In laying before the Public the result of eight years' labour, I must first pay a debt of gratitude. The following investigations could not have been accomplished without the construction of new instruments, which did not enter into the inventory of a Physiological Institute, and which far exceeded in cost the usual resources of a German philosopher. The means for obtaining them have come to me from unusual sources. The apparatus for the artificial construction of vowels, described on pp. 121 to 126, I owe to the munificence of his Majesty King *Maximilian* of Bavaria, to whom German science is indebted, on so many of its fields, for everready sympathy and assistance. For the construction of my Harmonium in perfectly natural intonation, described on p. 316, I was able to use the *Soemmering* prize which had been awarded me by the *Senckenberg Physical Society* at Frankfurt-on-the-Main. While publicly repeating the expression of my gratitude for this assistance in my investigations, I hope that the investigations themselves as set forth in this book will prove far better than mere words how earnestly I have endeavoured to make a worthy use of the means thus placed at my command. [vi]

Among musical instruments, the harmonium, on account of its uniformly sustained sound, the piercing character of its quality of tone, and its tolerably distinct combinational tones, is particularly sensitive to inaccuracies of intonation. And as its vibrators also admit of a delicate and durable tuning, it appeared to me peculiarly suitable for experiments on a more perfect system of tones. I therefore selected an harmonium of the larger kind, with two manuals, and a set of vibrators for each, and had it so tuned that by using the tones of the two manuals I could play all the major chords from $F_\flat$ major to $F_\sharp$ major.

This instrument therefore furnishes 15 major chords and as many minor chords, with perfectly pure Thirds, but with Fifths too flat by ⅛ interval by which an equally tempered Fifth is too flat.

On the Lower Manual we have the [316] complete scales of $C_\flat$ major and *G* major and in the upper the complete scales of $E_\flat$ major and B major inclusive complete. All the major scales exist from $C_\flat$ and they can all be played with perfect exactness in the natural intonation. But to modulate beyond B major on the one side and $C_\flat$ major on the other, it is necessary to make a really enharmonic interchange between B_1 and $C_\flat$, which perceptibly alters the pitch (by a comma $^{81}/_{80}$). The minor modes on the lower manual are B_1 minor or $C_\flat$ minor complete, on the upper manual $D_{1\sharp}$ minor or $E_\flat$ minor. [317]

The tuning of this instrument was easily managed. Herr Schiedmayer succeeded at the first attempt by the following direction:

Starting from a on the lower manual, tune the Fifths

d – *a*,

g – *d*,

c – *g*

perfectly just, and thus [316, fn] obtain

c,

g,

d.

Then tune the major chords

c – e_1 – *g*,

g – b_1 – *d*,

$d - f_{1\sharp} - a$,

giving the three tones

e_1,

b_1,

$f_{1\sharp}$,

and finally the Fifth,

$f_{1\sharp} - c_{1\sharp}$,

to obtain c

Then putting $e_1 = f_\flat$, $h_1 = c_\flat$, $f_{1\sharp} = g_\flat$, $c_1 = d_\flat$, tune the major chords

$f_\flat - a_{1\flat} - c_\flat$,

$c_\flat - e_{1\flat} - g_\flat$,

$g_\flat - b_{1\flat} - d_\flat$,

with pure Thirds giving no beats, thus obtaining $a_{1\flat} - e_{1\flat} - b_{1\flat}$, and finally the Fifth $b_{1\flat} - f_1$ giving f_1.

This completes the tuning of the notes on the lower manual.

For the upper manual first tune e as the perfect Fifth of the *a* in the lower manual, and then the three major chords

$e - f_{1\sharp} - b$,

$b - d_{1\sharp} - f_\sharp$,

$f_\sharp - a_{1\sharp} - c_\sharp$,

and the Fifth

$a_{1\sharp} - e_{1\sharp}$, giving b, $f_\sharp$, $c_\sharp$, and then $g_{1\sharp}$, $d_{1\sharp}$, $a_{1\sharp}$, $g_{1\sharp}$ and also $e_{1\sharp}$.

