Bach's Extraordinary Temperament: Our Rosetta Stone--1

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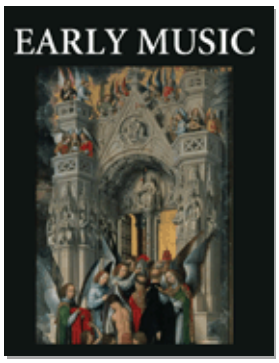

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Bach's extraordinary temperament: our Rosetta Stone—1

JOHANN Sebastian Bach never required equal temperament for keyboards. Music historians have hitherto failed to notice that he actually wrote down and made full use of a specific unequal alternative whose resources are much richer. Its layout is: five ⅙ comma 5ths F–C–G–D–A–E, then three pure 5ths E–B–F♯–C♯, and finally three 1/12 comma 5ths C♯–G♯–D♯–A♯. Although this may not look like anything special on paper, its sound is marvellous for the complex requirements of tonal music.

Bach 'was no lover of dry, mathematical stuff'.[1] Despite his aversion to computation in numbers and theoretical speculation in words, the 37-year-old composer notated that *specific* temperament on the title-page of *Das wohltemperirte Clavier* ('The well-tuned keyboard', hereafter *WTC*).[2] His presentation of the required tuning method is the sinuous spiral he drew at the top of the title-page (illus.1). It provides a set of tempering instructions for harpsichords, clavichords or organs, completely describing the distinctive character he expected for every key, every scale, every interval and every moment. The *WTC* is explicitly about tuning, the exploration of all possible tonalities (and *not* simply a transposition of a single major key sound, and a single minor key sound, to all possible positions).

Until now music history had lost three crucial pieces of information: (1) that Bach ever wrote down any required keyboard-tuning method at all; (2) that this drawing is his precise schematic; and (3) the proper derivation of a set of instructions, arising from normal 17th-century *temperament ordinaire* practice.[3]

Bach's method is a practical one. It is easy to set quickly by ear, usable in all keys, with a pleasing progression of key differences, and it yields convincing performances of the *WTC*. The book in its entirety shows that Bach was expert in tuning, expected a precise intonation on his keyboards, and allowed the sound to influence his creative imagination. As a guide to musicianship it teaches players to listen closely to the intervals produced in melody and harmony, as details of intonation can help to determine the *Affekt*, phrasing, articulation, tempo and accentuation of the music. The ears, the physical process of tuning, and the feel of the instrument during performance all support this. The music sounds so euphonious and pure that it seems otherworldly, especially after a lifetime of hearing the same music tuned differently.[4]

This article in its two parts examines the temperament thoroughly from many angles, including some of the 'dry, mathematical stuff'. For best direct perception of the material, however, it is important to set up this pattern of intonation on a keyboard and *play* with it!

Background: the commas and other problems to be solved

The choice of historically and musically appropriate keyboard temperaments always depends on the music to be played. What did the composer expect as a norm? What features of the music are to be highlighted? What is the appropriate balance of melody versus harmony? What key areas are visited during the composition? How many sharps and flats are in use, given that they might be tuned differently from one another? Does the composition have any special expressive effects to be brought out by the choice of temperament? What is the player/tuner's skill

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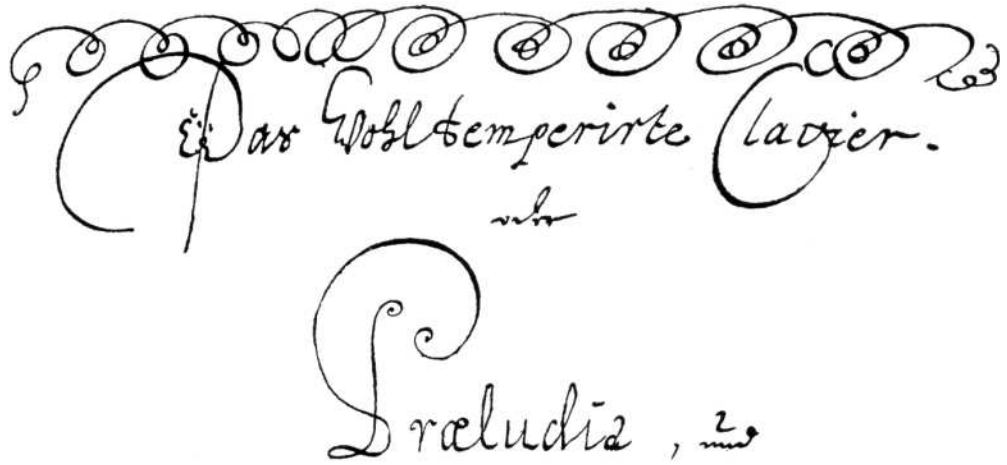


1 The top of the title-page of Bach's *Das wohltemperirte Clavier* (1722). The complete page is reproduced in the 1911 *Grove dictionary*, vol. i, p. 152, and in many modern editions of the music. (Staatsbibliothek zu Berlin Preußischer Kulturbesitz)

(then or now!) setting up different selections on different occasions? What other instruments and voices are to be used with the keyboard? What is the role of musical taste and experience? Are the instruments to be left in a particular temperament for years, needing only minor maintenance, or to be retuned afresh on every occasion? To understand the nature of these problems of keyboard temperament along with Bach's solution, a brief review of the basic tuning issues and nomenclature is required.

All octaves are pure, as a rule. Within that premise, the tuning of 12-note keyboards presents three competing problems. The tuner must find a musically appropriate and tasteful distribution of three different error intervals. These intervals are as follows:

Pythagorean comma (hereafter 'PC'): twelve pure 5ths, less seven octaves; the interval $^{531441}/_{524288}$. A cycle of twelve consecutive 5ths must *remove* a total of one PC, to avoid overshooting the octave. Since there are twelve 5ths, some or all of them must be tuned too narrow by some portion(s) of the PC. On average the 5ths must be 1/12 PC too flat.

Syntonic comma (hereafter 'SC'): four pure 5ths, less two octaves and a pure major 3rd; the interval $^{81}/_{80}$. A cycle of four consecutive 5ths must *remove* one SC if the resulting major 3rd is to be pure. Since there are twelve major 3rds, some or all of them must be tuned too wide by some portion(s) of the SC. On average the major 3rds must be 7/11 SC too sharp. (This is a large and easily audible amount: approximately 1/7 of an equal-tempered semitone.)

Lesser diesis (hereafter simply 'diesis'): an octave, less three pure major 3rds; the interval $^{128}/_{125}$. For example: if we tune three pure 3rds C–E, E–G♯, G♯–B♯ we get the interval C–B♯ which is much too flat to be an octave. As octaves must be pure, the diesis must be distributed to one or more of the three major 3rds making some or all of them wider than pure. This must be handled four times in any temperament: in the major 3rd stacks starting on F, C, G and D.

The geometric difference between the PC and the SC is called the *schisma*. It is very nearly the same size as either 1/12 PC or 1/11 SC.

Temperaments usually split either the PC or the SC into small, manageable portions of 1/12, 1/6, 1/5 or 1/4. These are distributed among some or all of the 5ths. The 5ths are made deliberately out of tune by these subtle amounts, such that the resulting 3rds and steps will have a pleasing balance in their own musical functions. For all practical purposes the 1/12 PC temperaments are 1/11 SC temperaments, as those two small portions have very nearly the same size.

The phrase 'regular 5ths' refers to two or more 5ths that are exactly the same size, geometrically. If they are tempered 5ths rather than pure 5ths, their tempering (not their beat rate!)[5] is the same. They are slightly out of tune, each by the same amount. 'Regular' temperaments, also called 'mean-tone' temperaments,[6] are those that have eleven 5ths the same size, and one 'wolf' 5th (truly a diminished 6th) allowed to be much too wide. The wolf 5th is a garbage area, absorbing all the accumulated amount by which the tempered 5ths overcompensated one PC.

The regular temperaments tend to emphasize the quality of major 3rds, providing eight major 3rds that are pure or nearly so, and four misspelled major 3rds (actually diminished 4ths) that absorb most of the SC and diesis errors. The composers then avoided these forbidden 3rds and wolf 5th, or used them very carefully as a special effect. In the regular temperaments the enharmonic pairs of notes (such as D♯ and E♭) are absolutely different from one another.

