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Center for the Study of
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(The Graduate Center,
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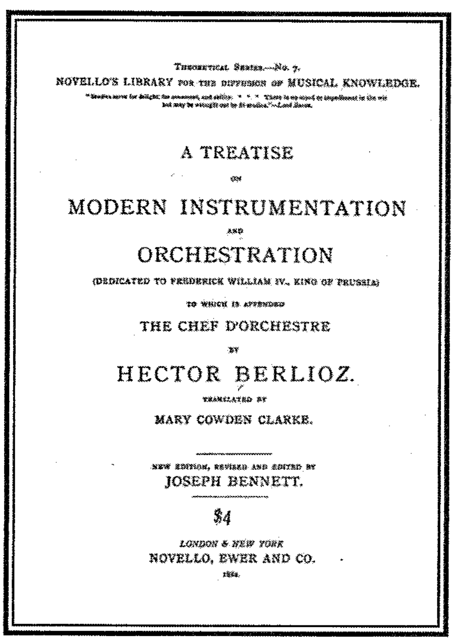
The English Concertina as an Instrument of Science

ANNA GAWBOY

If an 1851 visitor to London's Great Exhibition entered the Crystal Palace, ascended to the upper floor, and proceeded to the North Gallery, she would have been surrounded by an overwhelming array of objects listed in the catalogue under Class X, "Philosophical instruments and miscellaneous contrivances." Class X included "telescopes, microscopes, barometers, thermometers, areometers, scales, balances, nautical instruments, and various others used to illustrate the laws of mechanics, optics, light, heat, and electricity,"[1]but also included the subclasses of timepieces and musical instruments. If our visitor made her way to exhibit 526, she would have beheld Charles Wheatstone's 48-key English treble concertina, as well as baritone, concert tenor, concert bass, and double models.[2]

The English concertina did not win a medal at the exhibition.[3] In fact, one musical juror took an exceptional dislike to the concertina, as he later revealed in print. This juror was the composer Hector Berlioz, who published a critique of the concertina in the second edition of his orchestration treatise (see Fig. 1). Berlioz objected to the concertina's quarter-comma meantone temperament, which he believed would cause grating discords with an equally-tempered pianoforte or with the expressive intonation of a violin. [4] Quarter-comma meantone prioritized major thirds in pure (or nearly pure) 5:4 ratio, which meant that the concertina's A-flats and E-flats were tuned slightly higher than its corresponding G-sharps and D-sharps.[5] Berlioz noted that these inflections diametrically opposed those commonly used by string players, who tended to play sharped leading tones (such as G-sharp to A) slightly higher and flat upper neighbors (such as A-flat to G) slightly



THEORETICAL SERIES.—No. 7.
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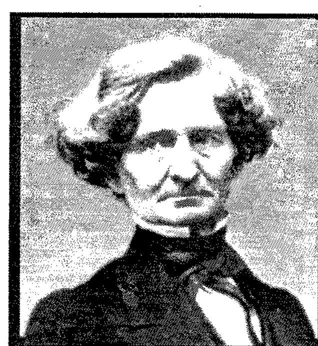
A TREATISE
ON
MODERN INSTRUMENTATION
AND
ORCHESTRATION
(DEDICATED TO FREDERICK WILLIAM IV., KING OF PRUSSIA)
TO WHICH IS APPENDED
THE CHEF D'ORCHESTRE
BY
HECTOR BERLIOZ.
TRANSLATED BY
MARY COWDEN CLARKE.

NEW EDITION, REVISED AND EDITED BY
JOSEPH BENNETT.

$4

LONDON & NEW YORK
NOVELLO, EWER AND CO.
[illegible]



Hector Berlioz

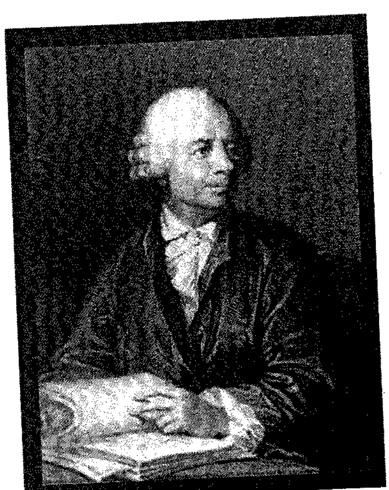
FIG. 1

lower. But these difficulties were merely symptoms of a greater problem that Berlioz identified with the concertina: the fact that it had been invented by a scientist, Charles Wheatstone. Berlioz heard the concertina's pure major thirds as a hallmark of the speculative acoustic tradition, which he characterized as the domain of mathematicians, obsessed with musical ratios and out-of-touch with a living musical practice. "[The concertina] thus conforms to the doctrine of the acousticians, a doctrine entirely contrary to the practice of musicians," Berlioz wrote. "This is a strange anomaly."[6]

Berlioz objected to the idea that musical consonance was defined by mathematics and was limited to intervals expressed by ratios involving the first six whole numbers, such as the pure 5:4 major third. But in real musical practice, musicians often performed intervals that deviated from the acoustic ideal by varying amounts. These minimal deviations were still largely considered consonant, even though the ratios of tempered intervals were considerably more complex. Berlioz continued,

> This ancient endeavor of the acousticians to introduce at all risks the result of their calculations into the practice of an art based especially on the study of the impression produced by sounds upon the human ear, is no longer maintainable now-a-days. So true is it, that Music rejects it with energy; and can only exist by rejecting it.[7]

In just a few sentences, Berlioz placed the concertina at the center of the ancient debate regarding the relationship of musical theory and musical practice. In his view, there was a fundamental incompatibility between the acoustician's music of the mind and the musician's music of the senses. But, at the time of Berlioz's writing, a debate was heating up within the field of



Leonhard Euler

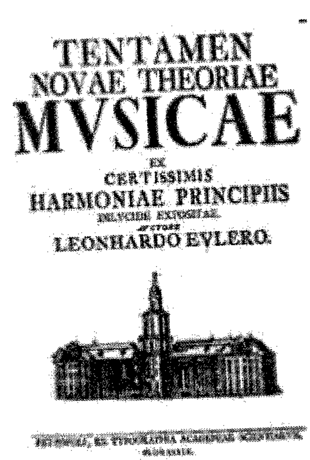


FIG. 2

theoretical acoustics over incongruities between what calculation predicted and what the senses perceived in experiments.[8] The dispute would eventually result in a reconsideration of the definition of consonance, and would energize the emerging field of physiological acoustics, leading to new theories regarding how the ear processed sound. And interestingly, among fellows of British Royal Society, Wheatstone's English concertina gained a reputation as a tool for experimental investigation and the public demonstration of these new theories. As an instrument of musical science, the English concertina blurred the boundary between subclasses of instruments exhibited in Class X at the Crystal Palace.

