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Singing and science

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Introduction

THIS study arose from a desire to combine the author's interests in singing and science. In general, it was felt that there must be measurable qualities which were related to the ability to sing, and the author instigated a computer-based pilot survey of a random sample of 500 famous singers (Smith, 1976). The biographical data (from Kutsch and Riemans, 1969) were analysed in order to determine factors common to these singers. The following facts emerged:

1. Most singers made their *débuts* between 20 and 25 years of age.
2. Most singers *did not* have musical upbringings during childhood, musical parents, spouses or other close relatives.
3. The commonest place of birth was Germany.
4. The commonest month of birth was May.
5. The commonest training-ground was Germany, followed in order by Italy, Austria, France, the U.S.A. and England.
6. The commonest age at death was 60 to 70 years, although 126 from the sample lived to between 90 and 100 years. (This does seem to be an unexpectedly large number).

These facts prove nothing by themselves, and the factors which determine whether a person becomes a successful singer are so diverse that no accurate study of them could really be carried out. Physical, cultural and sociological factors are among those involved.

The main problem has been summarized thus:

'Is it only training that makes the difference? [Between an opera singer's voice and that of a second-rate singer]. Or is it the instrument that produces an excellent singer's voice, itself totally different from other peoples?' (Sundberg, 1977).

Further:

'It is in the complex of knowledge, talent and musical instinct that is summed up as 'musicality', rather than in the anatomy of the lungs and the vocal tract, that an excellent singer's excellence lies.' (Sundberg, 1977).

The author decided to carry out a limited study of fifteen pupils of one

This article is based upon a thesis entitled 'A study of the factors involved in the development of the singing voice during vocal training', which was accepted in 1980 by the University of London for the degree of Master of Philosophy.

PREFATORY NOTE

Where other authors are quoted verbatim, any explanatory words added by the present author are indicated thus: '. . . [the] . . .', etc.

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TABLE I

SUBJECTS' VOICE TYPES, AND DETAILS OF THEIR MUSICAL ABILITIES

	Age in 1976	Voice type	Vocal range	Pitch of speaking voice	Index of speaking pitch	Pitching ability (singing intervals)	Sight-reading ability	General musical experience and ability
M1	27	'Tenor'	G2-B4	B2	0.14	Absolute	Excellent	Competent professional oboist and pianist
*M2	50	Tenor	F2-Bb4	G2	0.07	Poor	None	Inexperienced beginner
*M3	49	Bass	Eb2-F4	C3	0.35	Good	Reasonable	Very experienced amateur singer
M4	47	'Baritone'	F2-G4	Ab2	0.12	None	None	No musical training or experience
M5	51	'Bass'	E2-D4	G2	0.14	None	None	No musical training or experience
M6	25	'Bass'	E2-G4	Ab3	0.59	Good	Excellent	Competent amateur pianist
M7	24	'Bass'	E2-G4	C3	0.30	None	None	No musical training or experience
M8	25	'Baritone'	G2-G4	Eb3	0.33	None	None	No musical training or experience
M9	34	'Bass'	D2-G4	C3	0.34	Good	Excellent	Experienced pianist; academic musician
*M10	22	Bass-bar.	E2-Bb4	B2	0.23	Good	Excellent	Inexperienced school music teacher
*M11	25	Bass-bar.	F2-G4	D3	0.34	Reasonable	Reasonable	Experienced semi-professional singer
*M12	34	Baritone	G2-G4	—	—	Poor	Poor	Inexperienced beginner
*F1	48	Contralto	E3-C6	Bb3	0.19	Good	Reasonable	Competent amateur singer
*F2	15	Contralto	E3-C6	Bb3	0.19	Poor	Poor	Inexperienced beginner
*F3	27	Contralto	G3-Ab5	Ab3	0.04	Reasonable	Reasonable	Competent amateur singer
*F4	36	Mezzo-sop.	C3-A5	Ab3	0.24	None	None	Inexperienced beginner
*F5	16	Mezzo-sop.	C3-C6	Ab3	0.24	Reasonable	Reasonable	Inexperienced beginner
F6	24	'Mezzo-sop.'	G3-F5	C4	0.23	None	Poor	Very limited musical knowledge
*F7	15	Contralto	E3-C6	Ab3	0.13	Good	Reasonable	Inexperienced beginner
F8	38	'Mezzo-sop.'	F3-A5	F3	0.00	Good	Reasonable	Experienced amateur singer
*F9	47	Mezzo-sop.	C3-C6	B3	0.34	Reasonable	Poor	Very experienced singer
*F10	14	Soprano	F3-G6	D4	0.24	Absolute	Excellent	Inexperienced beginner
F11	41	'Contralto'	C4-F5	Ab3	−0.24	None	None	No musical training or experience
*F12	18	Contralto	E3-B5	B3	0.23	Good	Reasonable	Competent student flautist and pianist
F13	24	'Mezzo-sop.'	—	A3	?	None	None	No musical ability at all
*F14	42	Soprano	Bb3-E6	A3	0.02	Good	Reasonable	Experienced semi-professional singer
*F15	38	Contalto	Db3-C6	Bb3	0.09	Good	Reasonable	Experienced semi-professional singer
F16	25	'Mezzo-sop.'	D3-Gb5	Ab3	0.21	None	None	No musical training or experience
F17	17	'Mezzo-sop.'	F3-A5	A3	0.14	None	None	No musical training or experience