Any major 3rds resulting from four consecutive pure 5ths are called 'Pythagorean' 3rds, being one SC too wide.[7] The still wider diminished 4ths of regular temperaments are often called 'wolves', since they are scarcely more usable than the wolf 5th is. 'Good' temperaments (for the Germans) are those in which none of the twelve major 3rds are worse than Pythagorean. The grammatically incorrect English phrase 'well temperament' is a poor translation from German, and sometimes carries the additional connotation that a temperament has no wide 5ths. 'Circulating', 'enharmonic', 'semi-regular' or 'irregular' are better synonyms for 'good temperament': all 24 major and minor triads are available, at least approximately, with no serious wolves anywhere.

The tuning literature is filled with 'cents'[8] tables to measure small increments of pitch.[9] Unfortunately, that measurement system itself clouds some of the most relevant issues regarding 3rds and 5ths. Notably, the cent scale biases its users toward a norm of equal temperament (100 cents per semitone, and 1,200 per octave), and it is scarcely useful for any work with pure major 3rds (approx. 386.31 cents) or 5ths (approx. 701.96). It remains reasonably good for describing comparative sizes of tones and semitones.

For analysis of 3rds and 5ths I prefer the 'Temperament Units' (hereafter TU) method developed by the organ builder John Brombaugh, a much finer-grained logarithmic scale assigning 720 microscopic portions to the PC. The SC then works out to 660 TU, the schisma 60, and the diesis 1260. All these numbers are easy to handle on paper or mentally, divisible by 3, 4, 5, 6 and 12: the fractions used in most descriptions of historical temperaments. The TU system therefore allows a theorist or player to work almost exclusively with integers, visualizing a temperament by merely adding and subtracting easy portions of commas. The SC error of any major 3rd is found by adding the four TU values of the intervening 5ths, and dividing by 660. Three major 3rds stacked up must distribute a total of 1,260 somehow. All twelve 5ths in a temperament must add up to −720 TU. Temperaments can therefore be diagrammed easily on paper, with simple numbers, and competing temperaments can be compared directly.

Bach's diagram

Bach's *WTC* title-page (shown in illus.1) is a precise abstraction of his preferred tuning method, in the form of a pen stroke with 11 large loops.

A keyboard temperament can be described completely by the following parameters: (1) the relative sizes of eleven 5ths,[10] (2) the orientation[11] and (3) the knowledge that the endpoints do or do not connect to one another.[12] Bach's diagram has those elements, taking each large loop as an interval of a 5th (C–G–D–A etc.).[13] The diagram has three loops with one knot in them, then three empty loops, then five loops with double knots. The letter C orients the home base, middle C: second from the right. The endpoints do not meet, but we assume they must make a not unpleasant 5th (specifically B♭–F), as the book contains compositions in all keys, no exceptions.

As Bach pointed out in 1725, in his notes to teach principles of thorough-bass, one can write down only the rudiments of musical understanding, and then 'The other precautions that must be observed will explain themselves better in oral instruction than in writing.'[14] Thorough-bass, improvisation, composition, tuning and performance are all part of the *same* keyboard skill set to be learned from a

master teacher. Indeed, after one has learned Bach's 1722 lesson with regard to tuning, his practical instructions are elegant and easy to follow, setting his temperament quickly by ear. The report that Bach could prepare his entire harpsichord in 15 minutes[15] is nothing surprising; it is simple in this temperament, with a bit of practice and experience.

How would Bach teach his pupils to tune harpsichords and clavichords, as part of their all-round instruction? Obviously, hands-on demonstrations and explanations at the instruments are required. This is practical common sense in learning how to listen closely, handling the tuning lever, and making careful adjustments to the instrument. It is also reflected in the well-known anecdote from the Marpurg–Kirnberger debates, where Marpurg tried to throw Kirnberger's report of tuning lessons with Bach back into his face.[16] There is little or no need for any of the tuning instructions to be written down, as to the specific method or methods. The teacher is there to guide the process, showing what to listen for and verifying the adjustments.

Bach in 1722 applied for a teaching and supervisory position in Leipzig. How would the Leipzig authorities know, in his absence and before hiring him, how he might teach anything? Quite simply, he prepared a *curriculum vitae*, a set of written audition materials for the position.[17]

Wolff has clarified this hypothesis further, regarding Bach's use of the *WTC* (plus the Inventions/Sinfonias and *Orgelbüchlein*) as Leipzig audition material:[18]

> Clearly, none of the works was specifically composed for Leipzig. However, more likely than not, the final preparation of the fair copies of the *Well-Tempered Clavier* and the *Aufrichtige Anleitung*—in particular, the carefully coordinated phraseology of their title-pages (including that supplementing the *Orgel-Büchlein*)—was calculated to impress the authorities in Leipzig, especially an old, experienced teacher like Rector Ernesti, and to persuade them of Bach's teaching ability. That Bach later made extensive use of these distinctive instruction manuals is confirmed not only by the many copies made of them by Bach's Leipzig pupils, but also by first-hand references such as Gerber's to his lessons with Bach.

This is corroborated by the observation that Bach's wording in the middle section of the *WTC* title-page is a parody of the title-pages of Kuhnau's *Neuer Clavier-Übung* (1689, 1692).[19] Bach's emphasis here is the assertion that he will surpass the revered incumbent Kuhnau by handling *all* the *ut re mi* and *re mi fa* keys, not just most of them. Bach here demonstrates the complete flexibility he will bring as a candidate for Kuhnau's job in Leipzig. The application to Leipzig would have given Bach motivation both for this wording, and to write down explicit temperament instructions here at all (as one more part of the complete package, his pedagogical fitness). The project accomplishes several tasks: showing his potential employers his teaching materials, showing dedication to do his best, demonstrating the way his music sounds, and allowing them to study his musical science themselves at their leisure.

Bach's pupils were expected to make their own handwritten copies of assigned pieces from the source manuscript; this was normal pedagogy. My hypothesis is this: for the Leipzig audition, Bach included the required tuning method by which his music is to be played,[20] putting it at the top of the title-page of the *WTC*.

To learn Bach's tuning method, in his absence, all one has to do is to make a handwritten copy of the drawing (analogous to copying out pieces of music), understand what it means, and the lesson is learned.[21] This gave the Leipzig authorities everything they would need to know: set up a keyboard as specified, play through these three books of music, and be amazed at Bach's skill in controlling musical sound, his readiness to teach, and his readiness to co-ordinate church music. As we shall see, the tuning method also influenced the content of the musical subjects themselves, in the *WTC*'s preludes and fugues. These show Bach's readiness to derive invention from any inspiring source, including the subtle sounds of the intervals themselves.

Translation of the diagram: the practical recipe

How is a student (or the Leipzig board of examiners) to draw or trace the temperament diagram, making a copy to start learning the lesson? The solution, as students of drawing know, is to turn the page upside-down to see if it might be easier to copy that way. Indeed, Bach's diagram is difficult to copy right-side-up, in ink without smudging, getting the loops and sub-loops in the same directions as his.

But it is trivially easy for a right-handed person, left to right in a single flowing and sinuous stroke, with the page inverted. There are five loops with double spirals outward. Next come three empty loops. Next are three loops with single spirals inserted on the down-stroke, followed by the casual flourish at the end of the line.

The note-names are mapped to Bach's diagram as shown in illus.2. The note 'C' is in second position, where Bach wrote it (with the page turned right-side-up again). Each 5th is made either narrow or pure: normal practice in keyboard tuning. The details of this are made explicit by the diagram.

The first part of the temperament, as is normal practice, is to establish the regularly tempered set of natural notes: F–C–G–D–A–E. The normal amount of tempering is ⅙ comma,[22] leading to the major 3rds F–A and C–E, which are each sharp by the amount known in ordinary musical experience. The five tempered 5ths here are the double spirals of the diagram.

We have now arrived at E, and have built the size of C–E as the smallest (most nearly pure, most resonant) 3rd. A basic issue in temperament is to balance the three major 3rds that build a (pure) octave; therefore our attention turns to the next 3rd of the scale,[23] the building of G♯ upward from E such that it will also give a decent enharmonic A♭ to our C. According to the diagram, we tune four pure 5ths E–B–F♯–C♯–G♯ . . . and then, as indicated by the change in loop, we back the G♯ downward slightly, narrowing that 5th, giving it a savoury *Spur* (like 'eine Spur Pfeffer' to spice the cooking appropriately). This takes the edge off the very bright E–G♯, tastefully. And, sure enough, this G♯ played with C passes as a very pleasant A♭.

