# Measuring the tuning accuracy of thousands singing in unison: An English Premier Football League table of fans' singing tunefulness

David M. Howard

From the Media Engineering Research Group, Department of Electronics, University of York, Heslington, York, YO10 5DD, UK

Received 21 October 2002. Accepted 8 December 2003.

Logoped Phoniatr Vocol 2004; 29: 77–83

Tunefulness in singing is well understood in the context of solo stage performance, singing in small groups and singing in choirs, with or without accompaniment, and it can be readily measured under laboratory conditions. When thousands of people are singing outside in support of their football team, however, the singing is impromptu; there is no conductor, no starting note, and generally no accompaniment. This paper describes the measurement of the tunefulness of the singing of fans of the twenty clubs in the 2001–2002 English Premier League. The technique adopted is unusual in that it makes direct reference to the formal definition of pitch as a subjective phenomenon. The results are presented in the form of a 2001–2002 English Premier League football fans singing league table.

*Key words:* football fans singing, pitch measurement, singing.

*David M. Howard, Media Engineering Research Group, Department of Electronics, University of York, Heslington, York, YO10 5DD, UK. E-mail: dh@ohm.york.ac.uk*

## INTRODUCTION

Football is an extremely popular game in the UK and many thousands turn out to support their teams on a regular basis during the football season. Teams train and play in the highly competitive structure of the English Football League, and the presence of ardent supporters is a vital part of each team's game. The most significant manner in which fans make their presence felt in support of their teams is by making sound. This includes cheering, clapping, shouting, blowing whistles, waving football rattles, and sounding klaxon horns, but by far the most common form of sound heard from supporters at football matches is singing.

Singing at football matches involves thousands of people working together in a highly structured manner, but without any conductor. No starting note is given, and the words and music are known by heart. Only very rarely would there be any musical accompaniment. The start is completely spontaneous, often based upon just one or two individuals starting a well-known team chant, with the fans in their immediate vicinity soon joining in, and often within just a few bars, thousands can have taken up the chant.

How in-tune are fans when they sing at a football match? Can any reliable measurement be made to test this? Can a league table be produced for the English Premier League Clubs based on the tunefulness of the singing of their fans? This paper describes a response to these questions, resulting in a tunefulness league table for the twenty 2001–2002 English Premier League Football Clubs.

Tunefulness of thousands singing in unison cannot be measured using any standard analysis technique that might be employed for solo or choral singing, since these depend on individual acoustic features such as periodicity or harmonic structure being clearly identifiable, or on the use of specialist measurement devices such as an electrolaryngograph or electroglottograph (1, 2) on each individual. When thousands of individual sound sources are involved, all evidence of the periodicity associated with any individual's output is lost in the composite recording due to the small and varying tuning differences between each singer, as well as acoustic path length differences between each singer and the microphone.

In addition, recording conditions in a football stadium are far from ideal. Extraneous acoustic

 *ISSN 1401-5439* 
DOI: 10.1080/14015430410025064

signals are considerable, and fans are spread over such a large area that acoustic delays become important. Whilst standard recording practice might suggest that the microphone should be placed centrally, this would clearly be totally impractical since that is where the pitch is.

## METHOD

Singing ability might be assessed by one or more of a number of methods depending on which aspects are considered to be most important in a given situation. These might include: tuning accuracy to an absolute reference (such as a piano); relative tuning accuracy between each of the sung notes; tendency to go flat or sharp; rhythmic accuracy; overall vocal quality; overall blend between the singers; overall ensemble in terms of consonants and note onsets and offsets; overall musical nature of the performance.

Many of these aspects could never be measured for the singing of thousands of football supporters, especially given the presence of considerable competing acoustic noise (much of it from supporters of the opposing team), and the lack of a conductor or musical accompaniment. In addition, there is great variety in the sung material itself, and no absolute tuning reference. The only parameters considered as having the potential to provide a reliable and fair assessment of tunefulness were therefore: relative tuning accuracy, and tendency to go flat or sharp. Both of these are based on a measurement of the pitch of each sung note.