*An asterisk indicates that the subject was a trained singer. M1–M12: males; F1–F17: females

All singers were currently studying with the same teacher, except *M10, who produced an exaggerated upper range only with extreme effort.

singing teacher, one pupil of another singing teacher, and thirteen 'control' subjects. The latter had no experience of formal vocal training, but some were trained musicians. Basic information about these subjects is given in Table 1.

The collection of data from subjects was spread over a period of about twelve months in 1975 and 1976. Subjects were asked to attend four sessions at regular intervals, in order that changes in any parameter might be monitored; some attended on fewer occasions.

There follows a discussion of some of the factors which affect the singing voice, and how information was collected from the subjects of this study.

Factors affecting the voice

Heredity and voice type

There is some evidence which suggests that voice is a hereditary trait, although the total pattern of voice cannot be inherited (Luchsinger and Arnold, 1965). The following scheme for the Mendelian inheritance of voice type has been backed by statistical analysis (Luchsinger and Arnold, 1965).

	♂	♀
AA	Bass	Soprano
Aa	Baritone	Mezzo-soprano
aa	Tenor	Contralto

There were some possible exemplifications of this scheme amongst subjects of this study, *viz.* the husband and wife, *M2 and *F1, and their daughter, *F2; the husband and wife, M5 and *F9, and their daughter (not a subject); and *M11 and F17 (siblings) and their parents (not subjects). The evidence is tenuous, however.

Voices types illustrate continuous variation in the statistical sense, but can be divided into the above categories, and indeed, usually are for practical purposes (See also Fig. 1). The type of voice is partly decided by sound *quality,* and is dependent upon the dimensions of the larynx and supraglottic resonators, artistic inclination, cultural influences and the psychological personality structure (Luchsinger and Arnold, 1965).

The voices of the subjects of this study were classified at the author's discretion, the vocal ranges having been determined by experimentation. The vocal range can be extended by correct training, and only four relatively inexperienced singing subjects, *M12, *F5, *F7, and *F9, had shown no increase in range since singing tuition had commenced.

Subjects' speaking pitches are shown in Table 1, with each expressed as an *Index of Speaking Pitch.* This was devised by the author, as follows:

e.g. M1 had a vocal range from G_2—B_4 = 28 semitones.
His average speaking pitch was B_2.

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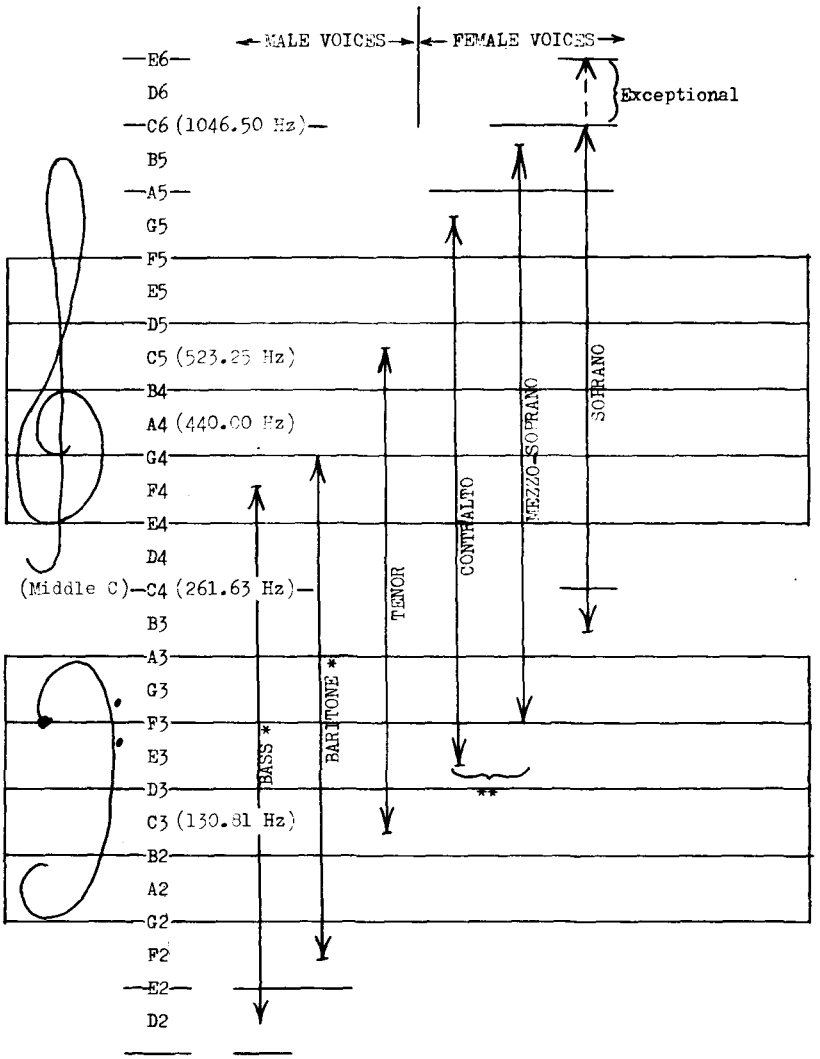