We are almost finished; for the final 3rd of the scale from A♭ back to C, it remains only to continue G♯–D♯–A♯, again (as the loops show) giving the same tiny *Spur* of impurity to each 5th. We already have F from earlier. The G♯, D♯ and A♯ here will be serving duty also as A♭, E♭ and B♭, and we need only ensure that the resulting 5th B♭–F is not obtrusively poor. If all the instructions here are followed carefully, it will be either very slightly wide (if we started with ⅙ PC in the naturals), or pure (if we started with ⅙ SC).[24]

We check all our major 3rds: first F–A and C–E give the calm sound of regular ⅙ comma tuning. Then G–B, D–F♯, A–C♯ and E–G♯ become increasingly sharp and spicy. Finally, B–D♯, F♯–A♯, D♭–F, A♭–C, E♭–G, B♭–D and F–A all relax from the peak of E–G♯. We are ready to play and compose pieces in all keys.

At the right side of Bach's diagram (marked* in illus.2), the A♯ does not join the beginning F; note the similar single knot in the flourish, probably representing its resulting 1/12 comma *wide* 5th. At the left side, note the three small loops: probably indicating the beginning beat rate of the F–A major 3rd, approximately three beats per second.[25]

It can also be observed that the single *Spur* of the last three sharps, during the tempering process, works out to be half the normal tempering of the naturals, drawn appropriately as double *Spuren*! How could Bach have represented his temperament any more elegantly than this, without recourse to written words or numbers (both of which he disliked in his self-expression)?[26]

To summarize Bach's temperament bearing: five ⅙ comma 5ths F–C–G–D–A–E; three pure 5ths E–B–F♯–C♯; three 1/12 comma 5ths C♯–G♯–D♯–A♯; end. Bach's handwritten letter 'C' is there in its position, too, lest anyone start in some wrong place, or miss the point that this is a temperament recipe at all. Each little knot within the bigger loops indicates some unit of tempering to be applied to its 5th (that is, the appropriate amount of spice or wavering noise to introduce into its tuning, deliberately). That unit works out to 1/12 comma, portioned out as single, double, or none. The drawing is beautiful and elegant, like his music.

2 The notes described by Bach's loops, with the page turned upside-down to see (and copy) the schematic. This is the same graphic as illus.1, with the words removed.

Mathematical modelling of the same: scientific reproducibility

To get the temperament *exactly* the same from day to day, and for mathematical analysis, it can be set onto the keyboard in a slightly different sequence. As with a problem-solving technique of mazes (working both forward and backward simultaneously), a tuner can set a temperament onto the keyboard in whatever sequence helps to get the job done accurately and comfortably, as long as the resulting layout is correct. Try the following step-by-step instructions:

1 Establish the naturals F–C–G–D–A–E in regular ⅙ PC; that is, set up the first half of 'Vallotti', which is already familiar to harpsichordists.[27] The most practical single thing to know is that the major 3rd of F–A (both in the tenor octave below middle C) has about 3 beats per second.[28] A second checkpoint is middle C up to E, with about 4.5 beats per second.[29]

2 Pure 5ths: E–B–F♯–C♯.

3 Pure 5ths: F–B♭–E♭. (This is a step to put E♭/D♯ exactly where it belongs.)

4 Put G♯/A♭ in place against C♯ and E♭, slightly tempered from each (i.e. 1/12): the single *Spuren* in Bach's diagram.

5 Go back to B♭ and lower it slightly, so that D♯–A♯ is similarly a 1/12 5th as shown by Bach's diagram, and B♭–F becomes a slightly wide 5th.

6 All octaves and unisons are pure.

The results are shown in table 1; compare again with illus.1 and 2 to see the correspondence, and play through all the 5ths in the sequence of Bach's drawing. The lesson is learned.

For those who are most comfortable setting temperaments from an electronic device, the bottom two rows of the chart show the adjustments from equal temperament, to the nearest cent, reckoned either from C or A. The deviations from regular ⅙ Pythagorean comma and regular ⅙ syntonic comma are also given, for keyboardists and ensembles accustomed to those standards.

In the results from Bach's drawing we have a set of the usual and regular ⅙ comma naturals; a pure B obtained from E; and then the remaining five accidentals are each tastefully adjusted: sharps raised slightly to build a remarkably high G♯, and flats lowered slightly from their classic positions . . . giving complete flexibility across the keyboard. The aural magic happens in Bach's specific details of those tasteful nudges. Since my April 2004 discovery of this method, it has already received a thorough workout and confirmation beyond my own regular use. Andrew Manze has toured with it for orchestral continuo,[30] and George Taylor has built it into the new Goshen College organ.[31]

Why hasn't this been found before?

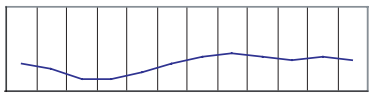
The following digest from the standard tuning literature and *WTC* literature should make it obvious why Bach's diagram has not been treated as evidence for any particular unequal temperament. Historiography, while allowing for the possibility that Bach had a specific practical temperament, has pointed away from investigation of unequal temperaments, and away from any evidence that is outside the realm of words.

Is Bach's drawing on the *WTC* title-page worth any more than a quick glance? The *Neue Bach-Ausgabe* (*NBA*) officially dismissed the spiral diagram, three times, as merely an ornamental flourish. (1) *Bach-Dokumente*, 1963: 'Titelseite: Wohltemperiertes Klavier, Köthen, 1722. (. . .) Autograph. (. . .) [Ü]ber dem Text hs. Ornamente, unter dem Text großer Schlußschnörkel . . .'[32] (2) *Kritischer Bericht* (*KB*), 1989: 'Titel, siehe Notenband, S. XIV und 1. (. . .) Über und unter dem Titel ornamentale Schnörkel.'[33] The *KB*, as always with the *NBA*, is so thorough and imposing with detail, representing so many years of close scrutiny by the world's top Bach scholars, it is surprising that the single most important piece of information at the top of the title-page could have been missed. (3) The *Notenband* itself (also 1989) presents a facsimile of the title-page, of course. But, on the opposite page of the same spread, only the words of Bach's macaronic introduction (and their layout) are reproduced in modern transcription.[34] The reader's attention is drawn immediately to the legible modern transcription of the words, and away from the photograph.

The Bach reader (1945; rev. edn 1966) presents the title-page in a clear English translation, preserving