### *Recorded material*

One recording of a song by each team's fans singing was provided via a public relations company. These had been acquired either from local radio stations or by recordings made at games using a pocket recorder. All recordings were made during the first few months of the 2001–2002 Premiership season, and provided via minidisk[1] (for example, see (3) chapter 12 for a description of minidisk operation). The overall quality of the recordings was variable in terms of the degree of competing acoustic noise during the singing, which included shouting, the sounds of whistles, klaxons and rattles, and in some cases, radio commentary. At least one complete rendering of a chant or song sung by the fans of each team in the 2001–2002 English Premier League was made available as the source material for this project.

### *Pitch measurement*

Laboratory techniques available for the analysis of fundamental frequency (f0) from the speech pressure waveform (e.g. (4, 5)) are all designed to work for a single voice only in the absence of high levels of competing acoustic noise. In the case of recordings of football fans singing, the level of competing noise is very significant (especially the response from the opposing supporters!).

This is illustrated in Figs. 1 and 2 where '*Oh when the saints go marching in*' sung by a solo male singer (Fig. 1) and by the Southampton fans (Fig. 2) can be compared. In each case, a spectrogram and time waveform is shown for the complete phrase, as well as a zoomed portion during the vowel of '*in*'. The acoustic waveform and spectral patterns that form the basis for f0 estimation using standard techniques, cycle-by-cycle periodicity and harmonic structure respectively, are clearly revealed for the solo male singer during '*in*'. The striations in the wide band spectrogram (vertical lines, each resulting from a vocal fold closure) during the voiced sections of the sung phrase are clearly visible in the upper plot. All of these features are completely absent in the plots for the singing of the Southampton fans (Fig. 2). The whereabouts of the sung sections can be identified in the upper spectrogram, but they appear essentially noise-like, with no evidence of the structured regularity of striations. In the plots for the vowel of '*in*', there is no evidence of periodicity in either plot; therefore no basis upon which a laboratory-based technique could function.

By way of illustration, the two waveforms shown in the upper parts of Figs. 1 and 2 have been analysed using the cepstral technique (6), which is particularly appropriate when the input speech is noisy. The results are plotted in Fig. 3. The f0 output for the solo male clearly shows the changes between the individual notes during the line of the song '*Oh when the saints go marching in*', whereas the plot for the Southampton fans exhibits no such pattern. Indeed, the f0 values that have been output are well below the perceived f0 in this example.

[1] Minidisk recordings (12) have been cited as being possibly inappropriate as a medium for recording data that is to be analysed for its acoustic properties in the laboratory, due to the processing involved when the audio data is compressed. This is not considered to be an issue for this work for two reasons. Firstly, such compression is a linear process in terms of frequency and therefore it will not affect the frequency position of spectral components although it can alter their amplitudes, and secondly, the analysis procedure eventually adopted was based on listening rather than a laboratory acoustic analysis to assign the pitch, where it is the unchanged frequency position of the components that is important.

