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GLOTTAL CREAK AS A MEANS OF SPEAKER DISGUISE[1]

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1. INTRODUCTION

In recent legal proceedings expert witnesses were called upon to establish whether it was possible to identify the speaker on a tape recorded message. A number of subjects had been identified and recorded for comparison with the disputed recording. This is a common scenario for a forensic phonetician. Hollien [11] shows that there are many obstacles in the way of proving conclusively that there is a match between two speakers. In order to make as sound a judgement as possible the forensic phonetician invariably employs a combination of careful listening as well as an acoustic examination of the disputed and known recordings (French [8, 9]). In the case which prompted this study a good quality audio recording of the disputed speaker's speech was available. However, it was immediately evident that the speaker was disguising his voice. He used primarily a form of vocal fold vibration known variously as glottal fry, pulse register or, as it is commonly known amongst British phoneticians, creaky voice (Crystal [5], Laver [20], and Ladefoged [19]).

This paper explores the nature of creaky voice and why it might be an effective speaker disguise. The difficulties in interpreting acoustic analyses of creaky voice will be considered. To test whether this type of disguise is particularly effective a study was carried out in which 10 speakers recorded speech samples with and without creaky voice. A test tape was compiled and played to 15 phoneticians and 12 non phoneticians. The listening task was far removed from the best-practice procedures used by forensic phoneticians when comparing recordings. Nevertheless the phoneticians achieved statistically significantly more accurate results than the non phoneticians.

These findings confirm the importance of using phonetically trained expert witnesses when analysing disputed speech material.

2. THE NATURE OF SPEAKER DISGUISE

The speech apparatus is remarkably plastic. it is common knowledge that speakers can change the way in which they habitually speak. They may do this deliberately if they are actors or mimics or they may do this quite unconsciously when expressing, for example, fear or anger. Unless speakers have some sort of pathology which inhibits the plasticity

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of the speech apparatus they can alter the rate, intensity and pitch of speech effortlessly. Speakers do this in order to express their intentions more accurately. It is easy for most speakers therefore to express surprise by, for example, changing the rate at which the vocal folds vibrate so that an unusually high pitch is produced. This is called falsetto voice. It is clearly different from the ordinary pitch range of individual speakers when they are speaking with their usual form of vocal fold vibration, usually called modal voice (Laver [20]). Other changes in the way in which the vocal folds vibrate can produce other voice qualities. Allowing rather more air than usual to escape between the vocal folds each time they open during the vibratory cycle. This type of voice quality, usually called breathy voice, is frequently associated with intimate conversations. Linking a communicative intention with a particular type of voice quality may depend upon a number of factors (Crystal [5]). However, speakers generally have little difficulty in selecting the appropriate modifications to the speech production mechanism in order to effect their communicative intentions.

If the speaker's intention is to disguise their usual form of speaking they have a considerable range of options. In addition to exploiting the variations in voice quality so far discussed, speakers can manipulate the shape of the resonant cavities above the vocal folds to alter the acoustic and perceptual quality of the resulting speech sounds. speakers may also modify their pitch, loudness and rate of speech. They may use a different pattern of pausing, or of pitch movement, or may choose to manipulate particular speech sounds so that, for example, "s" may be produced more like "sh" or "th". In addition to all these possibilities it is fairly straightforward to combine a number of these features. Of course it may not be particularly easy for a speaker to maintain some or all of the disguise consistently. Lapses in the disguise or features of the speaker's normal speech speech appearing through the disguise may enable the identity of the speaker to be established.

3. CREAK AND CREAKY VOICE AS A SPEAKER DISGUISE

3.1 The Phonetics of Creak

The speaker mentioned at the start of this paper was judged to be using a voice quality which was not usual for him. He was considered to be using primarily creaky voice though there were elements of breathy voice too. It was felt to be a disguise because creaky voice, while occuring in English, is never used throughout speech. Catford [3] describes the auditory impression of creaky vocal fold vibration as "a rapid series of taps, like a stick being run along a railing" (p.34). The nature of the phonetic events which produce this effect is less clearly understood than their perceptual effect. A number of accounts are reviewed in Laver [20]. The common factors in these are the relative thickness of the vocal folds, the relatively small amplitude of their vibration and the low subglottal air pressure initiating their vibration. The length of the vocal folds do not alter significantly during the production of creaky voice. Ladefoged [19] p.140 presents a photograph of the vocal folds in normal or modal vibration and in creaky voice vibration. This show clearly that, although the perceived pitch is low, the folds do not vibrate along their whole length. Moore, cited in Laver [20] presents evidence to suggest that the mass of the vibrating portion of the vocal folds is increased by means

of the ventricular or false vocal folds located just above the true vocal folds. The effect of this is to damp the movement of the folds.