Table 1 Mathematical analysis of Bach's temperament

	E♭	*B♭*	*F*	*C*	*G*	*D*	*A*	*E*	*B*	*F♯*	*C♯*	*G♯*
Bach (1722) title-page of WTC: ⅙ PC												
Fifth in TU	−60	60	−120	−120	−120	−120	−120	0	0	0	−60	−60
Fifth in PC	−1/12	1/12	−⅙	−⅙	−⅙	−⅙	−⅙				−1/12	−1/12
Fifth in SC	−1/11	1/11	−2/11	−2/11	−2/11	−2/11	−2/11				−1/11	−1/11
Maj 3rd % SC	**63.6%**	**54.5%**	**27.3%**	**27.3%**	**45.5%**	**63.6%**	**81.8%**	**90.9%**	**81.8%**	**72.7%**	**81.8%**	**72.7%**
Diesis portion	*33.3%*	*28.6%*	*14.3%*	*14.3%*	*23.8%*	*33.3%*	*42.9%*	*47.6%*	*42.9%*	*38.1%*	*42.9%*	*38.1%*
Min 3rd % SC	−81.8%	−72.7%	−90.9%	−81.8%	−72.7%	−45.5%	−45.5%	−45.5%	−63.6%	−81.8%	−100.0%	−90.9%
Tone c	203.9	202.0	196.1	196.1	196.1	196.1	200.0	203.9	203.9	202.0	200.0	200.0
Semitone c	94.1	96.1	94.1	98.0	100.0	102.0	103.9	109.8	105.9	102.0	98.0	96.1
Enharmonic	*D♯*	*A♯*	*E♯*	*B♯*	*Fx*	*Cx*	*B♭♭*	*F♭*	*C♭*	*G♭*	*D♭*	*A♭*
Enharm err % PC	*66.7%*	*75.0%*	*100.0%*	*100.0%*	*100.0%*	*100.0%*	*−100.0%*	*−100.0%*	*−83.3%*	*−66.7%*	*−50.0%*	*−41.7%*
d ⅙PC (C) c	**−7.8**	**−5.9**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**3.9**	**7.8**	**11.7**	**13.7**
Error % PC	−33.3%	−25.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	16.7%	33.3%	50.0%	58.3%
Primary function	**E♭**	**B♭**	**F**	**C**	**G**	**D**	**A**	**E**	**B**	**F♯**	**C♯**	**G♯**
d ⅙SC (C) c	−6.8	−5.2	0.3	0.0	−0.3	−0.7	−1.0	−1.3	2.3	5.9	9.5	11.1
d ET (C) c	−2.0	−2.0	2.0	0.0	−2.0	−3.9	−5.9	−7.8	−5.9	−3.9	−2.0	−2.0
d ET (A) c	**3.9**	**3.9**	**7.8**	**5.9**	**3.9**	**2.0**	**0.0**	**−2.0**	**0.0**	**2.0**	**3.9**	**3.9**
Major tetrachord	E♭-F-G-A♭	B♭-C-D-E♭	F-G-A-B♭	C-D-E-F	G-A-B-C	D-E-F♯-G	A-B-C♯-D	E-F♯-G♯-A	B-C♯-D♯-E	F♯-G♯-A♯-B	D♭-E♭-F-G♭	A♭-B♭-C-D♭
Ut-Re	203.9	202.0	196.1	196.1	196.1	196.1	200.0	203.9	203.9	202.0	200.0	200.0
Re-Mi	196.1	196.1	196.1	196.1	200.0	203.9	203.9	202.0	200.0	200.0	203.9	202.0
Mi-Fa	100.0	102.0	103.9	109.8	105.9	102.0	98.0	96.1	94.1	96.1	94.1	98.0
Minor tetrachord	E♭-F-G♭-A♭	B♭-C-D♭-E♭	F-G-A♭-B♭	C-D-E♭-F	G-A-B♭-C	D-E-F-G	A-B-C-D	E-F♯-G-A	B-C♯-D-E	F♯-G♯-A-B	C♯-D♯-E-F♯	G♯-A♯-B-C♯
Re-Mi	203.9	202.0	196.1	196.1	196.1	196.1	200.0	203.9	203.9	202.0	200.0	200.0
Mi-Fa	94.1	98.0	100.0	102.0	103.9	109.8	105.9	102.0	98.0	96.1	94.1	96.1
Fa-Sol	202.0	200.0	200.0	203.9	202.0	196.1	196.1	196.1	196.1	200.0	203.9	203.9
Handling diesis	A♭-C	**8**	D♭-F	**9**	F♯-A♯	**8**	B-D♯	**9**				
within the octave	E-G♯	**10**	A-C♯	**9**	D-F♯	**7**	G-B	**5**				
(portions of 21)	C-E	**3**	F-A	**3**	B♭-D	**6**	E♭-G	**7**				



only the words of the page and simulating their distinctive layout.[35] *The new Bach reader* (1998; hereafter *NBR*) gives the facsimile, and then the same English translation as a paragraph of prose.[36] As for calligraphic whimsy: the previous page in *NBR* reproduces the title-page of Anna Magdalena Bach's notebook, from the same year, in her handwriting. The various spiral decorations on her letters *are* merely decorative flourishes, as far as I have been able to determine.[37] With this juxtapositioning, then, it is easy for a reader to assume that all line-drawing flourishes are merely a bit of fun with the pen, and not to look closely at their details.

Murray Barbour's study *Tuning and temperament*, written as a dissertation in 1932 and published in 1951, is the classic text of the English-language tuning literature. It has launched the exploration of historical temperaments for countless 20th-century experts and dabblers. But he summarized:

> An equal temperament was needed for the keyboard works of Bach, both for clavier and for organ. It is generally agreed that Bach tuned the clavier equally. (. . .) The organ works of Bach show as great a range of modulation as his clavier works do. (. . .) The compass of Bach's organ works as a whole is E♭♭–C♯♯, 25 degrees! In these works is a host of examples of triads in remote keys that would have been dreadfully dissonant in any sort of tuning except equal temperament.[38]

Mainstream musicians of the early and middle 20th century, even the neoclassicists themselves, simply had no interest in turning back the clock to methods that had already been superseded by equal temperament in common practice. A typically dismissive view comes from Paul Hindemith in 1959: '[Unequal temperament is] the consideration of a lazy housemaid, hiding the gathered dirt under a corner of a rug.'[39]

Bach himself is partly to blame for sending his devotees down a wrong path, with the word *wohltemperirt*. Werckmeister used that word frequently enough in his writings that many people have assumed Bach's preferences to have something to do with Werckmeister.[40]

Christoph Wolff's authoritative biography of Bach tells readers the following, about tuning:

> [In the Inventions/Sinfonias, the *Aufrichtige Anleitung*] Bach explores the diatonic range of the tonal system without straying beyond the traditional framework of the fifteen keys (not exceeding four sharps or flats) that are playable in unequal temperament (a system of tuning in which the octave had not yet been divided into twelve equal semitones) and that endow each key with a distinct character. (. . .) The revised key structure of the *Aufrichtige Anleitung* conforms to the uniformly ascending key scheme of *The Well-Tempered Clavier*, but illustrates how to differentiate between the conventional diatonic scheme, on the one hand, and the fully developed chromatic scheme of twenty-four keys based on the premise of equal temperament, on the other. Bach's use of Andreas Werckmeister's term 'well-tempered' (*wohl temperirt*) indicates his preference for a slightly modified system of tuning with 'all the 3rds sharp', enabling him to play in all twenty-four keys without losing the characteristic features of individual keys—a loss that occurs if the octave is divided into absolutely equal semitones (what was to become a new standard would have been regarded then as a serious drawback).[41]

Wolff goes on further to connect Werckmeister, Bach and scientific progress. By implication, the reader automatically assumes that Bach's ideas about tuning grew directly from Werckmeister's work.

Several articles by Peter Williams have brought out plenty of Werckmeister–Bach connections that have little to do with tuning issues.[42] It is easy for a casual reader to infer that Bach drew his own temperament preferences from Werckmeister along with other technical details about organ-building and maintenance. Williams's articles in *Early music* continued the 1980s counter-revolution toward reacceptance of equal temperament for Bach.

> If the '48' was written as a set of instruction pieces for the young musician learning about temperament (this is the old chestnut about the well-tempered clavier) then some crucial things are not made clear to him: chiefly, what exactly does 'well-tempered' mean (recently interpreted evidence suggests that it meant 'equal temperament' after all), how is he to tune by it, and what precisely do the pieces demonstrate about the 24 keys other than how to get your fingers around them?

Furthermore, Williams dismissed tuning as a 'cul-de-sac of a subject'.[43]

The 2003 edition of Williams's *magnum opus*, his survey of Bach's organ music, further discourages the idea of taking unequal tuning seriously. For example, with regard to BWV566 in E or C, he wrote:

> A problem with the E major version being the original is the harmonies of bars 16–17, impossible in any unequal temperament and unusual in J. S. Bach, early or late. The progressions themselves, enharmonically notated, are not advanced (doubled leading notes!), but the passage of keys requires D♯ major and E major to be equally sweet-tuned.[44]

What is the casual reader or organ student to conclude, but that Bach expected equal temperament

to solve such confusing problems? Williams himself has had a brilliant career of comprehensive musical analysis. He has addressed areas of performance practice that few others have ventured to explore so thoroughly, including an article about non-harmonic notes in harpsichord music.[45] It seems unlikely, then, that he could have missed anything important about tuning!

Rudolf Rasch's tercentenary article in 1985 pre-empted the serious investigation of unequal temperaments. He pointed out that Werckmeister himself by the end of his life lost interest in the merits of unequal temperaments (which, again, does not *necessarily* have any bearing on Bach).

> [I]f the temperament is settled in such a way that all 5ths are tempered . . . by ½12 of a comma, and carried out and tuned by an accurate ear, then there will surely be a well-tempered harmony through the entire circle of 5ths and throughout the keyboard. Which can be an example of how all pious and well-tempered people will live and rejoice in a consistent, equal and eternal harmony with God.[46]

It is not too surprising that Werckmeister abandoned his own organ temperaments of the 1690s; the enharmonic notes in them do not circulate well at all for fully chromatic music, serving double duty in major 3rds.[47] But, Werckmeister himself turned it into a moral or spiritual argument against diversity, rather than a technical issue.