Wheatstone, Euler, and the concertina's just major thirds

Berlioz correctly intuited that Wheatstone's preference for 5:4 major thirds stemmed from his studies of theoretical acoustics, particularly the work of the eighteenth-century Swiss mathematician Leonhard Euler.[9] In an 1864 paper delivered before the Royal Society, Wheatstone's colleague Alexander John Ellis revealed that "the concertina, invented by Prof. Wheatstone, F.R.S., has 14 manuals to the octave, which were originally tuned as an extension of Euler's 12-tone scheme."[10]

Ellis was referring to a particular tuning that Euler had presented in his 1739 treatise, *Tentamen novae theoriae musicae* (*An attempt at a new theory of music*—see Fig. 2).[11] Euler's main objective in the *Tentamen* was to "present a comprehensive mathematical definition" of musical consonance, or, as he called it, musical "agreeableness." According to Euler, the human mind delighted in simplicity and order. It followed, then, that music was most agreeable when the relationships among tones were easiest for the mind to intuit. Since Euler believed that simple ratios involving small whole numbers were easier to grasp than complex ratios, he posited that musical relationships expressed by ratios involving the numbers 2, 3, and 5, their powers and their multiples, were the most pleasing.[12]

Of course, the idea that musical consonance had something to do with ratios involving small whole numbers was an ancient one, but Euler's approach to the subject was unique. In the *Tentamen,* he devised a formula to calculate the unique "degree of consonance" for any group of musical tones, as well as a system to rank the degree of consonance based on the least common multiple of the integers comprising the collection's ratio. Altogether Euler calculated eighteen separate pitch collections containing the most pleasing combinations of tones, according to his theory. These collections, or "genera," ranged from the first genus containing just two notes, a pitch and its octave, to the diatonic-chromatic genus, which corresponded to a twelve-note chromatic scale in just intonation.[13]The diatonic-chromatic genus represented the culmination of Euler's calculations and was his primary focus in the *Tentamen.* It was this scale that Ellis referred to as "Euler's 12-tone scheme."

In the *Tentamen*, Euler showed how the diatonic-chromatic genus could be generated from a very basic tuning method using only 3:2 perfect fifths and 5:4 just thirds. Beginning with a key's subdominant—for example, F in the key of C major—Euler first tuned a just 5:4 third, yielding A, and a fifth in 3:2 ratio, yielding C. His second step was to tune just thirds and fifths from A and C respectively, generating the pitches C-sharp, E, and G. Step three involved tuning just triads from E and G, adding G-sharp, B, and D. Euler continued the process to achieve twelve pitches, adding D-sharp, F-sharp, and A-sharp.[14]

Euler called his diatonic-chromatic genus "the most perfect genus, the genus best suited for producing harmony," claiming that it possessed "as many tones as harmony requires, no more and no less, and all the tones will have among themselves the relationship determined from the laws of harmony."[15] Given Euler's elevated rhetoric, it is perhaps not surprising that Wheatstone chose to tune his early instruments to the diatonic-chromatic genus.

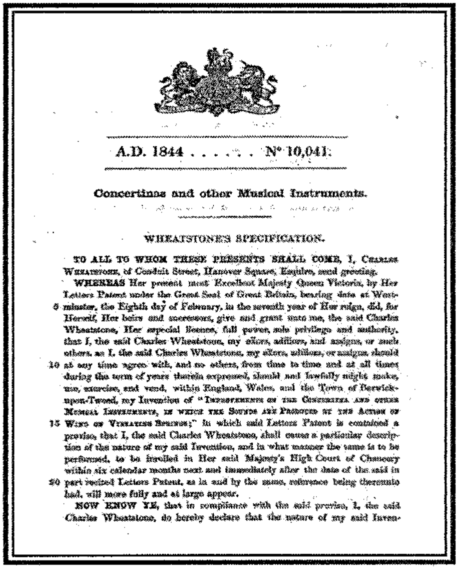
But Euler's claims were not exactly true, at least not for all chords in all keys. Just intonation was beloved by acousticians because of its high percentage of pure triads, but such perfection cannot be achieved uniformly for all scales if the instrument has fixed tones and a limited number of keys per octave.[16] Euler's diatonic-chromatic genus, containing twelve tones, possessed only six pure major triads (on E, F, A, B, and C) and six pure minor triads (on G-sharp, A, B, C-sharp, D-sharp, and E). Other triads in his system could differ from their pure forms by as much as a diesis (41 cents) or a syntonic comma (21.5 cents), which was enough to make the triad sound noticeably different.[17]

Wheatstone recognized these limitations on Euler's diatonic chromatic genus. In order to increase the number of pure thirds available on the concertina, he extended Euler's twelve-note scale to fourteen notes, subtracting the A-sharp and adding A-flat, E-flat, and B-flat, presumably each tuned in pure 5:4 thirds down from the C, G, and D, respectively. This procedure resulted in separate buttons for the pairs A-flat/G-sharp and E-flat/D-sharp. A concertinist could then play pure major triads rooted on A-flat, E-flat, F, C, G, A, E, B, and pure minor triads rooted on C, G, F, A, E, B, C-sharp, and G-sharp.