3.1.1 Creaky Voice. The above description is further complicated by the observations of Abercrombie [1] that there can be a mixture of modal voice and creak. In his opinion there could be two parallel vibratory cycles, one related to creak and the other to modal voice. The combination may also be the result of rapidly passing from one vibratory mode to the other. The combination of creak and modal voice is called creaky voice. Although pure creak can be readily produced by most speakers if asked to make a single vowel sound, creaky voice is the voice quality used by many speakers of English when they, for example, signal that they are ending their speaking turn (Crystal [5]). In some of the subsequent discussions discrepancies between acoustic measurements in studies may be related to whether pure creak or creaky voice was examined.

3.2 The Acoustics of Creak
An important acoustic criterion for creak is considered to be the damping of a single vibratory pulse to between 42 and 44dB of its maximum amplitude and the ventricular folds play a significant role in achieving this result. Another important acoustic characteristic of creak is its low fundamental frequency. Laver [20] reports the mean fundamental frequency to be 34.6 Hz with an average range for male speakers of 25-52Hz (p.122). He also cites Monson and Engerbretson (p.124) who claim that the fundamental frequency range is 30-90Hz.

3.3. Electrolaryngography and Creak
Electrolaryngographic studies measure the change in impedance across the larynx as the vocal folds open and close and are therefore a more direct measure of vocal fold movement than the acoustic pressure wave (Abberton, Howard & Fourcin [27]). The acoustic pressure wave of a vowel produced with modal voice is shown in Fig 1a.The electrolaryngographic (Lx) trace associated with the same vowel is shown in Fig 1b (from Ball [5], p.177). In Fig 2a and 2b acoustic and Lx traces for the same vowel produced with creaky voice are shown (from Ball [5], p.179). The traces were extracted from a section of continuous speech therefore it is more likely to be creaky voice than pure creak. Note the irregularity of the creaky voice Lx trace in 2b. Because the peaks are so variable, measures of fundamental frequency in creaky voice are particularly difficult to evaluate.

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Fig 1a: Acoustic Pressure Trace of Vowel Produced with Modal Voice Quality

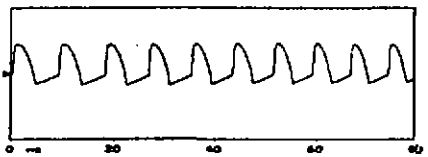

Fig 1b: Electrolaryngographic Trace of Vowel Produced with Modal Voice Quality

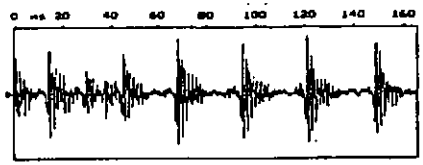

Fig 2a: Acoustic Pressure Trace of Vowel Produced with Creaky Voice Quality

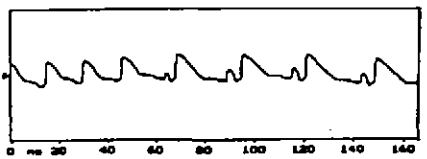

Fig 2b: Electrolaryngographic Trace of Vowel Produced with Creaky Voice Quality

In considering creaky voice as a speaker disguise it is important to note that , in addition to posing some problems for acoustic examination, it is also relatively straightforward for most speakers to produce. This is not surprising as it is found in many languages as part of the sound structure of that language (Laver [20], Ladefoged [19]). Crystal [5] also observes that some speakers tend naturally towards producing more creaky voice than others. He also observes that creaky voice may also be used deliberately by English speakers, often with the intention of showing some disparagement toward the listener (p.137). Creaky voice is therefore a reasonable choice to make for speakers who might want to conceal their voice in a manner which is relatively easy for them to produce.

4. AN EXPERIMENTAL EXAMINATION OF CREAKY VOICE

In an examination of creaky voice Hirson and Duckworth [14] showed that, in a random sample of 14 males, 10 were able to produce convincing versions of creaky voice which they were able to maintain throughout the reading of a test passage. For the 10 speakers the mean fundamental frequency of their modal voice measured on the **acoustic** analysis package on the PC-based version of the Electrolaryngograph ranged between 59-126 Hz which suggests that, even when reading in their modal voice, some of the speakers introduced some creaky voice. When producing speech

deliberately disguised by creaky voice the fundamental frequency measures show considerable variability.