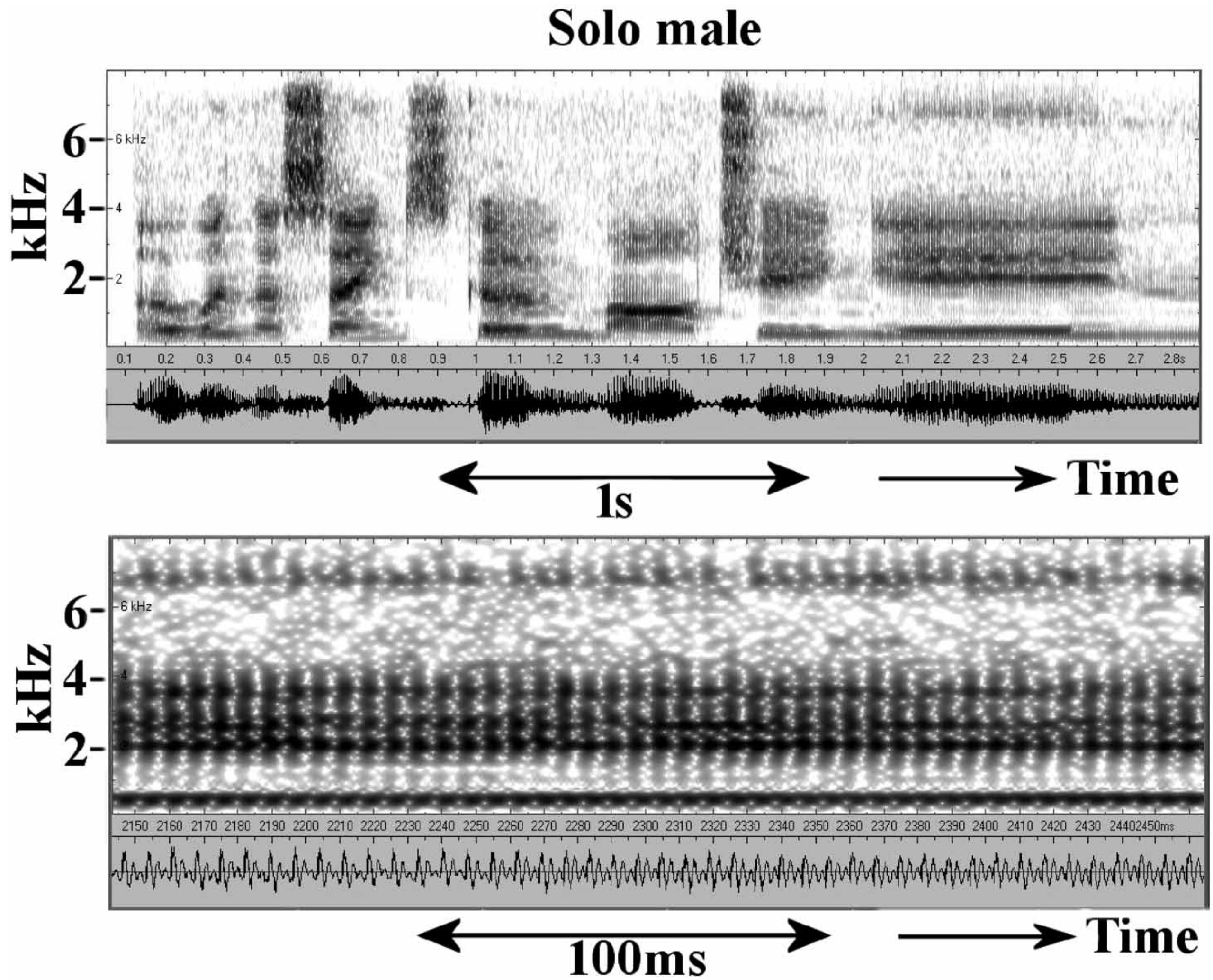


*Fig. 1.* Spectrogram and waveform for a solo adult male singing 'Oh when the saints go marching in' (upper) and for part of the vowel of 'in' (lower).

A measurement of relative tuning accuracy for the singing of thousands of football fans therefore requires an alternative approach. The starting point adopted is the formal definition of pitch, which is given by the American National Standards Institute (7) as follows:

'Pitch is that attribute of auditory sensation in terms of which sounds may be ordered on a scale extending from low to high.'

Pitch measurement is entirely subjective, that is, it requires the intervention of a human subject (8). Variations in f0, which are measured by computer-based systems, manifest themselves to the listener as pitch variations. The formal method for measuring pitch involves a listener matching the pitch of the unknown to that of a reference tone (a sine wave) by adjusting the frequency of the reference tone until the listener judges that the pitches are equal (9). This is the procedure adopted for measuring the pitch of the singing of the football fans.

The formal definition states that the reference tones should be sinusoidal, and these were produced from a sine wave sound available from a Roland Alpha Juno-2 music synthesizer. This particular music synthesizer was selected because it enabled the frequency of the sine wave to be noted through the use of its 'fine-tune' control, for which a frequency value is displayed that varies in 1 Hz steps. The intensity of the sine wave output was constant for all measurements, since the subjective pitch of a sine wave can vary with level (10).

