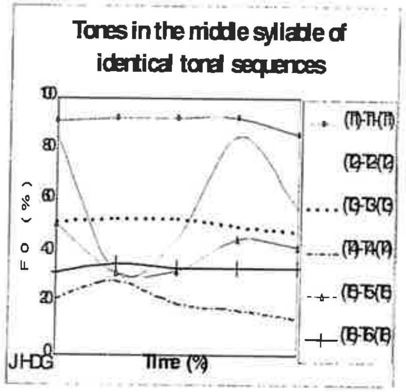
The following figures 9(a-c) illustrate the six tones in the middle syllable of the trisyllabic identical tonal sequences.

Fig. 9 (a-c) Mean F_0 contours of each of the six tones as they occur in the middle syllable of a sequence of three identical tones, produced by JCCF, JHDG and LTHJ, respectively.

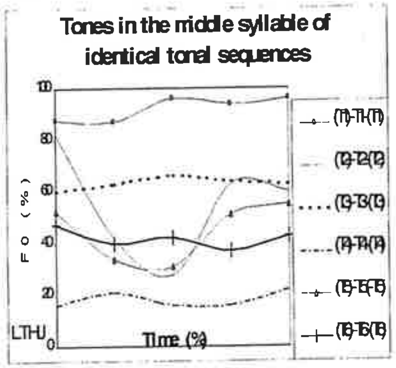
9.a.



9.b.



9.c.



Regarding the point about the characteristics of T1 and T4 being in the middle syllable of identical-tone trisyllabic utterances, see the discussion in 3.1.2 for the former and 3.1.4 for the latter on these two tones occurring in the middle syllable of compatible tonal environments; regarding the point about the characteristics of T2 being in the middle syllable of identical-tone trisyllabic utterances, see the discussion in 3.1.3 on this tone occurring in the middle syllable of conflicting tonal environments.

3.2.1 Tone 3 and Tone 6

The other two level tones, i.e., T3 and T6, can be taken as the tones in the middle syllable in compatible tonal environments when they are preceded and followed by the identical tones in three-tone sequences. Their onsets and offsets come in contact with the offsets of the preceding tones and the onsets of the following tones whose heights are similar to their own onsets and offsets.

These two level tones preserve their canonical shape and relative height. They maintain their level contours and their distinctions in height from one another and from the other level tone, T1. These are consistent with their tonal behaviours in two-tone sequences as shown in Flynn (2001). In the two-tone sequences T3-T3 and T6-T6, all tonal contours exhibit a sudden slight fall at the central portion while remaining downward as a whole. The gravity of T3 and T6 remains in the central portion of the contour. All level tones display a downward trajectory which is consistent with the canonical form and the forms in two-tone sequences.

3.2.2 Tone 5

The gradient of T5 rises gradually (in comparison with the high rising T2 with sharp rising gradient). T5, when it is preceded and followed by identical tones in three-tone sequences is considered to be in conflicting tonal environments. When it comes in sequences of identical tones, its onset will conflict with the high offset of the preceding tone and its offset will conflict with the low onset of the following tone.

T5 maintains its small fall and gently rising shape along with its particular height position. In terms of height, its rising contour in the last half of the duration remains somewhere between T4 and T3, which is consistent with its canonical form and its forms in two-tone sequences. Its fall extends from the onset to the midpoint of the tonal body before rising for informants JCCF and LTHJ. The steepest slope is the third quarter of the tonal duration, which is just the beginning of the rising part. The highest F_0 remains at or near the offset after rising. However, the second quarter of its tonal body changes from rising in the canonical form to continuous gentle falling in the experiment. Recall that the second quarter of the tonal duration does not always remain rising when it is in two-tone sequences (see Flynn 2001). Therefore, only the third quarter of the contour is where the gravity of tone falls. The gravity shows the identity of the tone - a gentle rise after a fall, where the beginning of the midpoint of

the contour is very close to the midpoint of T6 in terms of height and remains rising during the third quarter of the duration.