A particularly graphic way of demonstrating this is by mean of cross (Cx) plots from the same acoustic analysis package mentioned above. Fig 3a is data from the reading in modal voice of the whole passage by one of our subjects. The range and stability of the fundamental frequency is shown by the typical cigar shaped central tendency and relatively few excursions outside of this. The modal fundamental frequency of this subject's modal voice is 93Hz with a range mainly between 65.5 and 201.3Hz and an irregularity of 24.1%. The variability of the same speaker's creaky voice reading is shown in Fig 3b. Here the central tendency is still evident but the wide excursions outside of this are typical of creaky voice. The speaker's modal frequency on this occasion was 79.3Hz but the main variability was between 43.4 and 329.7Hz with an irregularity of 78.7%.

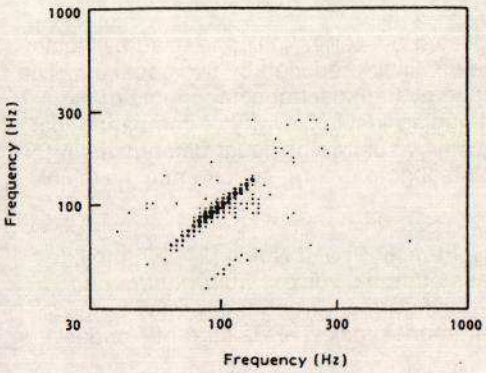

Fig 3a: Cross Plot (Cx) Showing the Acoustic Analysis of a Modal Voice Reading of the Test Passage

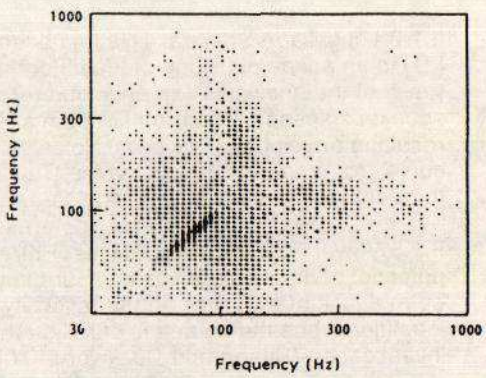

Fig 3a: Cross Plot (Cx) Showing the Acoustic Analysis of a Creaky Voice Reading of the Test Passage

5. SPEAKER VERIFICATION: THE FORENSIC PROCEDURE

5.1 Instrumental Analysis and Variability

Increasingly, considerable importance is place by many forensic phoneticians on instrumental examinations of speech samples. The enthusiasm for this type of examination has lead to some extreme claims about the value of visual examinations of spectrograms (e.g. Tosi [26]). More realistic views of the value of acoustic analyses have been expressed by Hollien [11], Nolan [22, 23] and French [9]. The variability of

the speech signal is well known. considerable effort has been expended upon discovering reliably invariant features in the acoustic signal. Perkell and Klatt [24] in their review of variability and invariance in speech show that the apparently invariant features are what we perceive rather than an easily definable aspect of the acoustic signal. Instrumental data therefore reveals considerable variability even in the acoustic data of undisguised speech. Nevertheless, French [8, 9], Nolan [22, 23] and Hollien [11, 13] describe acoustic analyses which can be used in the forensic examination of disputed recordings. These will be considered below and some of the problems of applying them to creaky voice will be discussed.

5.1.1 Fundamental Frequency. Mean and range of fundamental frequency have been cited by Hollien [11], French [9] and Künzel [18] as relevant for forensic analysis. The exact value of this measure remains in some doubt because many factors can affect a speaker's F0.However, in the present case measures of F0 will be of little help in comparing disguised and undisguised voices because, as was discussed in Section 4, the F0 figures for the two conditions are very different.

5.1.2 Long Term Spectra. This has been suggested by Hollien [11] and used by Nolan [21] in an academic study of the different voice qualities produced by two speakers. The result of the analysis is an envelope representing all the spectral components of the speaker's speech. The problem then arises of finding a suitable way of comparing the resulting envelopes. However, Nolan's study show visually significant differences in the curves for creaky and modal voice. This suggests that long term spectra may have little to offer in the case of voice disguise.

5.1.3 Vowel Formant Frequencies. Hollien [11], French [9] and Nolan [21, 22] provide potential of the value of this measure in the case of modal voice. Hitherto there has been a lack of evidence on the reliability with which formant frequencies may be identified when the source is creaky rather than modal voice.This is currently under investigation (Hirson and Duckworth [16]).