Rasch summed up further:

> What is the meaning of the term *wohltemperirt* in the title of Bach's collection? If the use of the word in the theoretical works of Werckmeister and Sorge is followed, it must mean 'appropriately tuned'. The appropriate tuning for a work which progresses through all twenty-four keys can be derived from the given statements by Werckmeister, Neidhardt, Mattheson, and Sorge: equal temperament. (. . .) [O]ne may not say that *wohltemperirt* equals 'equal-tempered' but rather that *wohltemperirt*, in the context of music requiring all keys to be playable, is the equivalent of 'equal-tempered'. (. . .) The conclusion must be that the quotations refer to the use of equal temperament, or something not perceptibly different. None of the authors cited considered Bach to adhere to any clear system of unequal temperament, although knowledge of unequal systems was widespread and easily available through the works of Sorge, Kirnberger, Marpurg, and others. Equal temperament was becoming the norm for tuning during the second half of the eighteenth century. If works of Bach like the *WTC* asked for a tuning substantially different from equal temperament, it is at least surprising that no eighteenth-century author had said so.[48]

Dominique Devie in 1990 countered Rasch's too-eager insistence on equal temperament, as reported in his thorough and clearly reasoned book *Le tempérament musical: philosophie, histoire, théorie et pratique*.[49] Rasch in 1985 had presented a clear summary of 20th-century reconstructions of hypothetical Bach-temperaments (by Kelletat, Kellner, Barnes and Billeter).[50] Rasch rightly dismissed them for various reasons, and in doing so he made the idea of reconstruction itself look like a passing fad from the 1960s–70s. Devie covered that same ground again, partly in response to Rasch, partly to take a swing at esotericism (Kellner *et al.*) as an unscientific method of inquiry, and partly to present the state of scholarly research clearly to readers of French.

One of Bach's best-known pupils, Kirnberger, was himself a theorist both of composition and tuning. Kirnberger's temperaments are very easy for tuning novices to set by ear, or to copy from preset selections in electronic tuning devices. Naturally enough, many people have believed that his published temperaments offer some reflection of his teacher's practices. However, Kirnberger had a rather anachronistic goal to represent as many concepts in the simplest fractions possible, in the name of purity. This included his use of neighbouring fractions to *approximate* irrational roots,[51] earning him the assessment from Marpurg (in his time), and Barbour and Lindley (in ours), that he was scarcely prepared at mathematics. In any case, Kirnberger's own temperaments reflect his own musical/mathematical priorities, not Bach's.

Owen Jorgensen, a hero in the piano-tuning world, attempted to clarify the 'well temperament' issues:

> The systems published in the seventeenth century by Andreas Werckmeister for the well-tempered clavier are similar to equal temperament in that they are unrestrictive, circulating temperaments allowing modulation through all the keys without encountering wolf intervals. (. . .) These types of temperaments can no longer be classed as an early form of equal temperament because the basic philosophy of twentieth-century equal temperament is to promote atonality with a neutral homogenized sound that has no color contrasts and no variety among the keys. Therefore, during the last half of the twentieth century the original seventeenth-century systems for the well-tempered clavier have come to be known as well temperaments.[52]

Unfortunately, this once again implies that Bach followed Werckmeister's layout of intervals at all. It also (as Jorgensen's own earlier book had done) restricts the understanding of 'well temperament'[53] to systems that have no wide 5ths, since that would cause 'harmonic waste' which according to Jorgensen is undesirable.[54]

The author of the *New Grove* articles, Mark Lindley, attempted to clarify the issues of both nomenclature and unequal-temperament practice, and to call for appropriate scepticism (against the headstrong presentations of Kellner, especially).

> 'Well-tempered clavier': a term used in particular by Bach to signify a tuning system suitable for all 24 keys. The fame of Bach's 48 preludes and fugues (. . .) has led to the mistaken assumption that *wohltemperirt* was a standard technical term in Bach's day to designate a particular tuning; and on the basis of this assumption a difference of opinion has arisen as to whether it was equal temperament. (. . .) It is doubtful whether Bach had any one secret mathematical formula of his own; he was not so mathematically inclined in matters of theory. (. . .) One point which emerges from a comprehensive study of Bach's organ music is that the most heavily tempered major 3rd was the one above C♯/D♭. (. . .) [T]he tender effect of the relatively low intonation, in a 'good' temperament, of D♭ (and, though to a lesser extent, of A♭) when used as the 7th in a dominant 7th chord is tellingly exploited in such well-known chorale-preludes as *O Mensch bewein'* (BWV622) and *Schmücke dich* (BWV654). To tune really well for Bach, one should think in such terms and test with some characteristic examples of his fine use of the various notes of the chromatic scale.[55]

Unfortunately, the expectation that D♭ and A♭ will be pitched expressively low is one that has been *read into* the music from Lindley's extensive experience with the basic 'workmaster' shape,[56] and from his own background as a developer of new temperaments within that same paradigm.[57] And it does not necessarily have anything to do with the way Bach himself did organ maintenance, or worked at stringed keyboards. This dictionary entry also has a glaring omission. Where the temperament examples are provided, no temperaments are given that would cross Lindley's observation about the quality of C♯–E♯. Most remarkably, Sorge's 1758 temperament with the Bachian harmonic shape (see below) would be welcome in the *New Grove* discussion, at least to show that 18th-century opinion was not unanimous about these shapes. Lindley had included it in his brilliant 1987 article,[58] noting especially Sorge's own assertions about this temperament's suitability for *Chorton* organs with *Cammerton* orchestras. Lindley's *New Grove* assertion about the necessarily worst C♯–E♯ major 3rd therefore comes across as the only possible game in town, and the only thing that really varies is the rusticity index of the town (following Neidhardt's various formulations). In short, the familiar workmaster shape (in various proportions) is presented as the only viable alternative to equal temperament. Temperaments that peak at E major are not judged as presentable.

As he had done in 1985,[59] and again with more speculative mathematics in 1997,[60] Lindley presumed that Bach's temperament must have been at some average position among contemporary solutions, and not extraordinarily different (even though Bach was, to most accounts, an extraordinary composer and performer). As my analysis in part 2 of this article will show, Bach's music demands a temperament shape other than 'workmaster' to handle the enharmonic equivalences. The averaging of unworkable solutions merely delivers mediocrity.

Lindley has been careful both in *New Grove* and in earlier writings[61] to emphasize that one must *listen to* temperaments in action on appropriate instruments before making any judgments about suitability. I agree. It is necessary to play all the way through pieces, and not merely look at the key signature. I have certainly fallen prey to the latter shortcut myself; for many years I believed that Bach's Inventions and Sinfonias celebrate the resources of slightly modified mean-tone (starting from either ⅕ or ⅙ comma; perhaps even an absolutely regular ⅙ comma). After all, the key signatures use the classic 15 keys of old-fashioned tuning. On a closer look, however, it is apparent that this book uses 24 different notes: B𝄫 to C𝄪 inclusive![62]

A problem from a different angle is in Lindley's *New Grove II* 'Temperaments' article, where C. P. E. Bach is hailed as the 18th-century composer most likely to have used equal temperament.[63] Lindley is once again careful to guide the reader away from inferences that C. P. E. necessarily got this from J. S. This scholarly scepticism is well placed.[64] However, C. P. E.'s own keyboard treatise of 1753, a comprehensive survey of harmony, points out that only 'most of' the 5ths are tempered in his normal tuning.[65]

That casts doubt on his presumed use of equal temperament. Furthermore, if the (tacit) argument is from C. P. E.'s deployment of flat keys in his music, such that equal temperament is supposedly the only reasonable solution, I would point out that it sets up an improper dichotomy. Yes, C. P. E.'s Sonatas in A♭ major and E minor (w49/2 and 49/3) sound awful in the workmaster temperaments, due to the visitations of extreme keys. But, when these pieces are played in his father's temperament, there are no such problems and the music has a brilliantly colourful 'glow'.[66]

Herbert Kellner's long series of meretricious presentations had a good side. In the 1970s and 80s these articles at least raised public awareness of unequal possibilities, against the unquestioned mainstream assumptions of equal temperament. In his enthusiasm and diligence, the scientific invalidity of it all seemed to be a minor inconvenience, as Kellner's invented temperament does sound musically plausible in *some* (especially 17th-century) music.[67] It is a fine product, but mislabelled with the name of 'Bach *wohltemperirt*'. Furthermore, the popularity of his work makes it appear (by example) that the derivation and assessment of temperaments *cannot* be properly scientific. His papers also took the pursuit of 'proportional beating' much too far.[68] At least it is a useful academic exercise for students of tuning to discern the technical and logical reasons *why* his conclusions are less convincing than they might first appear.