The recordings from each club were transferred onto a PC compatible computer using GoldWave (11), which enables sounds to be captured and manipulated

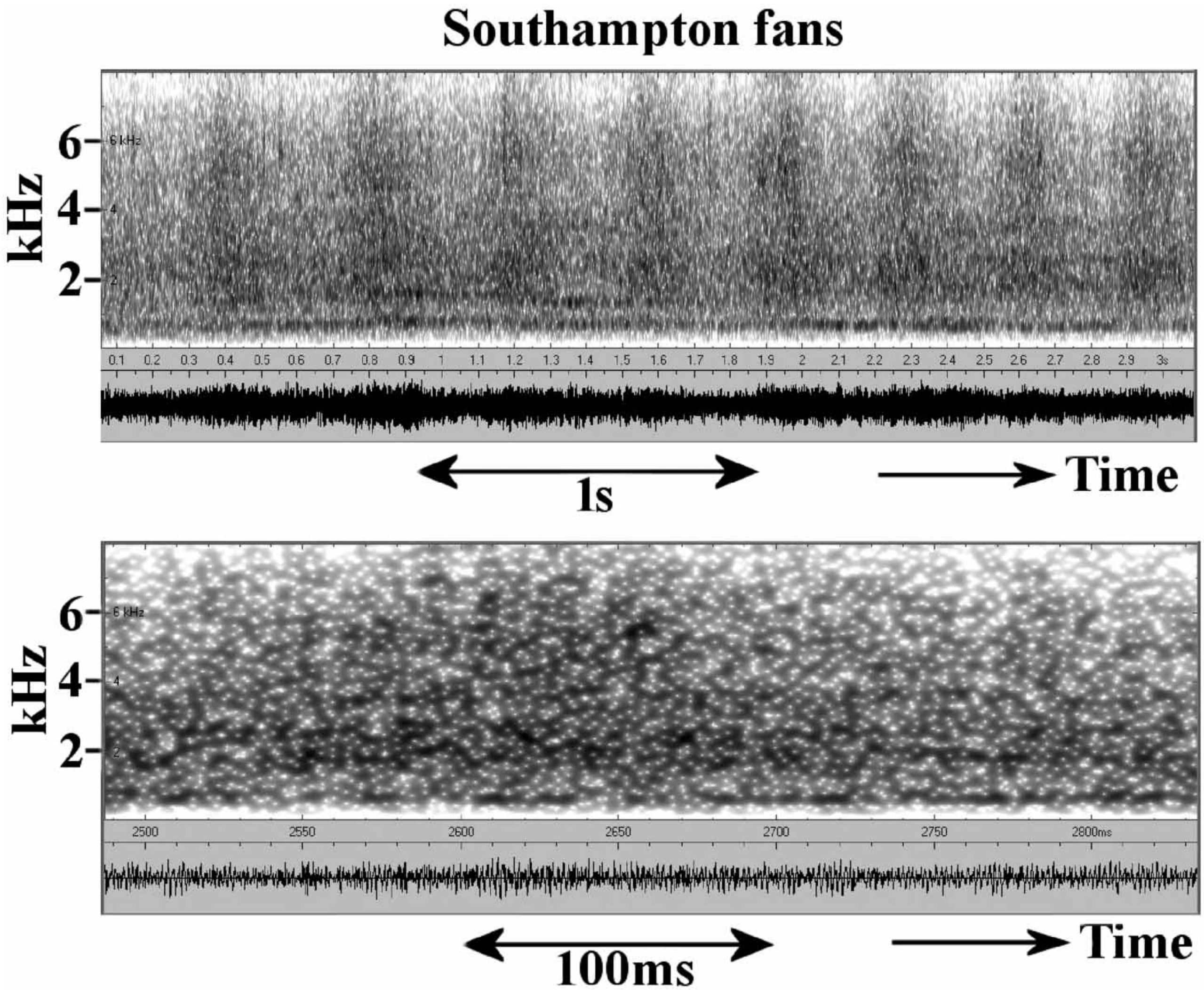


*Fig. 2.* Spectrogram and waveform for the Southampton fans singing 'Oh when the saints go marching in' (upper) and for part of the vowel of 'in' (lower).