Ellis wrote that the justly-tuned concertina "possessed the perfect major and minor scales of C and E," but there were still problems. The roughness of chords on B-flat, D, and F-sharp—with fifths a syntonic comma too narrow—"led to the abandonment of this scheme, and to the introduction of a tempered scale."[18] The first temperament to replace just intonation was, according to Ellis, quarter-comma meantone.[19] This temperament entailed splitting the problematic syntonic comma into four parts and narrowing each fifth on the concertina by that amount, roughly equal to five cents.[20] Ellis reported that quarter-comma meantone expanded the concertina's useable major keys to E-flat, B-flat, F, C, G, D, A, and E, and its useable minor keys to C, G, D, A, and E.[21]

But the concertina's thirteen useable keys in meantone temperament were not enough to impress Berlioz at the Great Exhibition of 1851. The concertina's thirds were still tuned very close to their pure forms, which Berlioz detested. Furthermore, meantone temperament generated wolf intervals that were very harsh indeed. If a player tried to substitute B-flat for A-sharp in an F-sharp major triad, the third of the chord would be too high; if a player tried to substitute C-sharp for D-flat in a D-flat major triad, the fifth between C-sharp and A-flat would be too wide. Berlioz was an advocate for equal temperament for instruments with fixed tones, such as the piano and concertina.[22] Not only would equal temperament eliminate the wolves, allowing the concertina to modulate freely to all twenty-four major and minor keys, it would also slightly widen the major thirds and narrow the minor thirds, which Berlioz heard on the meantone concertina as respectively too narrow and too wide.[23]

Wheatstone was fully aware of the advantages of equal temperament, especially in respect to modulation. In fact, seven years before the Crystal Palace exhibition, Wheatstone had registered a patent for the Double concertina, an instrument specifically designed for equal temperament and easy modulation to all 24 keys. Equal temperament allowed Wheatstone to reduce the Double's accidentals from seven to just five: B-flat, E-flat, F-sharp, C-sharp, and G-sharp. In addition, his


A.D. 1844 . . . . . . N° 10,041.

Concertinas and other Musical Instruments.

WHEATSTONE'S SPECIFICATION.

TO ALL TO WHOM THESE PRESENTS SHALL COME, I, CHARLES WHEATSTONE, of Conduit Street, Hanover Square, Esquire, send greeting.

WHEREAS Her present most Excellent Majesty Queen Victoria, by Her Letters Patent under the Great Seal of Great Britain, bearing date at Westminster, the Eighth day of February, in the seventh year of Her reign, did, for Herself, Her heirs and successors, give and grant unto me, the said Charles Wheatstone, Her special licence, full power, sole privilege and authority, that I, the said Charles Wheatstone, my exors, admors, and assigns, or such others as I, the said Charles Wheatstone, my exors, admors, or assigns, should at any time agree with, and no others, from time to time and at all times during the term of years therein expressed, should and lawfully might make, use, exercise, and vend, within England, Wales, and the Town of Berwick-upon-Tweed, my Invention of "IMPROVEMENTS IN THE CONCERTINA AND OTHER MUSICAL INSTRUMENTS, IN WHICH THE SOUNDS ARE PRODUCED BY THE ACTION OF WIND ON VIBRATING SPRINGS;" in which said Letters Patent is contained a proviso, that I, the said Charles Wheatstone, shall cause a particular description of the nature of my said Invention, and in what manner the same is to be performed, to be inrolled in Her said Majesty's High Court of Chancery within six calendar months next and immediately after the date of the said in part recited Letters Patent, as in and by the same, reference being thereunto had, will more fully and at large appear.

NOW KNOW YE, that in compliance with the said proviso, I, the said Charles Wheatstone, do hereby declare that the nature of my said Inven-

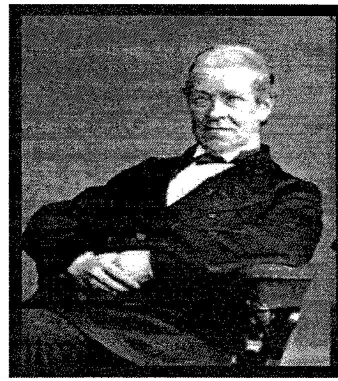

Charles Wheatstone

FIG. 3

innovative arrangement of the keys allowed scales related by major thirds to be fingered in precisely the same way, thereby limiting the number of scale fingerings a player would actually have to learn.[24] An early advertisement stated that "the Double Concertinas are tuned to the equal temperament, as Pianofortes are now tuned; this not only dispenses with the extra notes (viz. the difference between G sharp and A flat, and D sharp and E flat), which are absolutely required to make the principal chords sound agreeably on the usual Concertina, but also makes the tune in all the keys on the Double Instrument more equally perfect."[25]

Because equal temperament has become ubiquitous today, it is tempting to see the equally-tempered Wheatstone Double as a progressive, forward-looking instrument. Wheatstone registered his patent in 1844 (see Fig. 3), two years before the English piano manufacturer Broadwood and Sons converted all their instruments to equal temperament.[26] But for two decades (or possibly longer), equal temperament was merely an option at Wheatstone & Company, as they—and other manufacturers—continued to produce and market instruments in meantone temperament well into the 1860s, alongside equally-tempered models.[27]

An aspiring mid-nineteenth century concertinist was thus faced with a dilemma. Meantone or equal temperament? Both systems had their advantages and disadvantages. Like just intonation, mean-tone temperament yielded better-sounding triads, but these were limited to certain chords in certain keys. Equal temperament allowed free modulation to every key, but the triads sounded arguably worse. The choice of temperament also depended on the type of ensemble in which the concertinist hoped to perform. It was thought that just intonation and meantone temperament were better suited to vocal ensembles, and equal temperament was better suited to performances with the piano.[28] In 1865, the amateur concertinist William Cawdell presented the dilemma as a matter of taste, writing, "[the concertina] may be tuned to equal or unequal temperament and to any pitch that may be desirable; indeed, connoisseurs frequently have several instruments of different pitch and quality of tone, and sometimes more than one set of notes to the same instrument, an arrangement which affords advantages unattainable by any other means and of incomparable value under certain circumstances."[29]