Then put $g_{1\sharp} = a_\flat$, $d_{1\sharp} = e_\flat$, $a_{1\sharp} = b_\flat$, $e_{1\sharp} = f$, and tune the Thirds in the major chords

$a_\flat - c_1 - e_\flat$,

$e_\flat - g_1 - b_\flat$,

$a_\flat - d_1 - f$,

and the Fifth

$d_1 - a_1$

This […] completes the whole tuning, which is much easier than for a series of equally tempered tones. [317, fn]

As regards musical effect, the difference between the just and the equally tempered, or the just and the Pythagorean intonations, is very remarkable. The justly intoned chords, in favourable positions, notwithstanding the rather piercing quality of the tone of the vibrators, possess a full and as it were saturated harmoniousness; they flow on, with a full stream, calm and smooth, without tremor or beat. Equally tempered or Pythagorean chords sound beside them rough, dull, trembling, restless. The difference is so marked that every one, whether he is musically cultivated or not, observes it at once. Chords of the dominant Seventh in just intonation have nearly the same degree of roughness as a common major chord of the same pitch in tempered intonation. The difference between natural and tempered intonation is greatest and most unpleasant in the higher Octaves of the scale, because here the false combinational tones of the tempered intonation are more observable, and the number of beats for equal differences of pitch becomes larger, and hence the roughness greater. [319]

But it is impossible not to acknowledge that at the present day few even of our opera singers are able to execute a little piece for several voices, when either totally unaccompanied, or at most accompanied by occasional chords (as, for example, the trio for the three masks, *Protegga il giusto cielo*, from the finale to the first act of Mozart's *Don Giovanni*), in a manner suited to give the bearer a full enjoyment of its perfect harmony. The chords almost always sound a little sharp or uncertain, so that they disturb a musical hearer. But where are our singers to learn just intonation and make their ears sensitive for perfect chords? They are from the first taught to sing to the equally-tempered pianoforte. If a major chord is struck as an accompaniment, they may sing a perfect consonance with its root, its Fifth, or its Third. This gives them about the fifth part of a Semitone for their voices to choose from without decidedly singing out of harmony, and even if they sing a little sharper than consonance with the sharp Third requires, or a little flatter than consonance with the flat Fifth requires, the harmoniousness of the chord will not be really much more damaged. The singer who practises to a tempered instrument has no principle at all for exactly and certainly determining the pitch of his voice. [326]

And after all, I do not know that it was so necessary to sacrifice correctness of intonation to the convenience of musical instruments. As soon as violinists have resolved to play every scale in just intonation, which can scarcely occasion any difficulty, the other orchestral instruments will have to suit themselves to the correcter [sic!] intonation of the violins. Horns and trumpets have already naturally just intonation. [327]

Orchestral instruments can generally alter their pitch slightly. Bowed instruments are perfectly unfettered as to intonation; wind instruments can be made a little sharper or flatter by blowing with more or less force. They are, indeed, all adapted for equal temperament, but good players have the means of indulging the ear to some extent. Hence, passages in Thirds for wind instruments, when executed by indifferent players, often sound desperately [wrong], whereas good performers, with delicate ears, make them sound perfectly well. [324]

For singing, intonation is perfectly free, whereas on bowed instruments, the five tones of the open strings at least have an unalterable pitch.

In singing the pitch can be made most easily and perfectly to follow the wishes of a fine musical ear.

Hence all music began with singing; and singing will always remain the true and natural school of all music. The only intervals which singers can strike with certainty and perfection, are such as they can comprehend with certainty and perfection, and what the singer easily and naturally sings the bearer will also easily and naturally understand. [325]

Hermann von Helmholtz *On the Sensations of Tone as a Physiological Basis for the Theory of Music.* 1912; Longmans, Green