FIG. 1

(Compiled from Backus, 1970; Rushmore, 1971; and other sources.)

APPROXIMATE RANGES OF VOICES TYPES

(The principal voice types only are shown, excluding male falsetto voices such as counter-tenor.)

* The range of the 'bass-baritone' is similar to that of the baritone. The difference lies mainly in the former's 'heavier' voice quality and his rarer excursions to the upper extremes of his range.

** The distinction between these two voices is ill-defined, but lies again mainly in the 'heavier' quality of the contralto.

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G_2–B_2 = 4 semitones.
$\frac{4}{28}$ = an index of 0·14.

The male speaking pitch is usually said to lie between 80 Hz and 150 Hz, and the female speaking pitch one octave higher (Luchsinger and Arnold, 1965).

Upbringing and training

It is obvious that a latent ability may never be realized, either in the conscious sense or in the practical sense. There is no doubt that the ability to pitch, for example, is improved by musical study, and there is evidence which suggests that the possession of absolute pitch may be related to the age at which musical training is begun (Sergeant and Roche, 1973). It also appears possible for absolute pitch to be 'learned' to some extent by an ungifted person (Brady, 1970; Cuddy, 1968).

Some singers entered the profession too young to have been *trained,* and must have had 'natural' voices. (Marafioti, 1925). To quote Melba:

'. . . mine was an exceptional case, for I was born with a natural trill and an absolute control of breath so that as a child of seven I was as far advanced naturally as some mature students are after years of patient study' (Newnes, 1912).

On the other hand, although as a boy Caruso had a 'perfect physique' and was a 'capable boy soprano and a marvellous alto' (Caruso, 1913), 'His was a phenomenal voice indeed, but one made so by training, for in his own words, great singing is 10 per cent natural voice and 90 per cent hard work' (Kambata, 1977).

Neurological aspects

The two main types of intelligence which exist are probably related to the relative dominance of the two cerebral hemispheres (Luchsinger and Arnold, 1965):

1. Verbal-social, or linguistic, intelligence. (L-type: associated with the left hemisphere).
2. Mathematical-quantitative intelligence. (Q-type: associated with the right hemisphere).

Mathematicians may acquire intellectual musicality; however, they are usually not artistic, but show competence in the rhythmical aspects of music (Luchsinger and Arnold, 1965).

As far as auditory stimuli are concerned, the left hemisphere seems to be better at processing verbal material, whilst the right side is better at processing pitch and rhythm.

Congenital language disability and well-developed musical talent are at opposite poles of the scale, both faculties being connected with the left cerebral hemisphere (Luchsinger and Arnold, 1965). Linguistic problems are encountered in left-handed people at a higher frequency than in right-

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handed people, and *F4, the only left-handed subject, had difficulty in singing in tune, but no linguistic problems. Her husband and two daughters were also left-handed, and one of the latter had serious reading, spelling and psychological problems, despite having a very high I.Q.

Amusia is divided into two types (Luchsinger and Arnold, 1965):

1. *Expressive avocalia,* where the subject cannot play an instrument, and is a monotone, but enjoys listening to music. (F13 appeared to fall into this category).
2. *Receptive agnosia,* where the subject is 'tone deaf'.