Wheatstone's concertina patents do not make any direct reference to tuning or temperament, but they do show his awareness of the practical issues arising from the various intonation systems. He grappled with the problem of making the concertina as adaptable to as many tastes and performance situations as possible. One of Wheatstone's proposed solutions was a mechanism by which the performer could alter the pitch of any note by lengthening or shortening the vibrating spring by means of a sliding plate controlled by a screw.[30] According to Wheatstone, this enabled "the notes of the concertina to be tuned at pleasure, by which its pitch may be adapted to that of any other musical instrument which it may be required to accompany, or certain notes may be altered at will to render the instrument more perfectly in tune for the key in which a piece of music is to be performed."[31] Such mechanisms proved to be awkward to use in practice, and were not put into commercial production.[32]

Although the Double concertina had been introduced to the public around 1850 as an equally-tempered instrument, Wheatstone's 1844 patent also includes a Double keyboard layout that would have enabled it to be tuned in meantone temperament. The layout includes seven accidentals, with separate keys for E-flat /D-sharp and A-flat /G-sharp. Each face included eight rows of buttons, as if the layout of the treble model had been doubled and laid side-by-side.[33]

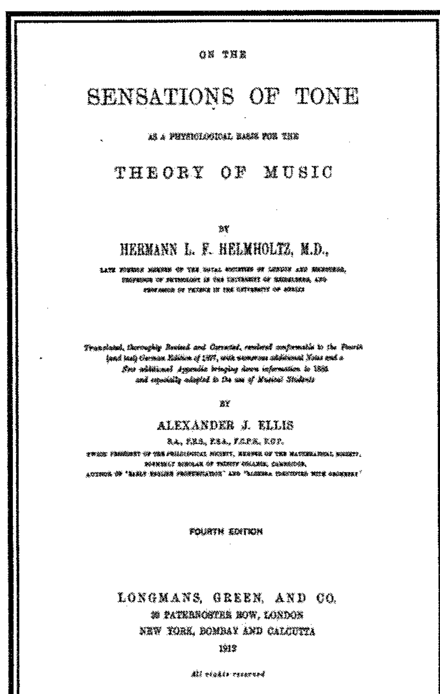
So why didn't Wheatstone and Company model its tuning practices on Broadwood and uniformly tune all their concertinas to equal temperament by mid-century? There are several possible explanations. First, equal temperament presented considerable practical difficulty for tuners. Tuners of the time plied their trade by ear, and achieving a good equal temperament was considerably more difficult than achieving a good meantone temperament.[34] In 1864, Ellis wrote that equal temperament was "so difficult to realize by the ordinary methods of tuning, that [it] has probably never been attained in this country, with any approach to mathematical precision."[35] Second, despite the conversion of Broadwood and Sons to equal temperament during the 1840s, other British instrument builders and tuners followed suit only gradually between 1850 and 1890. Ellis's survey of British organs, completed in 1880, revealed that many instruments were still in meantone temperament.[36] Third, the superiority of equal temperament was by no means a settled issue in the mid-nineteenth century. When George Herbert ordered the organ in Berkeley Square Roman Catholic Church to be retuned equally in 1854, he reported, "I was totally alone, everyone was against me, and I was about the best abused man in London for some time."[37] Fourth, as we have seen, the concertina was particularly adapted to unequal tunings. The concertina's fourteen pitches to the octave hid the wolf intervals of meantone temperament further among its "remote" chords than was possible on the piano. Additionally, the concertina's free-reed timbre with many audible partials actually caused tempered intervals, especially thirds, to sound slightly harsher than they would on a piano.[38] Finally, there is one other factor which likely influenced Wheatstone and Company's decision to retain meantone temperament at least through the 1860s: the concertina's ties to the British scientific community.

Helmholtz, the concertina, and the debate over equal temperament

By the mid-nineteenth century, temperament had become an issue of debate in musical and academic circles. One side argued that equal temperament made every key equally good, allowing free modulation. The other side argued that equal temperament made every key equally bad, as every interval (aside from octaves) was slightly mistuned from its pure form.[39] The dispute came down to differences of opinion regarding how musical consonance should be defined and what the ear could hear. Many acousticians who favored just intonation were committed to a definition of consonance based on simple ratios, which excluded the more complex ratios involved in equal temperament. Berlioz, a proponent of equal temperament, ridiculed this position on the ground that the acousticians' calculations had little relevance to practical music making, and that the musicians' ears should be the final arbiter of consonance:

> Whence it results that the sounds so-called irreconcilable by the acousticians are perfectly reconciled by musical practice; and that those relations declared false by calculation, are accepted as true by the ear, which takes no account of inappreciable differences, nor of the reasonings of mathematicians. . .
>
> These ridiculous arguings, these ramblings of men of letters, these absurd conclusions of the learned, possessed—all of them—with the mania of speaking and writing upon

Hermann von Helmholtz



ON THE

SENSATIONS OF TONE

AS A PHYSIOLOGICAL BASIS FOR THE

THEORY OF MUSIC

BY

HERMANN L. F. HELMHOLTZ, M.D.,

BY

ALEXANDER J. ELLIS

FOURTH EDITION

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39 PATERNOSTER ROW, LONDON

NEW YORK, BOMBAY AND CALCUTTA

1912

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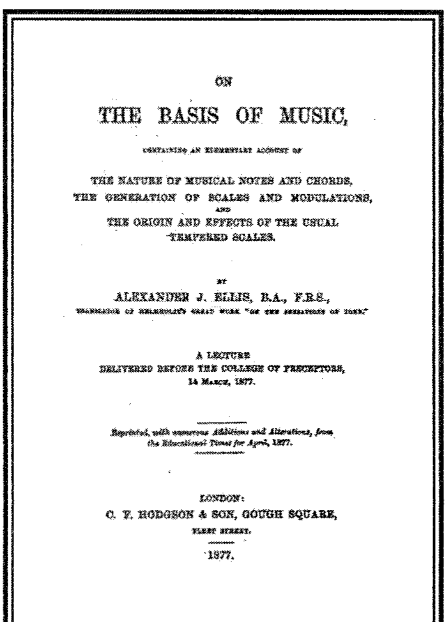
FIG. 4

an art of which they are ignorant, can have no other result than that of making musicians laugh.[40]

One problem facing acousticians was that they could not agree on a satisfactory explanation of why intervals expressed by simple ratios using the first six numbers were perceived as consonances. Euler had argued that the mind intuited the hidden order of the simple ratios and delighted in it at a subconscious level, but this theory could not account for the fact that a pure consonance sounded only slightly more smooth than an equally-tempered interval, despite equal temperament's greater complexity of ratio. Other problems vexed early nineteenth-century acousticians as well. What accounted for differences in timbre? What made a tone's fundamental more perceptible than its overtones? What accounted for the phenomena of combination tones? How, precisely, did the ear process sound?