5.1.4 Time Components. The value of examining rate, pausing, stress and rhythm has been emphasised by Hollien [11] who, with Ming Jiang [13], has upgraded this portion of his Semi Automatic Speaker Investigation Program (SAUSI). However, for all our experimental subjects who achieved convincing creaky voice the speed of speech was noticeably reduced. Thus, comparisons in the time domain are hard to make. In addition, the relative slowness is likely to have affected the way in which articulatory movements overlap with each other which, in turn will affect the spectral characteristics of sounds. The extent to which this happens however, remains to be investigated.

6. HOW CAN THE DISGUISE BE UNCOVERED?

6.1 Features Examined by Aural-Perceptual Methods

Although instrumental measures of formant frequencies may be difficult to make with sufficient confidence, there may nevertheless be sufficient information for a phonetician to make a comparison between the modal and creaky voiced vowels by carefully listening to them. Assuming the speaker is not deliberately trying to alter these and has not altered the shape of his oral cavity, then the disguised voice vowels should still be articulated in the same way as usual. For phoneticians familiar with listening to vowel sounds and using this information to compare them to a standard reference framework (e.g. Ladefoged [19], Rogers [25] or Catford [4]) it is possible to make auditory judgements of similarity and difference between vowels in similar contexts. Applying the framework requires considerable familiarity with it and the accuracy with which individual phoneticians can 'place' vowels in the auditory/articulatory space is variable. Nor is it know to what extent the different voice quality makes this task more difficult. An auditory examination of vowels would be only one perameter upon which an aural-perceptual (or auditory-perceptual) approach of disputed and known speech samples would be based.

A number of other features have been suggested. The list in Hollien [11] p.198 is typical:

- Pitch level and pitch patterns
- Idiosyncratic articulation including coarticulatory effects and speech defects
- Voice quality
- Temporal patterning of speech including rate, pausing and linguistic stress
- Vocal intensity
- Dialect
- Idiosyncratic language patterns.

6.2 Implementing Aural-Perceptual Methods

The use of aural-perceptual methods of speaker identification has been the subject of controversy (see Nolan [23]). The critical issues are familiar in research: how valid and how reliable are perceptual judgements? In addition there has been considerable circumspection about whether phoneticians can exercise any special claim to be able to make more reliable judgements (Nolan [21]). French [8], Baldwin and French [2] and Hollien [11] have all described the aural-perceptual methods they use. All involve repeated comparison of portions of the known and disputed speakers' speech samples. This can be effected by repeatedly playing and comparing specific pairs of matched utterances. Hollien [11] p.204 suggests that the investigator should "[make] up many pair of examples so that a series of rigourous and systematic comparisons can be carried out". French [9] also describes a procedure in which, by electronic editing portions of the disputed speaker's speech are inserted into that of the known speaker's to detect whether a change can be perceived.

In a recent conference presentation Hollien and Hollien [12] described the need for a careful parametric listening to all the features listed in 6.1. However, they, and the other

authors were addressing themselves primarily to comparisons of voices which were believed to be undisguised. Nolan [21] is pessimistic about the problems posed for forensic phoneticians who are faced with disguised voices. It is a problem for which no immediate instrumental solution is available. However, Duckworth, Hirson and Mathieson [15] and Hirson and Mathieson [17] are investigating the stability of voiceless sounds such as "s' and "sh" across this sort of disguise.

7. TESTING THE AURAL-PERCEPTUAL METHOD OF SPEAKER RECOGNITION ON CREAKY VOICE SAMPLES

7.1 The Experiment

A tape of 40 items was prepared by AH from the original recording of the 10 males judged by the present authors to be producing acceptable creaky voice when asked to imitate the model produced by MD. The details of this tape are to be found in Hirson and Duckworth [14]. Here it is sufficient to note that each item contained three single sentence tokens, each token lasting around 5 seconds. The first two tokens were in modal voice, the third token belonged to one of four groups:

Creaky voice produced by one of the two speakers uttering the previous tokens
Creaky voice matching neither of the previous two speakers
Modal voice produced by one of the previous speakers
Modal voice matching neither of the previous speakers.

Each item was repeated once, the whole test lasting about 20 minutes.

15 people with training in phonetics and regular experience of using this training listened to the tape. This is the experimental group (Ph). The control group of 12 non phoneticians (NPh) listened to the tape under similar conditions. The listeners recorded their judgements of the identity of the third token on a record form.