via a standard multi-media Sound Blaster card. GoldWave was used to replay the recordings in sections which varied in length from a note at a time to the whole file. The replayed sound could be automatically repeated, or looped, as required during the analysis. The pitch of every note under consideration was measured by directly comparing each with the sine wave reference from the Alpha Juno-2 synthesizer. The f0 of the sine wave reference was adjusted to match each sung note by first finding the nearest note on the keyboard of the music synthesizer, and then adjusting the fine-tune control to achieve a pitch match. The nearest note and the fine-tune setting that gave a pitch match for each note of the song were recorded in an Excel spreadsheet. The fine tuning frequency values were converted to cents (one cent is 1/100th of a semitone, and there are 12 semitones to one octave) using the following equation from Appendix 2 of Howard and Angus (8)(2001):

$$\text{Value in cents} = 3986.3137 \times \log_{10} (\text{fine-tuning value}/440) \qquad [1]$$

*Note on the methodology*

It is worthy of note that this method appears to be practical, repeatable and relatively straightforward. A quarter of the sung samples were analysed twice on separate occasions in order to check the repeatability of the method and the results obtained were within 1 Hz in each case. The use of this method has not been identified elsewhere, but it has enabled a tuning analysis to be carried out for large groups of singing fans which would not have been possible by traditional laboratory techniques.