In 1863, Hermann von Helmholtz published *On the Sensations of Tone (Die Lehre von den Tonempfindungen*, see note 19 for the full German title—see also, Fig. 4), a book that would revolutionize the field of acoustics.[41] Helmholtz synthesized previous research and data collected from nearly a decade of his own experiments to produce a comprehensive theory of musical perception which embraced its physical, physiological, and psychological dimensions. Helmholtz began by establishing that sound waves caused the internal structures of the ear to vibrate sympathetically at the same frequency. These inner-ear vibrations were then translated into impulses carried from the auditory nerve to the brain. Helmholtz proposed that the ear acted as a resonator, and that the ear's capacity to analyze the upper partials of a tone accounted for the perception of timbral difference as well as its perception of consonance and dissonance.


ON

THE BASIS OF MUSIC,

CONTAINING AN ELEMENTARY ACCOUNT OF

THE NATURE OF MUSICAL NOTES AND CHORDS,
THE GENERATION OF SCALES AND MODULATIONS,
AND
THE ORIGIN AND EFFECTS OF THE USUAL
TEMPERED SCALES.

BY
ALEXANDER J. ELLIS, B.A., F.R.S.,

A LECTURE
DELIVERED BEFORE THE COLLEGE OF PRECEPTORS,
14 MARCH, 1877.

Reprinted, with numerous Additions and Alterations, from the Educational Times for April, 1877.

LONDON:
C. F. HODGSON & SON, GOUGH SQUARE,
FLEET STREET.

1877.

Alexander J. Ellis

FIG. 5

Helmholtz theorized that when the wave-forms of the upper partials of two tones interacted in such a way to be coincident with one another, the ear perceived the resulting sound as smooth, or consonant. When the wave forms of two tones interacted in such a way to periodically cancel each other out, the ear heard the intermittent disruptions as "beats," or roughness. Helmholtz equated roughness with dissonance, positing a graduated spectrum between consonance and dissonance based on the rapidity of beats produced by any two given tones. The perception of relative consonance was also affected by combination tones, a faint third tone which arises when two pitches are sounded together under certain conditions.

Interestingly, Helmholtz's theory of consonance still favored the pure intervals of just intonation, but his careful empirical studies seemed to put his theory on a firmer foundation than Euler's vague hypotheses regarding the mind's ability to intuit the eternal beauty of ideal ratios. *On the Sensations of Tone* contains numerous descriptions of experiments and illustrations of instruments to aid the observation of musical phenomena. "All these beats of partial and combinational tone. . .are not inventions of empty theoretical speculation, but rather facts of observation, and can be really heard without difficulty by any practiced observer who performs his experiments correctly," Helmholtz wrote.[42]

The need to perform empirical investigations on instruments and to demonstrate the new acoustic paradigms transformed the English concertina into an instrument of science. This was primarily accomplished through the work of the philologist, mathematician, acoustician, and proto-ethnomusicologist Alexander John Ellis. Ellis had learned to play the English concertina as a boy, and so it was natural that he chose the concertina for his experiments with temperament.[43] But there was another reason the concertina made an ideal demonstration tool for Ellis. The concertina's partials were audible up to the eighth harmonic, making the instrument very sensitive to subtle changes in intonation.[44] Ellis possessed several concertinas tuned to different systems to facilitate their direct comparison. In this way, Ellis could make empirical judgments regarding the different qualities of Pythagorean intonation, just intonation, meantone temperament, and equal temperament.[45] Ellis's longstanding interest in the music of other cultures inspired him to test some non-western tuning systems on his English concertina. For example, he tuned one concertina so that he could compare slendro and pelog, two varieties of pentatonic scale used in Indonesian gamelan music.[46] On another concertina, Ellis replicated the Arabic lute tuning of Abdulqadir.[47]

In 1864, Ellis became acquainted with Helmholtz's theories and immediately saw their potential.[48] Ellis obtained a letter of introduction to Helmholtz through the philologist Max Müller, and offered to translate *Die Lehre* into English. When Helmholtz visited Ellis later that year to discuss the translation, Ellis played his experimental concertinas for Helmholtz.[49] The English translation appeared in 1875, with commentary and appendices by Ellis, who often referred to his own concertina experiments to elaborate points made by Helmholtz in the text (see Fig. 5).[50]

According to Helmholtz, the consonances of equal temperament were distinctly less smooth than those in just intonation, due to the interaction of the upper partials. He wrote, "it must not be imagined that the difference between tempered and just intonation is a mere mathematical subtlety without any practical value. That this difference is really very striking even to unmusical ears, is shown immediately by actual experiments with properly tuned instruments."[51] In 1864, Ellis presented a paper before the Royal Society in which he presented Helmholtz's theory of consonance and an argued for the superiority of just intonation on scientific grounds, citing his concertina experiments as evidence.