Personality

The author's opinion is that professional musicians are often not extroverts, and many are modest and shy when not performing. Attempts have been made to study the degree of tension which performers suffer (e.g. see Grüner, 1978), and personality must affect this. Respiratory physiology may also be profoundly affected by personality (e.g. see Clark and Cochrane, 1970), and this may be of importance to singers.

The Eysenck Personality Inventory (E.P.I.) was used in the standard manner in order to assess the subjects' personalities.

Musculature

'The voice is an instrument consisting of a power supply (the lung), an oscillator (the vocal folds), and a resonator (the larynx, pharynx and mouth). Singers adjust the resonator in special ways' (Sundberg, 1977).

Many muscles are used in the act of singing, and, '. . . the sub-glottal pressure obtaining at a given instant depends upon the integrated effect of many muscles acting in concert' (Sears, 1977).

Expiration is assisted during vigorous breathing by contraction of the abdominal muscles (Cotes, 1968). The abdominal musculature supports the weight of the viscera, thereby relieving the ribcage of an appreciable gravitational load. According to some authorities, the abdominal wall and diaphragm form a stable platform during the act of singing; the ribcage contributes actively to breath control, but its large surface area means that its apparent motion may appear small (Sears, 1977).

Well-developed control of the abdominal, diaphragm and ribcage muscles is the key to good breath control, and the maintenance of a suitable breath pressure when singing. Undue tension is created in the larynx if the air flow is too low.

The 'support' *(appoggio)* of which singers speak has been defined as 'the resistance that the inspiratory musculature offers to oppose the expiratory collapse of the breathing organ' (Winckel, 1952, quoted in Luchsinger and Arnold, 1965).

The large chests of professional singers apparently reflect the habit of keeping the upper chest in the inspiratory position when singing (Luchsinger and Arnold, 1965).

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In this study, measurements around the region of the diaphragm were recorded, both when the lungs were expanded and collapsed.

Lung function

During the course of this study, Wright Peak Flow Meter readings were taken in the usual manner, and the highest of three readings was recorded, as recommended by Godfrey *et al.* (1970), and by Gregg and Nunn (1973). Predicted values for Peak Expiratory Flow (P.E.F.) were found from a chart published by Clement Clarke International Limited, and observed/predicted $\times 100\%$ values were calculated.

A Vitalograph Spirometer was used in strict accordance with the manufacturer's instruction (Garbe, 1973). Readings were taken at A.T.P.S., and corrected according to the ambient temperature and pressure.

The usual parameters were calculated, *viz.*: F.V.C., $F.E.V._{1}$, F.M.F.T., and $F.E.F._{200-1200}$. Predicted values were found from nomograms by Kamburoff and Woitowitz (1973), reproduced in Garbe (1973), except those for subjects under the age of 20 years, who were not included in the nomograms. The observed/predicted $\times 100\%$ values were then calculated for F.V.C., $F.E.V._{1}$, F.M.F. and F.E.F., $F.E.V._{1\%}$ was calculated as $F.E.V._{1}/F.V.C. \times 100\%$. All results were recorded on a 'Pulmonary Function Test Report', similar to that suggested by Garbe (1973).

There are conflicting opinions about whether vital capacity may be increased by exercise, including singing. Some evidence suggests that this is so (e.g. see Cotes, 1968; Luchsinger and Arnold, 1965; Mackay, 1977). There is also contradictory evidence (e.g. see Cotes, 1968; Franklin, 1969; Thomas, 1977; Young, 1977). It may be the case that divers, and possibly singers show an increase in respiratory *efficiency*, though control of respiration and suppression of the normal psychological and physiological stimuli (Young, 1977).

$F.E.V._{1\%}$ may *decrease* as a result of physical training involving the muscles of the shoulder girdle (Cotes, 1968). Divers show varying changes in $F.E.V._{1\%}$ after training (Young, 1977).

Miller's Prediction Quadrant (see Garbe, 1973) was used to assess whether subjects were clinically 'normal', or showed obstructive or restrictive ventilatory defects.

Phonation time

This was measured by asking a subject to take the deepest possible breath, and then sing any note at a comfortable pitch for as long as possible. It was assumed that singers would show better breath control than non-singers, and thus have longer phonation times.

Vocal folds

Sound is derived from the regularly repeated interruption of air flow

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through the glottis, caused by the valving action of the vibrating vocal folds (Sears, 1977). In general, the thinner and more stretched the vocal folds, and the higher the breath pressure, the higher the frequency of the sound produced.