There are some similarities between T5 and T6 both in overall height and contour in the data of informant JCCF. What makes T5 differ from T6 is the relatively steep rise of T5 which makes T5 stand out from T6 particularly at the third quarter of the tonal duration. Moreover, the pre-rise fall in the first half duration of T5 also distinguishes it from T6 which is comparatively level, in the data of the other informants.

3.2.3 Declination

Across the informants, the rise in F_0 of the target T2 is much less compared with that of its preceding T2 and that of its following T2. The tonal peak of the target tone is lower than that of its preceding T2 (see figures 12). It is not surprising that the tonal peak of the last tone is higher than that of the target tone for informants JCCF and LTHJ, because it has more space to stretch itself as there is no force from the right to influence it. Even so, it is lower than the tonal peak of the first tone. The trend of the tonal contour, successively lower in pitch in trisyllabic identical-tone sequences, also appears in T3, T4 and T5 (see figures 10, 11 and 13). This may be attributed to the universal declination of intonation. Again, no intonation control attempt is made in the present experiment. The fact that a declining trajectory of the level tones, the falling tone and the rising tones occurs in all monosyllabic, disyllabic and trisyllabic words may indicate that the universal declination of intonation occurs in short utterances generally, whatever their length.

3.2.4 Sequences of T4-T2-T1

One would like to know what the contour will be if the tonal sequences are low-start but high-end, for instance, the tonal sequence T4-T2-T1. Will the low T4 trigger the lowering of the following tones as with the downdrift or downstep in many African languages? As a by-product in the present experiment, the following figures give evidence that the low-to-high tonal sequences in Cantonese act differently. T1 does not lose its high pitch position, nor does T4 lose its low pitch position. The rising peak of T2 is at offset and the maximum F_0 value of the three tone sequences is located in the middle portion of T1. (Alternatively, it is located at the first quarter of the duration of T1 for informant JHDG as he exhibits a fall variant for T1 here.)

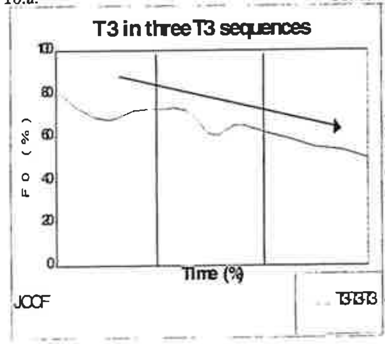
3.2.5 Six Tone Contrast

Vance (1977) synthesised 64 different pitch patterns by allowing each of the 8 frequencies, as onset frequency, to combine with each of the 8 frequencies, as offset frequency using the syllable /jɐw/ to identify tones. We would like to use results from Vance's perceptual experiment to support our claim. Here we reconstruct his identification results in which the value of each case is taken as the value indicated by over fifty percent of his subjects, to draw a figure of the six tonal contours. The subjects, as native speakers, tended to tolerate variations of pitch for each tone. As a result, some tones are identified in a wider pitch range. For example, T6 is associated with between 92 to 206Hz for the onset F_0 and between 92 to 154Hz for the offset F_0. In these cases, I take the middle F_0 value 149Hz for the onset and the middle F_0 value 123Hz for the offset. We summarise his identification results in figure 15 below from which we then reconstruct the tonal contours based on his response data and the method mentioned above.

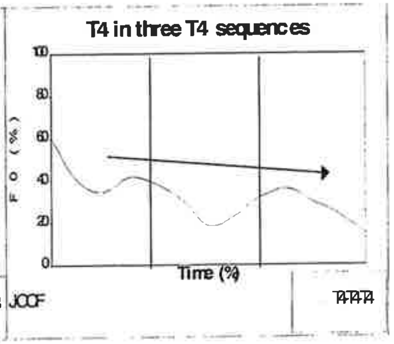
Fig. 10(a-c). Mean F_0 contours of T3 occurring 3 times consecutively, produced by JCCF, JHDG and LTHJ, respectively. Two vertical lines inside the figure indicate the tonal boundaries & the arrow indicates the declining F_0 contour.