7.2 The Aim of the Experiment

Although there were two presentations, the format of the listening test was not intended to replicate the way in which an expert witness might investigate known and disputed samples of this type. The aim of the experiment was firstly to discover whether creaky voice did indeed make detection of a speaker difficult and secondly to observe whether there was any difference in the accuracy of the two groups even with such limited exposure to the stimuli.

7.3 Accuracy of Identification

Table 1 summarises the raw and percentage correct scores for the two groups of listeners over the four types of listening task.

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Listening Task	Ph Raw Score	Ph % Correct	NPh Raw Score	Ph % Correct	Stat. Signif.
Creak Match	109 (150)	73	61 (120)	51	0.05
Creak No Match	81 (150)	54	70 (120)	58	n.s.
Modal Match	134 (135)	99	100 (108)	93	n.s.
Modal No Match	137 (165)	83	94 (132)	71	n.s.

Table 1: Raw and Percentage Correct Scores and their Statistical Significance (Mann-Whitney) on The Listening Task for the Phoneticians (Ph) and Non Phoneticians (NPh). The figures in parentheses are the total possible correct for each listener group and task.

The easiest task was undoubtedly identifying whether there was a modal voice match. This was probably facilitated by the matching sentence being an exact repetition of the same recording of the same utterance heard, at most, 7 seconds before the test item. The hardest task, however, differed between the two groups. The phoneticians had greatest difficulty in identifying when there was no match between the creaky voice test item and either of the preceding modal voices. The same tendency to find a match where none existed was, however, evident, in the NPh data too. The non phoneticians had considerably more difficulty in correctly identifying the modal voiced speakers when there was a match. The difference in the performance of the Ph and NPh groups on just this task indicated that the Ph group were significantly more accurate in their ability to match disguised and undisguised voices.

7.4 Error Types

Another way of examining the accuracy of two groups of listeners is to compare the types of errors made by the listeners in relation to the total number of errors they might make. This has forensic significance in so far as it shows the tendency to identify the wrong match or, conversely, to exclude a match which exists. In this analysis the following were examined:

- The number of times people in each group identified the wrong token as matching with the test item (false positive identification).
- The number of times it was claimed that there was no match when, in fact, there was (false negative identification).

The results are shown in Table 2.

Error Type	Ph Raw Score	Ph % Error	NPh Raw Score	NPh % Error
False +ve	107 (600)	18	112 (480)	23
False -ve	26 (285)	9	43 (228)	19

Table 2: Raw and Percentage Error Scores for Phoneticians and Non Phoneticians Classified by Error Type. The figures in parentheses refer to the total number of errors possible for each group and error type.

Both groups tended to assign a match when none was present but a Chi Squared analysis shows that the NPh group made significantly more errors of both types at the 0.05 level.

8. DISCUSSION AND CONCLUSIONS

Creaky voice is relatively easy to produce even for lengthy stretches of speech. Therefore it is likely that it will be used as a voice disguise in future cases. It is not a disguise which is readily penetrable by current acoustic investigations. The search for stable patterns in , for example, voiceless fricatives such as 's' and 'sh' may eventually be a fruitful avenue of research. This research may also have implications for investigating other disguises involving the manipulation of vocal fold vibratory patterns.

In the short term we will need to continue to explore aural-perceptual methods. From our results it is evident that it is possible that such methods can uncover creaky voice disguise. However, even in this small scale study, it is of significance to note that listeners with a background in phonetics and who are used to listening to the way in which people speak showed a greater aptitude for this task than did people with no such background.

Of course, caution should be observed in interpreting the group results. Some individual scores within the NPh group were as good as the majority of the Ph group and some of the Ph group had results more like the NPh group. Group outcomes are no substitute for individual listeners being able to evaluate objectively whether they are disguised or not (Hollien & Hollien [12]). French and Duckworth [10] in part of an on going research project are aiming to explore how expert witnesses can evaluate the accuracy of their judgements.

The development of the the profession of forensic phonetician has been greatly aided by an open discussion of the merits and limitations of currently available investigations of the speech signal. We hope this development will be enhanced by the development of methods to assist investigators to enhance the accuracy of their judgements. Given the seriousness of the expert witness' task the role of the International Association of

Forensic Phonetics in encouraging open debate will surely develop over the years. Finally, the interest of the Institute of Acoustics in this field is very encouraging. There is undoubtedly scope for the expertise of members of all the related areas to be shared. Co-operation of this order will foster research and development in areas of mutual interest and, one might reasonably hope, for the benefit of society as a whole.