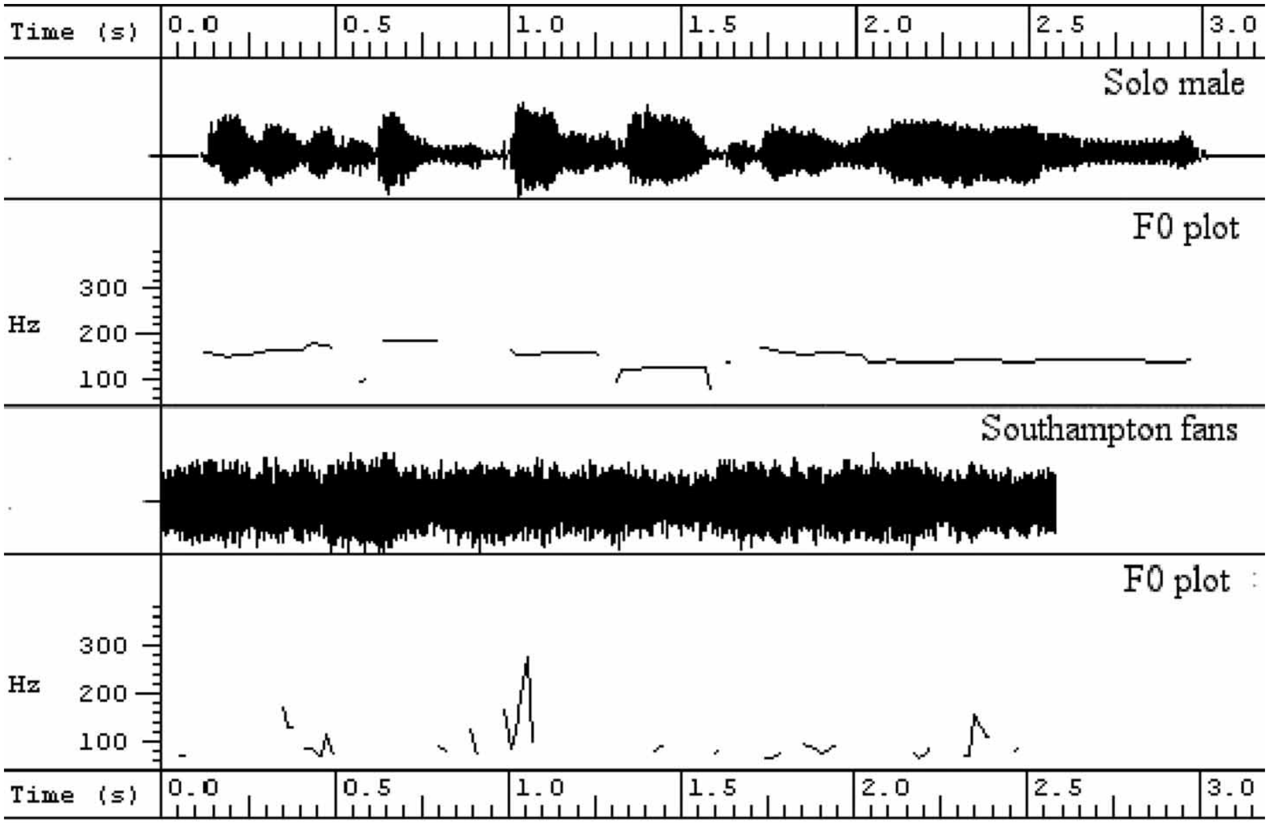


*Fig. 3.* Waveform and cepstral fundamental frequency analysis for the solo male (upper) and the Southampton fans (lower) singing 'Oh when the saints go marching in'.

## DERIVING A TUNEFULNESS LEAGUE TABLE

The two required derived measurements from the raw pitch data are: 1) the relative tuning accuracy, and 2) any tendency to go flat or sharp.

In order to provide a statistical summary of the data, the mean and standard deviation of the fine-tuning values were analysed. Given that these a represent tuning difference on a note-by-note basis from the semitones on the music synthesizer, which is tuned in equal temperament, the mean value represents the average absolute tuning variation from the synthesizer (the average fine-tuning setting), whilst the standard deviation provides an overall measurement of the variation in relative tuning with respect to equal tempered tuning. The standard deviation therefore gives a measurement of relative tuning accuracy, which is the first required quantity. These standard deviation values are given in Table 1 for each team. The lower the standard deviation value, the greater the tuning accuracy since this indicates a small deviation from the mean.

The second quantity required is some measure of any tendency for the pitch to drift flat or sharp during the singing. The measured fine-tuning in cents of every note is known, and the time course of this variation during the song will indicate the extent of any tendency to go flat or sharp. A best-fit straight line

Table 1. *Relative tuning accuracy for each team's fans as standard deviation in cents from the mean (the lower the value, the higher the tuning accuracy)*

| Order | Team | SD |
|---|---|---|
| 1 | Manchester United | 3.3 |
| 2 | Southampton | 5.4 |
| 3 | Charlton | 8.9 |
| 4 | Blackburn Rovers | 12.0 |
| 5 | Derby County | 13.4 |
| 6 | Everton | 15.5 |
| 7 | Liverpool | 16.1 |
| 8 | West Ham United | 18.0 |
| 9 | Newcastle | 18.1 |
| 10 | Ipswich Town | 19.5 |
| 11 | Leeds | 19.6 |
| 12 | Leicester City | 19.6 |
| 13 | Sunderland | 21.0 |
| 14 | Fulham | 21.6 |
| 15 | Middlesborough | 22.1 |
| 16 | Bolton | 27.3 |
| 17 | Aston Villa | 28.9 |
| 18 | Arsenal | 29.5 |
| 19 | Spurs | 38.2 |
| 20 | Chelsea | 38.2 |

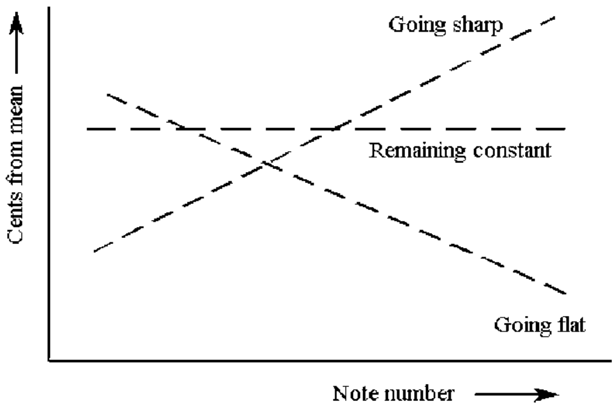


*Fig. 4.* Illustration of the nature of the graph when indicating a tendency for the tuning during a song or chant to go flat, sharp or remain constant.