Fig. 11(a-c). Mean F_0 contours of T4 occurring 3 times consecutively, produced by JCCF, JHDG and LTHJ, respectively. Two vertical lines inside the figure indicate the tonal boundaries & the arrow indicates the declining F_0 contour.

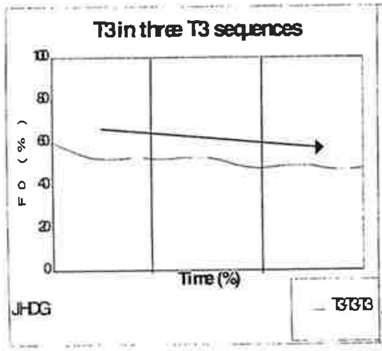
10.a.



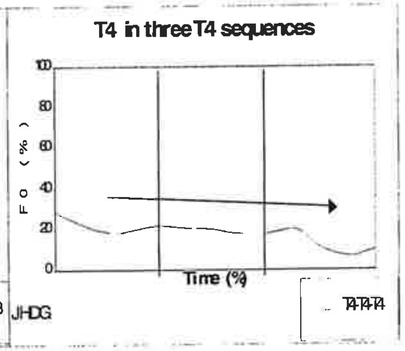
11.a.



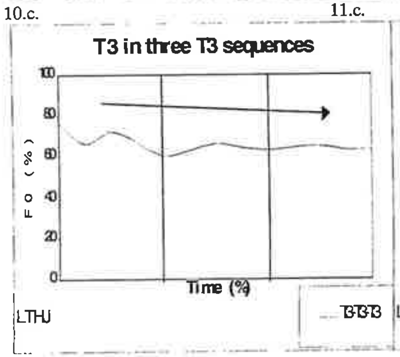
10.b.



11.b.



10.c.



11.c.

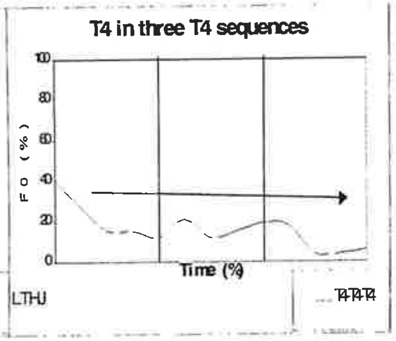
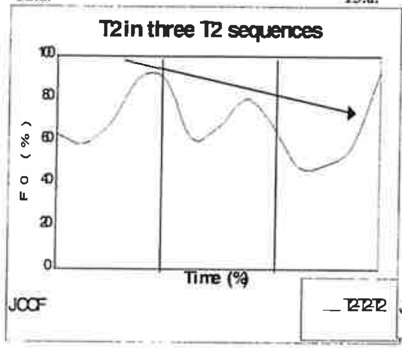


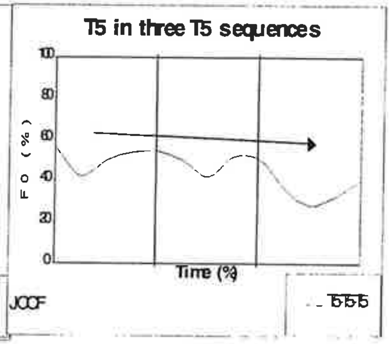
Fig. 12(a-c). Mean F_0 contours of T2 occurring 3 times consecutively, produced by JCCF, JHDG and LTHJ, respectively. Two vertical lines inside the figure indicate the tonal boundaries & the arrow indicates the declining F_0 contour.

Fig. 13(a-c). Mean F_0 contours of T5 occurring 3 times consecutively, produced by JCCF, JHDG and LTHJ, respectively. Two vertical lines inside the figure indicate the tonal boundaries & the arrow indicates the declining F_0 contour.