Craniometric and associated factors

The author devised the following series of measurements, suitable for use on living subjects, using a standard text on skeletons (Brothwell, 1972).

Number	Measurement	Standard symbol
I	Glabella to maximal occipital point. (Tape).	——
II	Glabella to maximal occipital point. (Callipers). (= maximum cranial length).	L
III	Glabella to gnathion. (Callipers).	——
IV	Circumference of skull. (Tape).	——
V	Bi-parietal breadth. (Callipers). (= maximum cranial breadth).	B
VI	Bi-zygomatic breadth. (Callipers). (= greatest breadth between the zygomatic arches).	J
VII	Bi-gonial breadth. (Callipers). (= distance between the gonia).	Go Go
VIII	Mental protuberance to angle of mandible. (Callipers).	——
IX	Distance between tips of upper and lower incisors, with mouth wide open. (Callipers).*	——

*The maximum opening of the mouth may be of importance in relation to vowel formants: see below.

Cephalic Index: this is found as follows:

$$\frac{\text{Maximum cranial breadth (B)}}{\text{Maximum cranial length (L)}} \times 100$$

Subjects are classified as follows:

Dolichocephalic:	<75·0
Mesocephalic:	75·0–79·9
Brachycephalic:	80·0–84·9
Hyperbrachycephalic:	>85·0

'. . . in most homogeneous groups, there will be a tendency for most indices to fall in one of these sections . . .' (Warwick and Williams, 1973).

In this respect, all subjects, except *F12, could probably be said to be part of a homogeneous racial group. *F12's mother was a Caucasian, but her father was a Micronesian.

Most appreciable skull growth is completed before singing training

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normally begins, but as the growth of the rest of the skeleton is completed later (Warwick and Williams, 1973), the author believes that the postural demands of singing and the demands on the ribcage may have an effect upon such growth.

Mouth and Jaw

Most good singers can lay their tongues flat when singing, presumably providing increased space for resonance. Flattening of the tongue also assists the lowering of the larynx during 'covered' singing (See below). The movements of the lips, jaw and tongue constrict or dilate the vocal tract, thus altering the resonator.

Dental information was collected from subjects, and recorded in the standard manner adopted by dentists. Teeth may have some significance acoustically, and it has sometimes been claimed that they act as a 'sounding-board'.

Nasal cavities

A deviated nasal septum or an inflammatory process is known to create a nasal tone (Kambata, 1977). The singing voice of the author (*M11) showed an improvement in this respect following septoplasty after the period of the present study.

Sinuses of the skull

'In spite of the frequently mentioned term 'sinus tone' amongst singers and vocal teachers, the paranasal sinuses do not appreciably alter the resonance of the voice' (Kambata, 1977).

'The frontal sinuses are frequently vestigial, and apparently not associated with any particular vocal characteristic' (Young, 1977).

'The function of the sinuses is doubtful. They lighten the skull and add resonance to the voice . . .' (Warwick and Williams, 1973).

There is obviously much divergence of opinion regarding the function of the sinuses. The author tried to devise a method of estimating sinus size without using X-ray techniques, but much investigation proved this to be impossible. There also appeared to be little hope of locating X-ray plates of famous singers which might show the sizes of their sinuses (Bashford, 1977).

It seems likely that 'sinus sufferers' produce a 'nasal' voice because blockage of the eustachian tubes leads to an alteration in the sounds perceived (Young, 1977).

There is some evidence that the head cavities are relatively spacious in low voices and small in high voices (Luchsinger and Arnold, 1965).

Height

Height and cephalic index give a good idea of physical build. There is much evidence to suggest that basses tend to be tall and athletic, whilst tenors are often short and pyknic. This was generally true of the subjects of

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this study, and this confirms the author's general experience. Baritones tend to form a rather heterogeneous group as far as body type is concerned. No similar bodily differences appear to have been suggested for female singers, and none was apparent in the subjects studied.

Vocal resonance

The resonances of the vocal tract enhance certain *partials* of the sound source. (Those partials related to the *fundamental* by multiples of 1, 2, 3, 4, etc. are called *harmonics).* Terms used by singers such as 'chest resonance', 'head resonance', and 'singing in the mask' probably describe vibration sensations which provide a proprioceptive 'feedback' mechanism for the singer (Sundberg, 1974, 1977; Young, 1977).

Nevertheless, the theory of 'vocal registers' is adhered to by many singers and teachers, and may be generally summarized as follows:

Head register

Middle register: approximately:
- soprano: F_4–F_5
- mezzo-soprano: E_4–E_5
- contralto: D_4–D_5
- tenor: F_3–F_4
- baritone: E_3–E_4
- bass: D_3–D_4

Chest register

Even if this is really a psychological phenomenon, much effort is devoted to acquiring an even tone 'across the break'. (Listen to the 'chest-break' of virtually any contralto singing 'But Who May Abide the Day of His Coming' from Handel's 'Messiah').