> It is easy to compare the different effects of [tuning] systems as applied to the same quality of tone, for harmonies which are common to both. Having two concertinas [tuned to mean-tone and equal temperaments, respectively] and a third tuned to just intervals, I have been able to make this comparison, and my own feeling is that the Mesotonic [i.e., mean-tone] is but slightly, though unmistakably, inferior to the Just, and greatly superior to the Hemitonic [i.e., equal temperament].[52]

He later explained,

> A triad in which the major Third is perfect, but the Fifth and minor Third both too small by a quarter of a comma or 5 1/8 cents (as in meantone temperament, in which I have a concertina tuned), has a much better effect than the equally-tempered triad, where the fifth is only one-eleventh of a comma or two cents too flat, and the major Third is seven-elevenths of a comma or 14 cents too sharp, and hence the minor Third is eight-elevenths of a comma or 16 cents too flat. The effect is much more strongly felt in playing passages than in playing isolated chords.[53]

In 1877, two years after the publication of his English translation of Helmholtz, Ellis reiterated his empirical investigations on the effect of different temperaments in a public lecture delivered before the College of Preceptors.[54] The lecture introduced Helmholtz's acoustic findings to a public audience, and launched a sustained argument in favor of just intonation. During the lecture, Ellis performed several versions of "God Save the Queen" on his concertinas to acquaint his audience with the audible differences between intonational systems. He showed how the pure harmonies of just intonation were related to the overtone series, grounding just intonation upon the natural laws of music itself. "Just intonation ensures real harmony," Ellis insisted.[55] As evidence for the expressive power of just intonation, Ellis recounted his experience listening to a concert of *a capella* singers who had been specifically trained to sing in just intonation. "I may perhaps be allowed to say that the most exquisite feelings I have ever experienced in the hearing of part music have been derived from listening to Mr. Proudman's Tonic Sol-Fa College Choir, when unaccompanied. But when it was accompanied, and all the relations were torn to pieces by the [equally-tempered] piano or organ, my ears were often so pained that I could not hear the music."[56]

In the decades following Helmholtz, many musical scientists championed the use of just intonation based on the argument that it had a "natural" justification in the overtone series. Helmholtz's theory of consonance allowed acousticians to base their preference for just intonation on empirical sensations rather than calculation alone. As we have seen, the concertina's numerous audible upper partials made it an ideal instrument for Ellis to demonstrate his argument in favor of just intonation in public lectures.[57] Wheatstone's own interest in acoustics and his professional connection to Ellis must have been yet another factor in the company's retention of meantone temperament, just intonation's more practical cousin.

The eminence of Wheatstone and Ellis permanently linked the concertina to questions of temperament in the minds of the British scientific community. In 1889, the Australian Reverend W.J. Habens submitted a paper on tuning and the musical scale to the Royal Musical Association, then a newly-formed assembly of British acousticians, musical scholars, and musicians (Habens himself was not present). In it, he defended Euler's definition of consonance and argued for the use of just intonation for the construction of a perfect musical scale. Habens's paper inspired a lively discussion among the assembled fellows, transcribed and published by the Royal Musical Association. After a consideration of whether or not ensembles of voices or stringed instruments really did perform in just intonation, George Herbert remarked, as a kind of non-sequitor,

> Did you know, by the way, that Wheatstone's concertina for twelve or fifteen years has been tuned equally? When Wheatstone brought it out he told me it was perfect [i.e., just] in 6 keys. Some years ago I had to choose a concertina for a friend by Wheatstone, and to my astonishment I found it was tuned equally. They have two keys for D-sharp and E-flat, and G-sharp and A-flat, but they give the same note. I suppose they found that they could not play with the pianoforte. Giulio Regondi, who was the finest concertina player, had two always, one for the orchestra and one for the piano.[58]

As Herbert made clear, by 1889 Wheatstone and Company had switched entirely to equal temperament for their commercial instruments, despite charges of acoustic inferiority brought against equal temperament by the scientific elite. Did Wheatstone and Company succumb to pressures of the commercial market? By the fourth quarter of the nineteenth century, the piano's commercial success and domestic popularity had made equal temperament (or its Victorian approximation) ubiquitous.

Although equally-tempered concertinas were available through the 1850s and 1860s, it is possible that a complete conversion did not occur at Wheatstone and Company until much later. Herbert's off-the-cuff estimate would place the conversion point around 1875, the year Charles Wheatstone died.[59] Like all new converts, Wheatstone and Company vilified its past ways once the switch occurred. An undated (though late nineteenth-century) Wheatstone and Company catalogue described their equal tuning as a point of pride, adding that, "nearly all inferior makes of Concertinas are tuned on a plan called unequal temperament."[60]

The details of Wheatstone and Company's tuning practices and its timeline cannot be definitively established due to lack of documentation. However, it is clear that tensions arising from the concertina's dual role as an instrument for practical music making and an instrument of science left a mark on its tuning history, and an understanding of this tension sheds some light on an obscure and convoluted thread of the Wheatstone English concertina's story.

NOTES

1.*Guidebook to the Industrial Exhibition; with Facts, Figures, and Observations on the Manufactures and Produce Exhibited* (London: Partridge and Oakey, 1851), 14.

2.Commissioners for the Exhibition of 1851, *Official Catalogue of the Great Exhibition of the Works of Industry of All Nations, 1851* (London: W. Clowes & Sons, n.d.), 72.

3.The most prestigious medal, the Council Medal, was awarded to Sebastien Érard for pianos, Adolph Sax for brass instruments (including the saxophone), Jean-Baptiste Vuillaume for stringed instruments, and Alexandre Ducroquet for organs. Charles Wheatstone did earn a less prestigious Prize Medal for his portable harmonium.

4.Hector Berlioz, *Grand traité d'instrumentation et d'orchestration modernes*, 2nd ed. (Paris: 1855), translated by Mary Cowden Clarke as *A Treatise Upon Modern Instrumentation and Orchestration* (London: Novello, Ewer and Co., 1856), 235-236. Although there are more recent and reliable translations of Berlioz's treatise, I have chosen Clarke's original English translation because Wheatstone would have had access to it.

5.For example, if C and E are tuned in pure 5:4 ratio (386 cents), and G-sharp was tuned as a 5:4 major third *up* from E, and A-flat was tuned as a 5:4 major third *down* from C, the resulting A-flat transposed up an octave would be about a diesis (41 cents) higher than the G-sharp.

6.Berlioz/Clarke, *A Treatise Upon Modern Instrumentation and Orchestration,* 235.

7.Ibid., 236.

8.See R. Steven Turner, "The Ohm-Seebeck Dispute, Hermann von Helmholtz, and the Origins of Physiological Acoustics," *The British Journal for the History of Science* 10/1 (March 1977): 1-24.

9.See Anna Gawboy, "The Wheatstone Concertina and Symmetrical Arrangements of Tonal Space," *Journal of Music Theory* 53/2 (2009): 176-79.