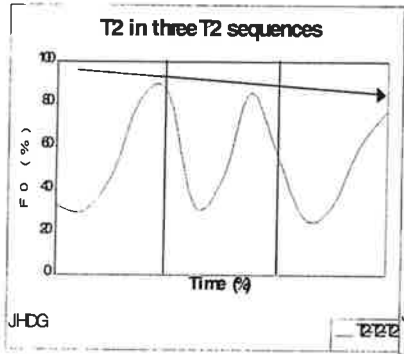
12.a.



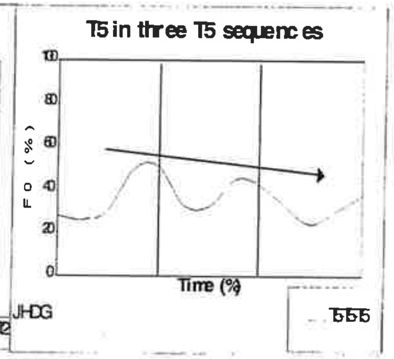
13.a.



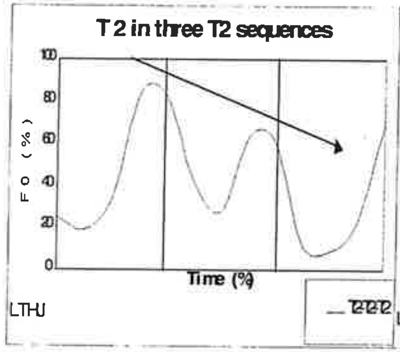
12.b.



13.b.



12.c.



13.c.

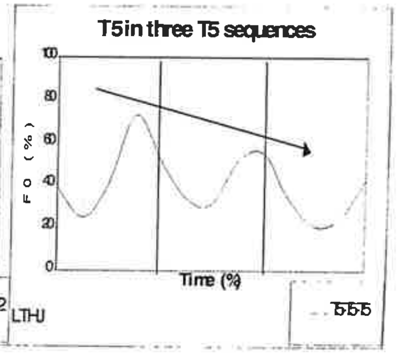
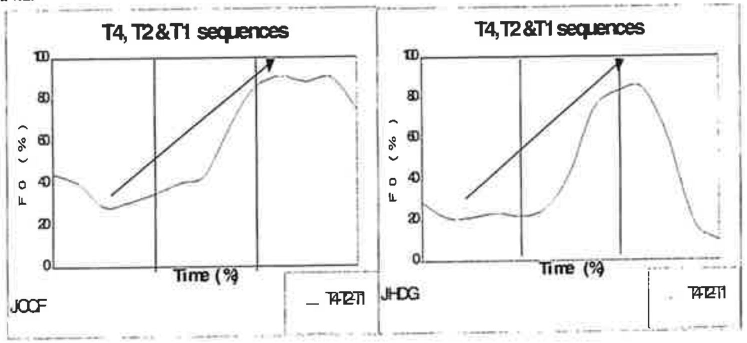


Fig. 14 (a-c). Mean F_0 contours of T4, T2 and T1 occurring consecutively, produced by JCCF, JHDG and LTHJ, respectively. Two vertical lines inside the figure indicate the tonal boundaries and the arrow indicates the rising F_0 contour.

14.a. 14.b.



14.c.

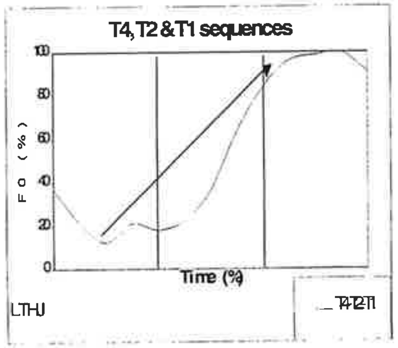


Fig. 15. Summarised response data from Vance (1977). Stimuli on which there was over fifty percent agreement (except T4 which was identified only nine times out of twenty). (cf. Cheung 1986)