Rasch again:

> During the nineteenth century and the first half of the twentieth, virtually nobody ever doubted the view that Bach's *WTC* was intended to be played on an equal-tempered keyboard, and that *wohltemperirt* or 'well-tempered' meant 'equal-tempered'. This view was adopted as self-evident and not based on any particular research. During the last three decades [1950s–80s] doubts have been cast upon this opinion, and several musicologists have proposed unequal Bach temperaments, designed especially to serve the *WTC*. While they have looked for a variety of arguments as foundations for their Bach tunings, the resulting tunings are rather similar 'concentric' tunings, not unlike Werckmeister III, Kirnberger III, Vallotti's tuning, etc. Other authors have gone no further than stating that *wohltemperirt* should mean unequally tempered with possibilities for all twenty-four keys. The latter opinion has been shared by many musicians.[69]

Again, such careful balance and scepticism of conclusions is the right scholarly thing to do, leaving the door slightly ajar to unequal possibilities. Unfortunately, the rest of the article has already led readers to assume that the issue is decided in favour of equal temperament for the *WTC*. The only unequal temperaments presented are the usual suspects, in which the traditional mean-tone extremities are harsher than E major is.

Richard Jones, ending in 1994, prepared a superlative performance edition of *WTC I*, updating Tovey's commentaries and providing the most thorough text-critical study available in English.[70] In the preface, however, for the question of temperament he said little beyond congratulating Rasch on clearing things up once and for all. Equal temperament was good enough for Werckmeister and his spiritual and practical followers. Therefore, it should be good enough for us, too, and why would Bach oppose that system?

David Ledbetter's book about the *WTC* (2002)[71] provides an admirable summary of tuning background and practice in Bach's lifetime and into the next generation. Between this, Devie's book, and Lindley's 'Stimmung und Temperatur' essay, the history is covered as thoroughly as could be done without Bach's solution in hand. Ledbetter argues, however, that tuning is not the main pedagogical issue of the *WTC*, and he argues against the taking of *wohltemperirt* as a term for any specific solution. Ledbetter's exposition of the 1722 title-page[72] treats only the words on the page; nothing about the *ornamentale Schnörkel* (as the *NBA* had put it). Furthermore, he has used Bach's words (phrase by phrase) as the outline for his entire book (chapter by chapter). This is an excellent way to organize his material, but unfortunately it downplays any information that is not contained in words.

Background about key character is available both in Ledbetter's chapter 'All the tones and semitones' and more thoroughly in Rita Steblin's dissertation.[73] Their reports and assumptions about key character and colour, however, are from backgrounds of the workmaster temperament shape. Nothing about Bach's particular arrangement of key character (as far as it derives from unequal temperament) is available either to confirm or refute the present findings.

Reports about A, E, B, F♯, D♭, A♭ and E♭ majors and C, F, B♭, E♭, D♯, G♯, C♯ and F♯ minors would be especially useful here, if they could be located directly in Bach's milieu.

In the 2003 paperback reprint of a currently popular book, Stuart Isacoff in his afterword summarized flatly, 'The truth is, I don't know what tunings Bach wanted. Neither does anyone else.'[74] His cursory and dismissive treatment of 'well temperaments' in general also leads readers away from giving them any serious musical consideration. A main point of his book is that modern science has allegedly triumphed in giving us equal temperament, 'the final solution'.[75] Indeed, equal temperament as a modern standard eliminates important properties of tonal music, destroying diversity within melody and harmony.

Many people are scarcely aware that alternative methods to tune keyboards exist at all. From a background of pianos and modern organs, the current satisfaction and success of generic tuning may make it unattractive to explore more specialized solutions. Or, to those who do have a bit of experience with unequal methods, the complexity of the field quickly becomes daunting, as a minefield for historians and players. Having two or three favourite methods in hand (a mean-tone variant or two, and perhaps a few workmasters, along with some vague ideas about their historical application to repertory), they stop exploring the bewildering array of additional choices. Unequal temperaments are treated like an outfit of clothing for the day, selected from very small wardrobes. The tuning might fit the 'body shape' of the music or it might be horribly wrong . . . or all music could be forced into the shapeless uniform of equal temperament (as if all sharps and flats are created equal). In any case, that clothing of intonation is treated as a mere afterthought, not as the place to *start* building an interpretation. As for the ways in which intonation might affect phrasing, timing, tempo and more: keyboard players generally abdicate responsibility to understand it, but respond (if at all) to only the several methods already in the comfort zone. The standard assumption is, apparently: the fundamental key-colours are found in 'Vallotti' and/or 'Werckmeister III', and all other temperaments are merely refinements of that. But Bach's temperament crosses that line, as its shape handles the keys beyond three sharps or flats in a profoundly different manner.

The question of harpsichords versus organs versus clavichords remains wide open. Suppose an accomplished composer/performer/improviser had firm preferences of temperament installed at home or office (i.e. on harpsichords or clavichords), during composition and rehearsal. Such a musician would still be at the mercy of perhaps less than optimal layouts in performance on organs, or for *any* gig in which someone else set up the keyboards. (Let us remind ourselves: according to his son's report, Bach insisted on tuning the keyboards himself, as no one else could get it to his satisfaction.)[76] How much did or could organ temperaments be altered to suit the incumbent organist's own artistic preferences (from technical, economic and political angles)? With small organs of stopped/shaded/sleeved flues it is relatively easy,[77] but larger instruments with reeds and coned flues take considerably more work, and retuning can cause irreversible changes to the pipes.[78]

Furthermore, the extant organ literature itself sometimes reflects a transposition or a transcription from keyboard tablatures. This again makes it difficult to discern what a composer's original use of enharmonic notes was in practice . . . or indeed to know if the music sounded in tune at all, whatever the ideal intentions may have been. Conclusions from the scores are therefore only tentative at best. Still, Bach did *publish* the *Schübler* chorales and *Clavierübung III* in definitive format, and continued to update his personal copies of both.[79] We can make at least some educated guesses about his practical intonation expectations for organ music, with his temperament installed on home stringed instruments or small organs.

Finally, the autograph manuscript of the *WTC* itself has changed format in the 20th century, most notably (for present purposes) with damage from the ink itself, plus the trimming of the title-page's margins.[80] In all the facsimile reproductions I have seen in print, the page is cropped very closely to the edges of the diagram and has lost part of the strokes, both at the top and the right side. The standard reproductions make the spirals look merely decorative, and the proliferation of reproductions

(all differing in grayscale clarity) make it appear that the page always had its present tiny margins. In July 2004 John Brombaugh and his associate Doug Leedy supplied me with a jaw-dropper, a photographic reproduction from the second edition of *Grove's dictionary* (1904–11),[81] before the deterioration and the change of margins (see illus.1). The temperament diagram is obviously not marginal at all, or a crammed-in afterthought, but an integral and obviously important part of the page, with plenty of white space around it. The better photograph of the whole page confirms even more clearly that the spirals and letter 'C' were Bach's method to convey information about the required temperament, either secretly or overtly.

Is the reconstruction of Bach's temperament today merely a counter-counter-revolution to overturn equal temperament's supremacy? I am sure that some will see the present article in that light. My concern, however, is simply to take the evidence of Bach's title-page, and most importantly, *Bach's music itself*, with the seriousness and thoroughness it deserves (see Part 2). A viable alternative to equal temperament does exist in Bach's own handwriting. Sorge knew such a sound in 1758, whether he got it from this title-page or more directly from Bach ten years earlier, or by study of Bach's Leipzig organs (in *Chorton*) at any time. The distinctive harmonic shape is back above ground again now in 2005, and on the table for discussion.

Origins and destinations

Spitta, Barbour and Ledbetter all cite the anecdote about the 1706 tuning contest between the Jena organist Johann Nikolaus Bach and young Neidhardt. In all three instances the story is told from the (foregone) assumption that both contestants were attempting to set absolutely equal temperament. Nikolaus Bach won it by setting his set of 8′ flutes entirely by ear, while Neidhardt worked on his similar set from a monochord whose ratios he had worked out mathematically, matching the sounds from the string. All three writers apologize similarly for Neidhardt's defeat, saying that the difficulty must have been in the technical area only.