9. REFERENCES

[1] D ABERCROMBIE, 'Elements of General Phonetics.' Edinburgh: Edinburgh University Press, 1967.
[2] J BALDWIN & JP FRENCH, "Forensic Phonetics" London: Pinter, 1990.
[3] J C CATFORD, 'Phonation Types: The Classification of some Laryngeal Components of Speech Production. In D Abercrombie et al (Eds.) "In Honour of Daniel Jones". London: Longmans, 1964.
[4] J C CATFORD, 'A Practical Introduction to Phonetics". Oxford: Clarendon, 1988.
[5] D CRYSTAL, 'Prosodic Systems and Intonation in English'. Cambridge: Cambridge University Press, 1969.
[6] M BALL, 'Phonetics for Speech Pathology, 2nd.ed.' London: Whurr, 1993.
[7] M DUCKWORTH, A HIRSON & M MATHEISON, 'Glottal Fry and Voice Disguise', Proceedings of the Conference of the International Association of Forensic Phonetics, Trier, 10-14 July 1993. Trier: Trier University Press (in press).
[8] J P FRENCH, 'Analytic Procedures for the Determination of Disputed Utterances', In H Kniffka (Ed.) Texte zu Theorie und Praxis forensischer Linguistik'. Tübingen: Max Niemeyer, 1990.
[9] J P FRENCH, 'Acoustic Phonetics', Chapter 3 in J Baldwin and J P French 'Forensic Phonetics'. London: Pinter, 1990.
[10] J P FRENCH & M DUCKWORTH, 'Recognising Speech in Identical Twins' (On going research)
[11] H HOLLIEN, ' The Acoustics of Crime: The New Science of Forensic Phonetics.' New York: Plenum, 1990.
[12] H HOLLIEN & P A HOLLIEN, 'Upgrading Aural-Perceptual Speaker Identification Techniques.' Proceedings of the Conference of the International Association of Forensic Phonetics, Trier, 10-14 July 1993. Trier: Trier University Press (in press).
[13] H HOLLIEN & M JIANG, 'Upgrading the SAUSI Prosody (TED) Vector.' Proceedings of the Conference of the International Association of Forensic Phonetics, Trier, 10-14 July 1993. Trier: Trier University Press (in press).
[14] A HIRSON & M DUCKWORTH, 'Glottal fry and Voice Disguise: A Case Study in Forensic Phonetics', Journal of Biomedical Engineering, **15**, 193-200 (1993).
[15] M DUCKWORTH, A HIRSON & M MATHIESON, ' Forensic Implications of Vocal Creak as Voice Disguise.' Proceedings of the Conference of the International Association of Forensic Phonetics, Trier, 10-14 July 1993. Trier: Trier University Press (in press).
[16] A HIRSON & M DUCKWORTH, 'Investigations into the Forensic Implications of Creaky Voice' On going research.
[17] A HIRSON & M MATHIESON, 'Automatic Speaker Recognition on the Basis of the Phoneme /s/' (in preparation).

[18] H KÜNZEL, 'Sprecherkennung: Gründzüge forensischer Sprachverarbeitung.' Heidelberg: Kriminalistik-Verlag, 1987.
[19] P LADEFOGED, 'A Course in Phonetics, 3rd. ed.' New York: Harcourt, Brace Jovanovich, 1993.
[20] J LAVER, 'The Phonetic Description of Voice Quality.' Cambridge: Cambridge University Press, 1980.
[21] F NOLAN, 'The Phonetic Basis of Speaker Recognition.' Cambridge: Cambridge University Press, 1983.
[22] F NOLAN, 'The Limitations of Auditory-Phonetic Speaker Identification.' In H Kniffka (Ed.) Texte zu Theorie und Praxis forensischer Linguistik'. Tübingen: Max Niemeyer, 1990.
[23] F NOLAN, 'Forensic Phonetics' , Journal of Linguistics, **27**, 483-493 (1991).
[24] J PERKELL & D KLATT (Eds.), 'Invariance and Variability in Speech Processes.' Hillsdale, New Jersey: Lawrence Earlbaum, 1986.
[25] H ROGERS, 'Theoretical and Practical Phonetics.' Toronto: Copp, Clark Pitman, 1991.
[26] O TOSI, 'Voice Identification: Theory and legal Applications.' Baltimore: University Park Press, 1979.
[27] E ABBERTON D HOWARD & A FOURCIN, 'Laryngographic Assessment of Normal Voice - A Tutorial' Clinical Linguistics and Phonetics, **3**, 281, 286 (1989).