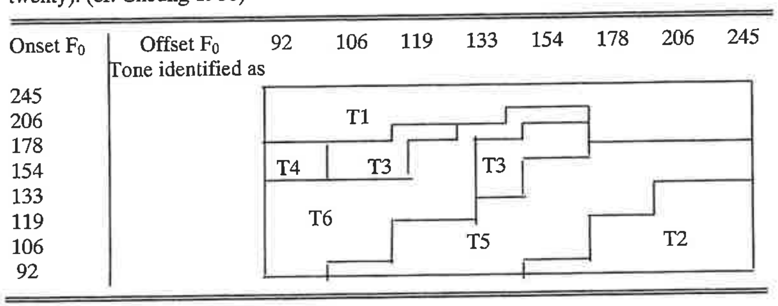
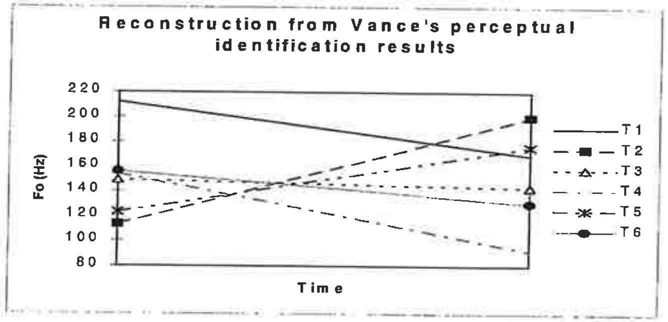


Fig. 16. Reconstruction from Vance's (1977) perceptual identification results. (See discussion above.)



The response results in Vance's experiment show that the tonal onsets tend to be crowded in the low F_0 range and the tonal offsets tend to spread out. The onset F_0 value is considered less relevant than the offset F_0 value in the identification of Cantonese tones. The present experiment further claims that the most important element in representing the identity of tones is the gravity of tones. The gravity is never located at the beginning or the end portions of the tonal body but in the central portion. The beginning and the end portions of the tonal body need to make considerable adjustments to accommodate to the adjacent tones, and this can result in a change in their height and direction. This leads listeners to tolerate a wide pitch range at the beginning and the ending of a tone. The reconstructed figure shows clearly that the height hierarchy and the direction of the slope coincide with those in the monosyllables shown in our experiment in Flynn (2001). Moreover, if our hypothesis about less relevance in the beginning and ending portions turns out to be right, we will find that the height hierarchy and the direction in the central portion of the tonal contours in the reconstructed figure not only coincide with those in the monosyllables shown in our experiment in Flynn (2001) but also coincide with those in the gravity of the middle syllable in the three-tone sequences shown in the present experiment. We can safely say that the height and slope of tonal contour in the gravity are both important in terms of tone production and perception in Cantonese.

3.3 Summary

A tone maintains its identity in terms of height and slope in its gravity - which is located in the central portion of the tonal body - while allowing the two ends to be modified in terms of height and slope in order to adjust to the preceding and following adjacent tones. The location and the characteristics of the gravity of the six tones when in the middle position of a three-tone sequence are listed below. They coincide with the characteristics of the six tones in monosyllables and disyllables.

Table 1. The location and the characteristics of the gravity of the six tones.

	T1	T2	T3	T4	T5	T6
location	centre area	centre right	centre area	centre left	centre right	centre area
height & direction	high & level	high & rising	mid & level	low & falling	mid-low & rising	mid-low & level

The gravity is the least affected in accommodating to its adjacent tones. When a tone is in a conflicting tonal environment, its two ends (about a quarter of the duration from each end) are open to modification in terms of height and slope. When a tone is in a compatible tonal environment, its canonical form can be preserved to a greater extent, but does not remain exactly the same. This is due to the coarticulation occurring at both ends - a tonal contour is triggered by forces from both left and right. The central portion of the tonal body in compatible contexts draws close to and may overlap with the gravity of the tonal contour in conflicting contexts.