10.Alexander J. Ellis, "On the Conditions, Extent, and Realization of a Perfect Musical Scale on Instruments with Fixed Tones," communicated by Charles Wheatstone, 7 January 1864, in *Proceedings of the Royal Society of London* 13 (1863-1864): 103.

11.The *Tentamen* was highly esteemed and frequently cited by scientists of Wheatstone's generation, and Wheatstone himself referred to Euler's formula for the calculation of vibrational motion in two articles: Charles Wheatstone, "On the Figures obtained by strewing Sand on Vibrating Surfaces, commonly called Acoustic Figures," (1833); "Note relating to M. Foucault's new Mechanical Proof of the Rotation of the Earth" (1851), both in *The Scientific Papers of Sir Charles Wheatstone* (London: Physical Society, 1879), 64-83 and 303-6.

12.These are Euler's preferred numbers in the *Tentamen;* later, he would expand the set to 7. For ratios expressing intervals, this seems to make intuitive sense. For example, the perfect octave 1:2 is perceived as more consonant (or "agreeable") than the major second, 9:8. But with larger collections of tones such as chords and scales, Euler was forced to do additional calculations to determine agreeableness. Euler first defined a group of tones according to their ratio. For example, the major triad would be defined as 4:5:6, consisting of a major third (4:5) and a perfect fifth (4:6, or 2:3). Euler then found the least common multiple of the numbers in the ratio—in this case, 60—and then expressed this number through prime factors and exponents: 2^2x3x5. He then used the formula ($s - n + 1$) to determine the degree of consonance, where s is the sum of the prime factors of the exponent and n is the number of these factors. For the major triad, s=12 and n=4, so 12-4+1=9. In other words, the major triad belongs to the ninth degree of agreeableness.

13.Wheatstone's interest in just intonation can be seen in his "Harmonic Diagram" of 1824, a didactic tool used to explain scales and key signatures. A copy held at the Massachusetts Institute of Technology may be viewed at *http://libraries.mit.edu/archives/exhibits/harmonic/index1.html#top.* Wheatstone's explanation of the diagram does not specifically mention just intonation, and some of his discussion is a big vague concerning the sizes of different intervals. It is clear, however, that he has some sort of unequal tuning (such as just intonation) in mind. His division yields thirty-five distinct pitches within the octave, and enharmonic equivalence is not assumed. The diagram not only includes key signatures for major scales on A-flat, E-flat, B-flat, and F, but also absurd enharmonic key signatures for major scales on G-sharp, D-sharp, A-sharp, and E-sharp. While these features of the harmonic diagram point to just intonation, Wheatstone's description of the diatonic scale is rather loose. He writes that it is comprised of tones and major semitones, but a diatonic scale in just intonation actually has two differently-sized whole steps in the ratios 9:8 (204 cents) and 10:9 (182 cents). See "Explanation of the Harmonic Diagram," in *The Scientific Papers of Sir Charles Wheatstone,* 16-17.

14.See Charles Smith, "Leonhard Euler's *Tentamen novae theoriae musicae*: a translation and commentary," Ph.D. diss., Indiana University (1960), 201-2.

15.Ibid., 188.

16.Ellis proposed that a true just intonation required 72 separate pitches, but only 48 of these were absolutely necessary if one allowed schismatic substitution; see "On the Conditions, Extent, and Realization of a Perfect Musical Scale on Instruments with Fixed Tones," *Proceedings of the Royal Society of London* 13 (1864): 98-101.

17.An equally-tempered half-step is 100 cents. If a concertinist were to play C-sharp, F, and G-sharp for a D-flat major triad, the "third" between C-sharp and F would be wider than the pure third between D-flat and F by a diesis. Similarly, if the concertinist substituted C, D-sharp, and G for a C minor triad, she would find that the "third" between C and D-sharp was narrower than the pure third between C and Eb by a diesis.

18.Ellis, "On the Conditions," 103.

19.Ellis identifies quarter-comma meantone with the concertina in his translation of Hermann von Helmholtz, *On the Sensations of Tone as a Physiological Basis for the Theory of Music,* 4th ed. (London: Longman, Green and Co. 1912), 321n (originally published as *Die Lehre von den Tonempfindungen als physiologische Grundlage für die Theorie der Musik* [Brunswick (D), 1863).

20.A pure 3:2 fifth equals about 702 cents. The tempered fifth in quarter-comma meantone is about 697 cents.

21.Ellis in Helmholtz, *On the Sensations of Tone,* 321n.

22.Berlioz/Clarke, *Treatise Upon Modern Instrumentation and Orchestration,* 325.

23.A pure 5:4 major third is 386 cents, while an equally-tempered major third is 400 cents; a pure 6:5 minor third is 315 cents, while an equally-tempered minor third is 300 cents.

24.Joseph Warren, *Instructions for the Double Concertina* (London: Wheatstone & Co. n.d. [ca. 1850]), 2.

25."The Double Concertina, (C. Wheatstone, Inventor) a New Musical Instrument," (Wheatstone & Company, ca. 1850), online at: *www.concertina.com/pricelists/wheatstone-duet/Wh-Pricelist-Duet-c1850.pdf.*

26.Ellis, in Helmholtz, *On the Sensations of Tone,* 548-549.

27.It is not known precisely when Wheatstone & Company switched entirely to equally-temperament. Allan Atlas considers several scholarly opinions in *The Wheatstone Concertina in Victorian England.* (Oxford: Clarendon Press, 1996), 44-47.

28.Ellis, "On the Temperament of Musical Instruments with Fixed Tones," *Proceedings of the Royal Society of London* 13 (1864): 420-21.

29.William Cawdell, *A Short Account of the English Concertina, Its Uses and Capabilities, Facility of Acquirement, and Other Advantages* (London: St. Johns, 1865), 6; online at: www.concertina.com.

30.Wheatstone, "Improvements on the Concertina and Other Musical Instruments, in which the Sounds are

Produced by the Action of Wind on Vibrating Springs," (British Patent no. 10041, 8 February 1844).

31.Ibid., 7.

32.Neil Wayne, "The Wheatstone English Concertina," *Galpin Society Journal* 44 (March 1991) 125-26.