But look more closely at the conditions of the contest. I suspect that Neidhardt did achieve equal temperament or something indistinguishably close to it, while Nikolaus focused on a temperament that *seems* 'equal' to all but the most finicky keyboard geeks, but is more musically pleasing (more sensitive to the behaviours of the natural harmonic series).

The 1722 Bach temperament seems equal *in effect*; I have confirmed this by playing it to (and with) many friends and colleagues, some of whom are professional instrumentalists and singers. The temperament is so suave that it *is* equal, in musical context . . . unless one listens very closely with the technical skills of a keyboard tuner by ear. One must play chords and melodic bits slowly in isolation, and explain exactly what to listen for, for these differences to be noticed in practice. Played in the context of tonal music, the differences among the keys are audible, but come across as different psychological effects rather than anything especially noticeable in pitch differences. This makes the temperament, as a whole, seem almost magically alive, while not remarkably unequal. Such a listening experiment as this should be confirmed more scientifically, of course, with all manner of listeners. The point is: reading the Nikolaus/Neidhardt story with *this* perspective in my ears and mind, I believe that the 'Bach' temperament was already a family heirloom before Sebastian wrote it down in 1722.

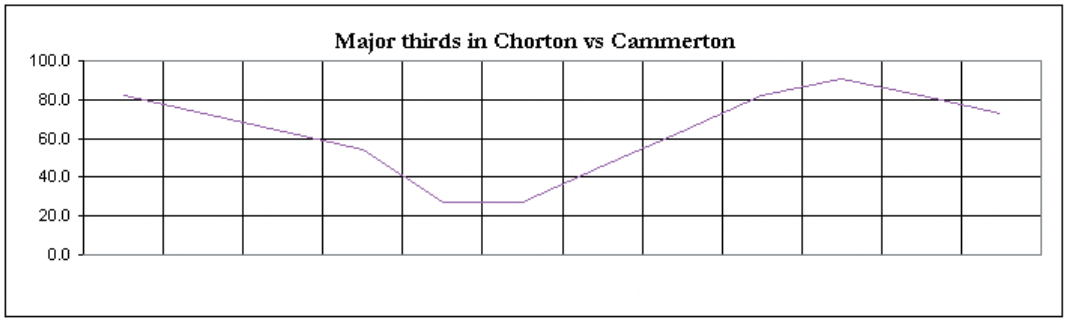
The judgement in favour of Nikolaus was, finally, from a professional singer who found the resulting B♭ minor easier to sing with, ahead of Neidhardt's. That is an excellent key for such a test (along with touching on everything else along the way), both with respect to melodic intervals and the behaviours of the triads and 7ths. The B♭ minor tonic is calm, the dominant F major is the most resonant triad anywhere, and the nearby F minor, A♭ major, D♭ major, E♭ major, C minor and diminished chords all have pleasing 'glows' to them. Sharp keys are less problematic anyway, and would have less bearing on close decisions in such a contest; musical ears can tolerate more deviation from too-sharp sharps than from too-flat flats. (To understand this in practice, set up a keyboard in *regular* ⅙ comma and play through music in all keys. Wrongly spelled notes such as D♯, A♯ and E♯ are quite high, but not as

bothersome as A♭, D♭, G♭ and C♭.) To ears accustomed to the sounds and limitations of regular or mildly irregular layouts from E♭ to G♯, the Bach solution of the flat side of the resources seems like magic, and comes across as 'equal' temperament.

If Nikolaus in 1706 already had the 'Bach family' temperament, is it possible he got it from his own father, Christoph, the Eisenach organist whose music Sebastian revered for its harmonic innovation and expressivity?[82] Nikolaus himself went on to become an innovative instrument-builder, the first Bach to use the famous B–A–C–H musical motive in compositions, and by the late 1740s the oldest living relative of Sebastian. Admittedly, this 'family temperament' suggestion is speculation: and a conjecture that should be tested by better historians than I. The search for this temperament's origin should be easier now that we know how it sounds, and having this (now) *documented* temperament as an alternative to the various Werckmeister and Bendeler options of the 1690s.

Where did it go? The firmest expert witness is the writing of tuning expert Georg Andreas Sorge in 1758. He had joined the Mizler society in 1747, the same month as Johann Sebastian Bach. His own writings about music theory and tuning, of the 1740s, promoted equal temperament, Neidhardt layouts, and several of his own; he also in 1744 cited a Pythagorean comma version of the shape we know as 'Kirnberger III' more than 30 years ahead of Kirnberger's syntonic comma presentation.[83] All those unequal temperaments have the common Werckmeister/Neidhardt shape which merely tames but does not change the traditional mean-tone relationships (as to which keys are worst: A♭, D♭, F♯ and B majors). May we call that shape 'workmaster'?

But, remarkably, in 1758 Sorge has jettisoned all that and promotes only two temperaments: mathematically equal temperament, and a new one whose shape treats the E major area the same way Bach's does![84] On closer inspection from the perspective of Bach's temperament, it becomes clear: eight of the twelve notes in it are *identical* with Bach's. Sorge, the equal temperament fan, has made subtle and understandable changes to the other four. By lowering F (by ⅙ comma) and raising E and B (1/12 each, again pure with one another), he slightly widened each of the major 3rds F–A, C–E and G–B (which also tames the extremities of D♭–F, B–D♯ and E–G♯ accordingly). The lowering of F also converts B♭–F to be 1/12 narrow rather than 1/12 wide, i.e. removing its distinctiveness. Finally, the C♯/D♭ is repositioned to be mean as a major 3rd between A and the new F. (It was also such a mean in Bach's, with the higher F.) The net result of all this is that Sorge's 1758 temperament has the same harmonic shape as Bach's (see illus.3), but is slightly gentler in those contours:[85] more like equal temperament. In summary, Sorge by 1758 had realized that the Bach shape is the only unequal one that really works for tonal music (and especially for *Chorton* organs), even though Sorge himself preferred equal temperament in theory.[86]



3 Bach's temperament in Chorton (organ tuned a tone higher than the orchestra), reinterpreted as it sounds in Cammerton to the players and singers reading their parts a tone higher.

I have a further hypothesis that the 1722 Bach temperament, or at least something with the same shape (may we call it the 'brook' shape?), remained C. P. E. Bach's career temperament: and was also the ordinary temperament at the royal court during his tenure there. In his own treatise he remarked that only 'most of' the 5ths are tempered in his ordinary practice (and eight or nine of twelve is 'most'), and more importantly, his musical examples in the book (and his broader keyboard *oeuvre*) work beautifully in this tuning.

The flute treatise by Quantz confirms this court hypothesis. Quantz presents an exemplary Adagio,[87] to teach the keyboard accompanist how to play dynamics expressively by the harmonic tendencies of dissonances and consonance, listening to the sound of every moment. The piece includes 77 dynamic markings in its 45 bars. I have played this piece using Bach's tuning and noticed that the dissonant/consonant content of the harmony matches his dynamic scheme, with regard to the treatment of tension, resolution and surprise. Readers are invited to explore this same exercise, to hear the dynamic effects as they derive directly from the quality of intonation, the temperament's subtle irregularities. In more equalized temperaments than Bach's, or in regular ⅙ comma, these directional tendencies in the sound are minimized, and Quantz's notated dynamics can seem artificial and overdone. Quantz himself worked directly with at least three former pupils of J. S. Bach (Johann Friedrich Agricola, Christoph Nichelmann and C. P. E. Bach), giving him plenty of opportunity to learn and play with the Bach temperament.

Further confirmation of the Bach temperament at court is Sebastian's *Das musikalisches Opfer*. The keyboard ricercars are adventurous enough that they have caused Lindley (several times) to assert in print that only equal temperament will do. However, they too work without problem in Bach's temperament (or Sorge's 1758), and draw interesting colours from keyboard instruments. Furthermore, the *Canon per tonos* has some startling effects when played by or with a keyboard tuned Bach's way. As the king's theme and its accompaniment rise through C minor, D minor and E minor, things seem normal enough (while markedly different in all three). Into F♯ minor, G♯ minor and B♭ minor the sound is increasingly disturbing: 'so shall the king's fame increase'. Is such a hidden political statement, perhaps, part of the reason why the court never acknowledged the gift of this book, and Bach had it printed at his own expense to hand out to his friends? In Part 2 we will explore more fully such suggestions of meaning hidden in the *sound*.