Formants are peaks in the sound spectrum which include one or more harmonics, and are independent of the pitch being sung. Each vowel has characteristic formants, and the *exact* position of the intensity maximum within a formant area depends upon the pitch of the fundamental harmonic.

Alterations of the shape of the vocal tract shift formant frequencies, and singers use this technique to improve resonance and tone quality. Thus the quality of a sung vowel tends to deteriorate as the pitch is raised, and listeners therefore complain that opera singers are unintelligible!

Most trained singers use the technique of 'covered' singing, whereby vowels are darkened on high pitches. The opposite, 'open' singing, is offensive to the ears of most discriminating listeners. Adjustments of the vocal tract which accompany covering are similar to those involved in yawning. Flattening of the tongue assists the lowering of the larynx, leading to increased resonance in the widened supraglottic tube (Luchsinger and Arnold, 1965).

The present study included the analysis of sung tones by a Mini-Ubiquitous Spectrum Analyser, Model 440A, manufactured by Nicolet

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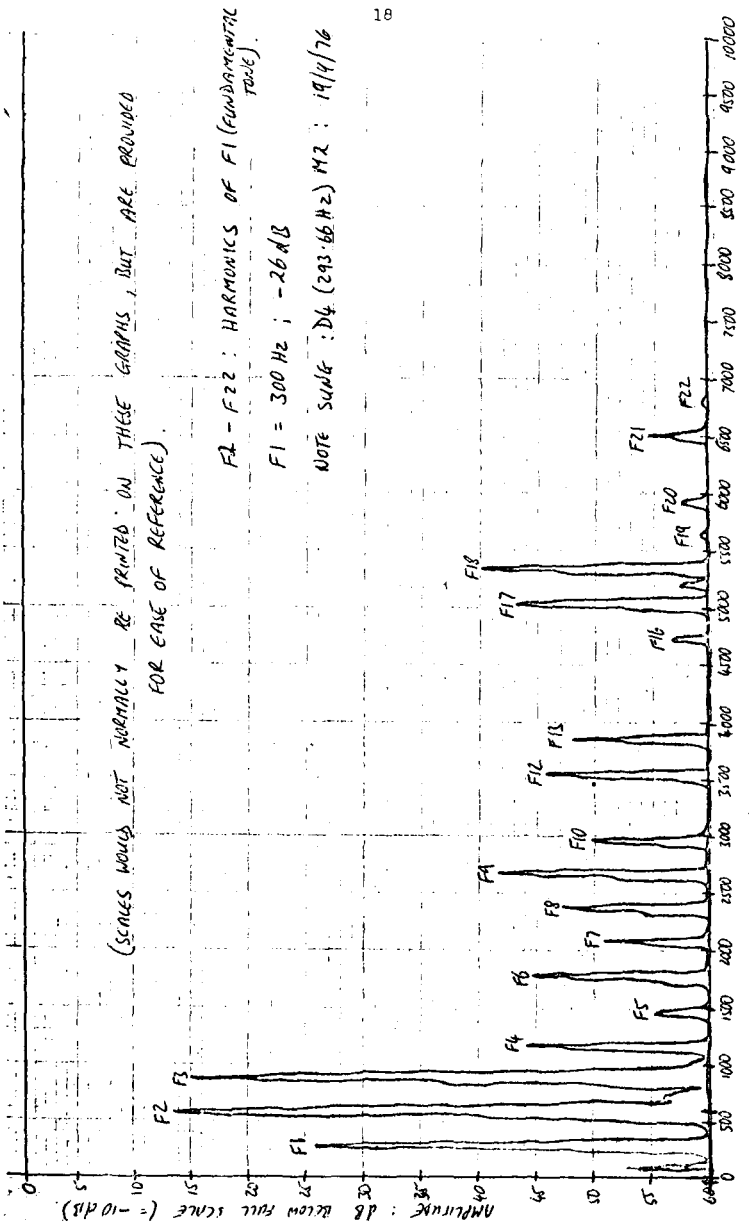


FIG. 2

An example of a sound spectrograph produced during the present study by the mini-ubiquitous spectrum analyser.