Table 2. *Extent of tendency to go flat (b) or sharp (#) during the song as indicated by the gradient of the best-fit straight line to the note fine-tuning data (the lower the gradient, the less the tendency to drift flat or sharp)*

| Order | Team | Gradient | b/# |
|---|---|---|---|
| 1 | Southampton | 0.0614 | b |
| 2 | Manchester United | 0.2390 | b |
| 3 | Derby County | 0.5628 | b |
| 4 | Charlton | 0.6244 | # |
| 5 | Liverpool | 0.7171 | # |
| 6 | Newcastle | 0.7408 | # |
| 7 | West Ham United | 1.2004 | b |
| 8 | Chelsea | 1.3701 | # |
| 9 | Blackburn Rovers | 1.5826 | # |
| 10 | Everton | 1.6211 | # |
| 11 | Leicester City | 1.8928 | # |
| 12 | Spurs | 2.3508 | b |
| 13 | Leeds | 2.6837 | b |
| 14 | Sunderland | 2.6879 | # |
| 15 | Fulham | 2.9153 | b |
| 16 | Arsenal | 2.9410 | b |
| 17 | Ipswich Town | 3.0419 | # |
| 18 | Middlesborough | 3.0457 | b |
| 19 | Aston Villa | 3.1448 | b |
| 20 | Bolton | 4.5330 | # |

is applied in Excel, and the slope of this line indicates whether the tendency is to go sharp (rising line), flat (falling line) or remain constant (horizontal line), as illustrated in Fig. 4. The steepness of the line indicates the extent of the tuning shift, and this is given as the gradient of the best-fit straight line as provided by Excel. These gradient values as well as the direction (falling/flat or rising/sharp) are given in Table 2.

The two measurements each produced numerical values as shown in Tables 1 and 2. In both cases, a lower value indicates the better singing ability, and these values are combined by multiplication. In order that no team is disadvantaged simply because of the differences in the number of notes that had been made available for analysis, the result is divided by the actual number of notes analysed (NNA) to normalize the standard deviation measurements, and hence the overall results.

The overall league table is shown in Table 3, which is ordered by the ascending rank ordering of its final column. The final column values have been calculated as:

$$(\mathrm{SD} \times \mathrm{GRAD})/\mathrm{NNA} \quad [2]$$

where:

SD = the standard deviation in cents from equal tempered tuning
GRAD = the gradient of the straight-line fit to note fine-tuning data
NNA = the total number of notes analysed.

## DISCUSSION AND CONCLUSIONS

A procedure based on the formal definition of pitch has been adopted for the analysis of the unison singing of thousands of fans at football matches in order to create a league table based on the singing of fans of the 2001–2002 English Premiership League teams. It was not possible to make use of any existing quantitative laboratory-based technique for f0 analysis, since these are designed to work for the output from a single singer or speaker. A technique was implemented that is based on the formal definition of pitch, which was found to be practical, repeatable and relatively straightforward to apply. The final league table (Table 3) is based on the relative tuning accuracy of the sung notes as well as any tendency to go flat or sharp. These data are combined by multiplication and normalized for the number of notes available for analysis.

By way of a postscript, it is clear after listening to the singing of these football fans that there are some basic singing skills that they could adopt, which would immediately enhance their overall tunefulness. Many of the songs were sung at a pitch that was far too high for comfort and the vocal abilities of non-trained singers. There were many instances of G4 ($f0 \approx 390$ Hz) for adult male fans and G5 ($f0 \approx 780$ Hz) for female and child fans. This is considerably higher in pitch than one would typically find associated with any folk song or church hymn. Indeed, many regular choral singers, particularly altos and basses, would find such notes extremely uncomfortable to sing, if not entirely unreachable. Fans sang most of these high notes extremely flat, and the overall sound quality