The carryover effect appears to be greater than the anticipatory effect. The modification in the first quarter of the duration is greater than in the last quarter of the duration. The declination effect interacts with tonal contour as shown in the downward trajectory of level tones, of the falling tones, and of the rising peaks of the rising tones when in sequences. These findings are consistent with the results obtained in the experiment on tonal behaviour in two-tone sequences (in Flynn 2001).

Appendix: list of trisyllabic utterances

1.	/tɕʰɐw^1 ji:n^1 joŋ^1/	smoke-old-man - old man smoking
2.	/pi:w^2 ji:n^2 ji:^{2}/	perform-perform-chair - chair used for performance
3.	/ɕɐw^3 ji:n^3 jɐn^3/	thin-swallow-print - print of thin swallow
4.	/tɕʰœ:ŋ^4 ji:n^4 le:ŋ^4/	long-prolong-age - prolong the life
5.	/jɐw^5 ji:n^5 jɛ:^{5}/	have-pot-thing - a pot of (food)
6.	/ta:j^6 ji:n^6 low^6/	big-expose-expose - expose to view
7.	/m^4 ji:n^2 ŋa:m^1/	not-perform-correct - not perform correctly
8.	/ta:j^6 ji:n^2 wa:n^1/	big-perform-bay - Big Performance Bay (place name)
9.	/pi:w^2 ji:n^2 jɐn^4/	perform-perform-people - performer
10.	/tɔ:^{1} ji:n^2 jy:n^4/	many-perform-person - many performers
11.	/hi:n^2 ji:n^4 wa:n^1/	obvious-look-bend - obviously bending
12.	/tʰi:n^1 ji:n^4 wa:n^1/	sky-look-bay - natural bay
13.	/fɔ:ŋ^4 ji:n^1 mu:n^4/	prevent-smoke-door - smoke blocking door
14.	/fɔ:ŋ^4 ji:n^1 jɐn^5/	prevent-smoke-addict - preventing smoking-addiction

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On sounds that like to be paired (after all): an acoustic investigation of Hungarian voicing assimilation

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1 Introduction[1]

In this paper we report on a pilot experiment designed to assess whether the process of regressive voicing assimilation in Hungarian applies in a categorically neutralizing manner, as implied by recent phonological analyses, e.g. Szigetvári (1998), Ritter (2000), Siptár & Törkenczy (2000), or whether it is better modelled as a gradient, phonetic rule (following Burton and Robblee 1997, Barry and Teifour 1999).

Our results, based on acoustic data from two speakers, indicate that Hungarian regressive voicing assimilation is not a neutralisation phenomenon. Whilst some assimilation in terms of phonetic voicing and the duration of the preceding vowels can be observed, underlying distinctions in obstruents targeted by the process are still detectable. In addition, we observe mismatches between the behaviour of voicing and segmental duration in obstruent clusters that contradict the predictions of a lexical feature analysis. As far as the lack of neutralisation and the behaviour of phonetic voicing are concerned our results are consistent with a phonetic approach to voicing assimilation. However, it is unclear how the effect of partial assimilation on the duration of vowels preceding obstruent clusters can be captured by a phonetic model.

The structure of our paper is as follows: in section 2.1 we provide an overview of Hungarian voicing assimilation as occurs in contemporary standard Hungarian, as described in reference grammars e.g. Kenesei, Vago & Fenyvesi (1998). Section 2.2 provides historical background, by investigating the evolution of voicing assimilation in Hungarian up to the earliest known descriptions of the phenomenon. In section 3 we outline 2 different models which have been used by researchers to capture voicing assimilation in various languages: lexical feature analyses and gradient, phonetic models. The predictions made by each type of model are explored. Our experimental methodology (speakers, stimuli, procedures etc) is outlined in 4.1, whilst in 4.2 we present our results. These are discussed in the concluding section of the paper. An appendix containing all raw data is to be found following the reference section.

2 3000 years of Hungarian voicing assimilation

2.1 21st century Hungarian voicing assimilation

Hungarian is a Uralic (Finno-Ugric, Ugric) language spoken by around 15 million people in Hungary and (as a minority language) in several of the surrounding states.

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