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Instruments Limited. A special computer program ('SPEC') was designed by the author to handle the results of sound spectrum analysis. The object was to look for differences in the harmonic structures of tones sung by singers and non-singers, and differences between sung and spoken tones. In addition, an attempt was made to link harmonic structures with 'psychological sound qualities' suggested by Luchsinger and Arnold (1965), *viz.*:

'Dark' timbre [i.e. covered]: low partials predominate.
'Light' timbre [i.e. open]: higher partials predominate.
'Dull' timbre: too few higher harmonics.
'Shrill' timbre: too many higher harmonics.
'Sharp' timbre: emphasis of the range 3000 Hz to 4000 Hz.

In fact, the author's results were remarkable in the *lack* of correlation which they showed in respect of the above scheme.

The *singing formant* is a peak in the sound spectrum at about 2800 Hz, produced by professional male opera singers. This enables the voice to carry over the sound of an orchestra, whose highest sound level is at about 450 Hz. (Sundberg, 1977). The higher female voices do not need this formant. The singing formant was looked for in the sounds analysed during this study.

Hearing

The author was interested in envestigating whether musicians have a lower auditory threshold than other people, a view held by some, for example Miller (1975). Subjects' hearing levels were measured in the usual manner, using an Amplivox audiometer, model 83, and audiograms were plotted. In order to simplify statistical procedures, the data from each subject were grouped in three sections, *viz.*: total numbers of readings from both ears showing a hearing loss of more than 10 db. at frequencies below 1000 Hz, at 1000 Hz, and at frequencies above 1000 Hz.

Females are said to hear higher pitches than males, and the author wondered whether this was true of the subjects studied. Also, it was felt that such an ability might be a necessity, because women *vocalize* higher pitches than men, with correspondingly higher partial tones. The maximum audible frequencies detected by subjects were therefore measured with a signal generator and headphones.

It is worth noting that some authorities (e.g. Hood, 1977) state that we hear our own voices at a higher level than would a listener nearby, but this is not true, in the author's experience, when singing in an ensemble. In this case, '[the] sense of vocal effort may be the only guide the individual singer has to judge his own sound intensity when singing in close proximity to other singers' (Sears, 1977). This is corroborated by Borg and Zakrisson (1975), who believe that a link between the laryngeal nervous system and the middle-ear nervous system may facilitate the damping of one's own voice when talking [and singing?].

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Health

In general, all the subjects of this study were in good health, but M4 suffered from multiple sclerosis, which may have accounted for his slightly monotonous speaking voice.

Subjects' weights were recorded at each session.

The statistical analysis of collected data

It is not possible to tabulate here the large amount of data which was collected from subjects. These data can be examined in the original thesis, or are available in tabulated form from the author.

It was important to consider whether all subjects were members of the same, or different, populations as far as different variables were concerned, and so they were grouped in different ways, repeating the analyses for each grouping:

	Maximum total
1. Population of singers and non-singers (W).	29
2. Population of all males (♂).	12
3. Population of all females (♀).	17
4. Population of all singers (S).	16
5. Population of all non-singers (N).	13

Variances of the population pairs ♂ and ♀, and S and N were compared for each variable, to check whether these could effectively be grouped as one population in each case.

Ninety-five per cent *confidence limits* were used, as in much work of a biological nature, i.e. a *probability level* of $p = 0{\cdot}05$. As the sample numbers were small, *'Student's t'* was used in place of the *standardized normal deviate, d.*

Most statistical tables consulted were by Fisher and Yates (1963), but others by Campbell (1967), Frank (1974), and Lindley and Miller (1953) were also used.

Where a set of data showed a *coefficient of variation* greater than 10 per cent, it was regarded with great caution.

The following procedures, A to D, were employed. A, B and C involved computer programs specially written by the author, in BASIC language. (Details are available in the original thesis, or from the author).

A. Processing of each set of data for each population, in order to determine the basic statistical parameters, such as $\bar{x}$; s^2; s; t at $p = 0{\cdot}05$, etc. A program called STAT II was used, which was modified from a program published by Kemeny and Kurtz (1971).

B. Processing of sets of data for each population where differences were observed between readings taken on different occasions. This highlighted subjects with abnormal variations in any particular factor, such as F.V.C., between two sessions. The method was

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devised specifically for this study, not having been noted elsewhere. The program STAMOD was used here.

C. The data analysed in B were subjected to a *paired-sample test,* as described by Parker (1973). This found any overall differences in a factor between two sessions for a *complete* sample of individuals. Thus it was possible to see whether *all* singers showed a significant difference over a period of time, as compared with *all* non-singers, for example. The program STTWO was used here.