Table 3. *Overall league table based on the rank ascending ordering of the final column (shown in bold) which has been calculated as: ((SD × GRAD)/NNA)*

| Order | Team | SD | GRAD | NNA | (SD × GRAD)/NNA |
|---|---|---|---|---|---|
| 1 | Southampton | 5.37627 | 0.06140 | 44 | **0.00188** |
| 2 | Manchester United | 3.30666 | 0.23900 | 24 | **0.03293** |
| 3 | Derby County | 13.40117 | 0.56280 | 25 | **0.10056** |
| 4 | Newcastle | 17.97635 | 0.74080 | 31 | **0.14319** |
| 5 | Liverpool | 16.13764 | 0.71710 | 26 | **0.14836** |
| 6 | West Ham United | 17.96702 | 1.20040 | 19 | **0.37838** |
| 7 | Charlton | 8.86570 | 0.62440 | 12 | **0.46131** |
| 8 | Blackburn Rovers | 12.04452 | 1.58260 | 20 | **0.47654** |
| 9 | Everton | 15.47413 | 1.62110 | 20 | **0.62713** |
| 10 | Chelsea | 38.21033 | 1.37010 | 26 | **0.67118** |
| 11 | Leeds | 19.62863 | 2.68370 | 17 | **0.77467** |
| 12 | Sunderland | 20.95066 | 2.68790 | 24 | **0.78213** |
| 13 | Arsenal | 29.48211 | 2.94100 | 31 | **0.93233** |
| 14 | Middlesborough | 22.09793 | 3.04570 | 23 | **0.97542** |
| 15 | Ipswich Town | 19.50558 | 3.04190 | 20 | **0.98890** |
| 16 | Leicester City | 19.62863 | 1.89280 | 24 | **1.54804** |
| 17 | Aston Villa | 28.89201 | 3.14480 | 21 | **2.16332** |
| 18 | Fulham | 21.56090 | 2.91530 | 20 | **3.14282** |
| 19 | Spurs | 38.16615 | 2.35080 | 12 | **3.73837** |
| 20 | Bolton | 27.31486 | 4.53300 | 11 | **5.62810** |

SD = the standard deviation in cents from equal tempered tuning.
GRAD = the gradient of the straight-line fit to note fine-tuning data.
NNA = the total number of notes analysed.

often became more of a corporate shout than a sung note. Overall, tunefulness would be greatly improved if lower starting notes were used.

It is heartening to note the enormous exuberant spontaneity in the fans' singing, born out of their intense corporate thrust of support for their teams. It would be completely inappropriate to do anything to dampen this. The unimpeded, carefree and impulsive nature of their singing is in itself both a joy and a testament to this most basic of corporate human communication channels.

## ACKNOWLEDGEMENTS

The author would like to thank Lexis Public Relations for providing the stimulus to carry out this work as well as for providing the recordings of the fans singing.

## REFERENCES

1. Fourcin AJ, Abberton ERM. First applications of a new laryngograph. Med Biol Illus 1971; 21: 172–82.
2. Baken RJ. Clinical measurement of speech and voice. Boston: College-Hill Press; 1987.
3. Pohlmann KC. Principles of digital audio. New York: McGraw Hill; 2000.
4. Hess W. Pitch determination of speech signals. Berlin: Springer Verlag; 1983.
5. Howard DM. Practical voice measurement. In: Harris T, Harris S, Rubin JS, Howard DM, editors. The voice clinic handbook. London: Whurr Publishing Company; 1998. p. 323–80.
6. Noll AM. Cepstrum pitch determination. J Acoust Soc Am 1967; 36: 296–302.
7. ANSI. American Standard Acoustical Terminology. New York: American National Standards Institute; 1960.
8. Howard DM, Angus JAS. Acoustics and psychoacoustics. 2nd ed. Oxford: Focal Press; 2001.
9. Moore BCJ. An introduction to the psychology of hearing. London: Academic Press; 5th Ed., 2003.
10. Terhardt E. Pitch of pure tones: its relation to intensity. In: Zwicker E, Terhardt E, editors. Facts and Models in Hearing. New York: Springer Verlag; 1974. p. 353–60.
11. WWW-1: http://www.goldwave.com/
12. Maes J. The Minidisk. Oxford: Focal Press; 1996.