33.Wheatstone, "Improvements to the Concertina" (1844), Figure 9.

34.Owen Jorgensen, *Tuning: Containing the Perfection of Eighteenth-Century Temperament, the Lost Art of Nineteenth-Century Temperament, and the Science of Equal Temperament* (East Lansing: Michigan State University Press, 1991), 1-7. Jorgenson identifies William Braid White's *Modern Piano Tuning and Allied Arts* (1917) as the first tuning method to ensure a true equal temperament.

35.Ellis, "Temperament," 419.

36.Ellis, "On the History of Musical Pitch," *Journal of the Society of the Arts* 27/1424 (March 5, 1880). 295.

37.George Herbert, in W. J. Habens, "On the Musical Scale," *Proceedings of the Musical Association* (1889-1890): 16. None of the English organs exhibited at the Crystal Palace was in equal temperament. The first commercial organ to be tuned equally was built by Gray and Davidson for the Congregational Chapel at Blackburn in 1854. See Ellis, in Helmholtz, *On the Sensations,* 549.

38.Ellis, "Temperament," 420. Ellis claimed that equal temperament was tolerable on the piano because its partials were only audible up to the 5th harmonic.

39.Ellis, *On the Basis of Music, Containing An Elementary Account of The Nature of Musical Notes and Chords, The Generation of Scales and Modulations, and The Origin And Effects of the Usual Tempered Scales* (London: C.F. Hodgson & Son, 1877), 37.

40.Berlioz/Clarke, *Treatise on Modern Instrumentation and Orchestration,* 236-37.

41.See David Cahan, *Hermann Helmholtz and the Foundations of Nineteenth Century Science* (Berkeley and Los Angeles: University of California Press, 1993).

42.Helmholtz/Ellis, *On the Sensations,* 227.

43.Ellis bought concertinas from Wheatstone & Company on 1 November 1838 and 10 September 1847, according to Wheatstone & Company Sales ledgers; see Allan W. Atlas, "The Victorian Concertina: Some Issues Relating to Performance," *Nineteenth-Century Music Review,* 3/2 (2006): 48-49, note 28. One of Ellis's concertinas is held by the Horniman Museum, catalogued as instrument M9a-1996. Ellis's markings on the instrument indicate that it was used in experiments with temperament; see Alice Little, "Free and Squeezy: The New Web Catalogue at the Horniman Museum," *Papers of the International Concertina Society* 5 (2008): 92. For more information on Ellis and the concertina, see also Atlas, "Who Bought Concertinas in the Winter of 1851? A Glimpse at the Sales Accounts of Wheatstone and Co.," in *Nineteenth-Century British Music Studies* 1, edited by Bennett Zon (Aldershot: Ashgate, 1999), 63-64.

44.Ellis, "Temperament," 420; see note 37.

45.See Ellis, *On the Basis of Music,* 17.

46.Ellis, in Helmholtz, *On the Sensations of Tone,* 526.

47.Ibid., 281n.

48.Ellis referred to Helmholtz's work as "the first satisfactory theory of consonance and dissonance" in "On the Conditions, Extent, and Realization of a Perfect Musical Scale on Instruments with Fixed Tones," *Proceedings of the Royal Society of London* 13 (1863-1864): 94n.

49.Benjamin Steege, "Material Ears: Hermann von Helmholtz, Attention, and Modern Aurality," (Ph.D. diss., Harvard University (2007), 251. Ellis's correspondence with Helmholtz is collected in the archives of the Berlin-Brandenburger Akademie der Wissenschaften, Bestand NL Helmholtz, No. 131. Although Helmholtz very much wanted to meet Charles Wheatstone and sought out the older physicist on two occasions, they apparently missed each other in 1864; see Leo Königsberger, *Hermann von Helmholtz,* translated by Frances A. Welby (Oxford: Clarendon Press, 1906), 111-13.

50.See Gawboy, "The Wheatstone Concertina," 182ff. Ellis's lengthy and detailed description of his just concertina appears in Helmholtz, Appendix 20, section F, "Experimental Instruments for Exhibiting the Effects of Just Intonation," 471-72, as well as descriptions of other instruments for experimental acoustics, such as Helmholtz's specially designed harmonium, Colin Brown's voice harmonium, Henry Poole's organ, and Robert Bosanquet's Generalized keyboard and harmonium.

51.Helmholtz/Ellis, *On the Sensations of Tone,* 320.

52.Ellis, "Temperament," 421.

53.Ellis, in Helmholtz, 320n.

54.Ellis, *On the Basis of Music;* see also Gawboy, "The Wheatstone Concertina," 182-84.

55.Ellis, ibid., 34.

56.Ellis, "On the Basis of Music," 35. The "Tonic Sol-Fa" method was specifically designed by John Curwen (1816-1880) to instruct singers in just intonation; see Steege, "Material Ears," 253-70.

Interestingly, however, Ellis and Alfred J. Hipkins invented the "cent," a unit of measurement used to compare minute differences between various tuning systems based on twelve equal divisions of the octave. Ellis introduced the cent as a practical way to compare the musical scales of different cultures; see Ellis and Hipkins, "Tonometrical Observations on Some Existing Non-Harmonic Musical Scales," *Proceedings of the Royal Society of London* 37 (1884): 368-85.

58.Herbert, in Habens, "On the Musical Scale," 23.

59.Some scholars have argued that the switch occurred much earlier. For example, Pat Robson suggested that the switch occurred in 1861, as a result of the collaboration between Wheatstone and the German acoustician Johann Matthias Stroh, although this suggestion lacks strong documentary support; see Robson, "Mainly About Concertinas," *English Folk Dance and Song Society* (1983): 4-5. Atlas's survey of concertina music composed in the 1850s and 1860s suggests that some works were specifically composed for an equally- tempered instrument, but that does not rule out the possibility that meantone instruments were also commercially available during the same period; see Atlas, *The Wheatstone English Concertina,* 45-46.

60.*Instruction Books and Methods for the Concertina* (Wheatstone & Company, n.d.), quoted in Atlas, *The Wheatstone English Concertina,* 46.