D. Analyses of *linear regression* and the *correlation coefficient* were carried out on data relating to pairs of variables, such as phonation time and F.V.C., for example, which might have been expected to show some degree of correlation. A Sinclair Cambridge Programmable calculator was used, programs being provided by the manufacturer (Sinclair Radionics Ltd., 1977). More weight was attached to regression analysis than correlation methods, as it is usually the rule for the former to be more appropriate (Bailey, 1959). Scatter diagrams were plotted where a relationship between two variables was indicated.

Results

Again, it is not possible to discuss the results in detail, and what are considered to be the most important or significant findings are outlined here. It is most important to realize that the main constraint when analysing data was that resulting from the small sample sizes involved. The author was very conscious of this fact, and the results shown below must be treated with caution. Nevertheless, there are some potentially interesting findings, which would warrant further, more detailed, study.

No general differences in personality were observed between the population groups. However, the author's subjective opinions about a number of subjects' personalities were strongly confirmed by the E.P.I.

Diaphragm expansion was not generally found to be greater in singers than non-singers, and singers did not show consistently longer phonation times than non-singers. Diaphragm expansion was not correlated with any lung measurements, but it did correlate to some extent with phonation time. F.V.C. also correlated quite well with phonation time, and this would be expected.

No obvious differences in lung function were noted between singers and non-singers, in general, with individual exceptions. In particular, M9 showed a significantly low value for $F.E.V._{1\%}$ observed/expected $\times 100\%$. This may well have been related to his strenuous exercise habits (an effect noted earlier). $F.E.V._{1\%}$ generally fell as subjects' heights rose. F11, for example, tended to show low values for $F.E.V._{1\%}$ which could have been related to her above-average height and large frame. This combination of features might, presumably, like the effects of exercise, lead to a large F.V.C., but not an increased $F.E.V._1$, thus lowering the $F.E.V._{1\%}$, and

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indicating an obstructive ventilatory defect on Miller's Prediction Quadrant.

*M11 (the author) also tended to show low values of F.E.V.$_{1\%}$, which could have been related to exercise undertaken during his extensive singing experience. However, he had a history of asthma in childhood, and, latterly, hay-fever.

F.V.C. generally rose with increasing height, as expected, and there was also some indication that the vocal range became smaller as F.V.C. and height increased. This is contradictory to a view attributed to Preissler by Luchsinger and Arnold (1965), that basses (who are usually taller than tenors) have wider vocal ranges than tenors. Observations made of subjects certainly supported the widely-held view that the vocal range is extended by vocal training.

It seems possible that some unexplained variability in the F.V.C. observed/predicted $\times 100\%$ data from females was caused by the menstrual cycle. Subjects were not asked for the dates of menstruation, as very personal questions might have destroyed their co-operation. M4, who had multiple sclerosis, showed great inconsistency in several lung measurements.

Males and females appeared to be members of the same populations for all craniometric measurements apart from bi-gonial breadth. (This confirms a sexual difference noted by others, e.g. Brothwell, 1972). M1 and *M2, the only true tenors, appeared to have comparatively large jaws; jaw opening is one of the important factors affecting vocal resonance.

Males and females formed different populations as far as cephalic index was concerned; this might well be expected. Skull *shape,* as shown by cephalic index, seemed to vary with height, a higher cephalic index generally being found in shorter subjects. On the whole, there was very good correlation between the different craniometric measurements in individuals.

There was some evidence that vocal ranges became wider as skull sizes decreased. *F15, the only experienced true soprano, showed a significantly small tape measurement from the glabella to the maximal occipital point. This is interesting, in view of the comment made earlier about small head cavity spaces occurring in singers with high voices.

No obvious relationships were noted between teeth and the number of fillings, and other variables.

No overall differences were observed in the numbers of harmonics in sung and spoken tones. Non-singers appeared to be no less consistent in the tonal contents of their sung sounds than singers. Male subjects tended to modify the first formant area of 'ah' more than females (possibly because of the 'covering' technique), and non-singers more than singers (possibly because of poor singing technique).

Male subjects generally produced the singing formant more often than female subjects, and singers more often than non-singers. This would be

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expected, in view of comments already made. The most experienced male singer, *M11 (the author), showed marked evidence of the singing formant. It did not appear possible to lay down specific criteria likely to be observed in the sound spectra of good voices, apart from the appearance of the singing formant in males.

No significant differences in hearing were noted between the different population groups, and there was no obvious correlation between age and the maximum audible frequency.

Further comment would be superfluous, as one should not try to read too much significance into results based upon a relatively small number of individuals. Nevertheless, it is hoped that a small contribution has been made to the study of the singing voice. There is no doubt that the author's own singing technique has been improved as a result of being made to think more carefully about voice production.

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