Ensemble music

Because most of Bach's naturals are tuned in the normal 18th-century regular temperament (⅙ comma), instrumentalists and singers find those pitches exactly where expected. B and the five accidentals are placed more expressively: increasingly sharp in the sequence B–F♯–C♯–G♯–D♯–A♯. Those pitches are smoothly connected to one another in pure or nearly pure 5ths, and easy to find by intuition and experience. (This is better demonstrated in practice than described in print.) As several colleagues have already reported to me from their concert performances, and as I have found by playing through Bach's violin sonatas with a friend, this temperament is remarkably easy to use in ensemble, switching from Vallotti's and other methods to which they were accustomed. The goal is not necessarily to match every pitch on the keyboard exactly,[88] but rather to play as naturally and comfortably as possible, being free to explore expressive nuances and not *worry* about intonation at all, consciously. In December I used Bach's tuning secretly for the continuo of Handel's *Messiah*, and noticed that it conforms to the instinctive way string players handle intonation. No one remarked about the tuning at all, but only that the orchestral and continuo playing seemed especially beautiful and expressive.

What about the accompaniment of vocal works in situations that originally had a *Chorton/Cammerton* split, with the keyboard player reading from a part notated a whole step below the orchestra's?[89] Most obviously, this group of compositions includes Bach's vocal music from Leipzig. How well does Bach's temperament fare in this situation, where the organ is treated as a transposing instrument in D?[90]

Illus.3 shows Bach's temperament in *Chorton*, i.e. sounding a tone higher than the rest of the orchestra in *Cammerton*. For example, as the organist reads

and plays in D major, the orchestra reads and plays in E major.[91] This doubly labelled graph shows that in Bach's expectation the *Cammerton* G and D major are the best in tune (which is not surprising for a string-based ensemble, and trumpets in D), and the *Cammerton* keys of F♯, D♭ and B major are the worst: to be used least frequently in concerted vocal music.

As a modern practical compromise, if the keyboard player(s) must read from scores or parts that have been transposed to *Cammerton*,[92] the following 'D' temperament can be used to realign the transposition of *Affekt*. That is, it restores all the intervals to their proper positions from the orchestra's and singers' perspective.[93] This version is derived from Bach's diagram by imagining the note 'D' in place of 'C' (where Bach wrote it, second from the right) and taking the series of 5ths from there, as before.

G–*D*–A–E–B–F♯ ⅙ comma; F♯–C♯–G♯–D♯ pure; E♭–B♭–F–C 1/12 comma

At the outside ends the resulting 5th C–G is 1/12 comma *wide*. All the other 5ths are narrow or pure, as shown.

For an electronic tuning device: in cents values deviating from equal temperament, reckoning from A rather than C (so the A will match exactly the orchestra's gospel A), that is:

C (+0), C♯ (−4), D (+2), E♭ (+0), E (−2), F (+0), F♯ (−6), G (+4), G♯ (−2), A (+0), B♭ (+0), B (−4)

Notice that this transposed temperament (in D) is especially easy starting from modern equal temperament, as the notes C, E♭, F, A and B♭ are all in their normal modern positions according to electronic tuners.[94]

Wind players should tune either to the keyboard's A or to the tonic of the composition.[95] The string players should tune open strings to the keyboard's regular ⅙ comma G–D–A–E, and note the irregular (slightly lower) C.

It should be emphasized here: this modern transposition of Bach's temperament into D is for accompaniment *only*, to re-create the performance sound of the *Chorton/Cammerton* situation (from an assumption that Bach's organs, pitched in *Chorton*, were tuned in his own temperament).[96] I have played through both the B minor Mass and St Matthew Passion in this; and although I have 'known' this music as a player and listener for 20 years, it is like hearing it for the first time.

This remarkable temperament solves the classic problem of having the continuo organist play in *Chorton*, while the orchestra and singers reading in *Cammerton* can find pitches easily and be centred in the most resonant keys for themselves. Of course, for Bach himself this was not a 'problem' as he already knew the layout of his instruments—and his harmonic resources—before writing the music. He took advantage of this transposing situation, letting it aid the shape of the drama in his choices of keys and surprising chords, rather than treating it as an inconvenience or hardship.

This 'D' version of Bach's temperament should also be useful to the student of harmony and counterpoint, when using Bach chorales (C. P. E. Bach/Riemenschneider) as a textbook. If it can be ascertained that a particular chorale came from a *Chorton/Cammerton* situation (especially from the Leipzig cantatas), a play-through in this temperament reveals the crunchiness—or not—of any particular moment of harmony arising from motion of independent lines. Some dissonances that seem excruciating in equal temperament are hardly beyond 'mild' here, especially when used in weak metric positions in the bar, while other moments may stand out as surprisingly brisk. That is: the composition student is *not* getting an accurate assessment of *Affekt*, and the overall behaviour of counterpoint, by merely playing through Bach chorales on equal-tempered pianos and organs. Chorale harmonization is not independent of tuning issues. Analysis of text-setting and linear motion should take this into account: the Bach chorales have musical secrets (invisible on the page but palpable in the sound) waiting to be heard again. Vocal and theory/composition instructors might set up a rehearsal piano or harpsichord in this 'D' version, to explore these features in Bach's vocal music.

Part 2 of this article will discuss some of the implications of this discovery on our understanding of Bach's keyboard music. A good deal of additional supporting evidence also appears on the *Early music* website, at http://www.em.oupjournals.org.

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1 Carl Philipp Emanuel Bach, *c.*1774, in a letter to Johann Nikolaus Forkel: recounting the working methods of his father and only teacher. *The new Bach reader*, ed. H. T. David, A. Mendel and C. Wolff (New York, 1998), no.395; *Bach-Dokumente*, iii (1972), no.803. Forkel's resulting biography of Bach is also included in *The new Bach reader*.

2 'The appropriately-tuned keyboard' is another good title, suggested in R. Rasch, 'Does "well-tempered" mean "equal-tempered"?', *Bach, Handel, Scarlatti tercentenary essays*, ed. P. Williams (Cambridge, 1985), pp.293–310.

3 'Ordinary' temperament was, and remains, a *practical* tuning strategy: while preserving the naturals of a regular mean-tone temperament, the tuner tastefully raises the sharps and/or lowers the flats slightly from their mean-tone positions until the circle nearly meets itself, and therefore all tonalities are usable with subtle distinctions among them. Bach's tuning specifies that amount of tasteful adjustment precisely, and calls also for a slightly raised B.

4 The first public performance using this temperament, to my knowledge, was Robert Hill's broadcast on Swiss radio, 6 May 2004, a few weeks after I notified him of my discovery. He played a programme of Bach, Handel and Scarlatti on his Cristofori-style fortepiano. It was also used on both organs in a performance of Bach's *St John Passion* by Apollo's Fire, June 2004, set secretly by Ross Duffin, who told the other performers only that it was an experiment with 'a new version of a well temperament'. Duffin reported to me: 'The reviewer here referred to the *orchestra* as "well-tuned." In other words, it sounded great. (. . .) The musical advantages of the temperament are immediately clear to anyone who has tried it, and the impression on listeners is remarkable as well.'

5 The 'beat rate' is the deliberate impurity of two notes forming an almost-pure interval. Upper harmonics of both notes have a frequency that is almost identical, at some point several octaves above the fundamental frequency, and the discrepancy sets up an interference pattern audible as a slow rhythmic wavering. Tuners count these wobbles to determine precise amounts of tempering. Two consecutive 5ths of equal size (equal amount of tempering) have beat rates in a 3:2 ratio; for example, G–D (flanking middle C) beats ⅔ as fast as the D–A above it, like duplets against triplets.

6 The historical debate continues: does (and did) 'mean-tone' refer only to a regular quarter syntonic comma, or to all the regular layouts generated by a consistent size of 5th? And, can divisions of the *Pythagorean* comma be considered 'mean-tone' at all, having nothing to do with $^{80}/_{81}$? But all *regular* temperaments do place D as a 'mean tone' within whatever C–E major 3rd has been established, and in that sense they (and 'Pythagorean' tuning by pure 5ths, and equal temperament) are 'mean-tone' layouts, as far back as Grammateus. This problem of nomenclature complicates the tuning literature considerably.

7 In this case, the word 'Pythagorean' comes from the ancient system of tuning only by pure 5ths.

8 The cents measurement, invented by Alexander John Ellis in the 19th century, is a modern logarithmic method of describing temperaments, with an assignment of 1,200 equal portions in the octave. That is, a cent is the 1200th root of 2.

9 And, since the grain of cents is not fine enough for sufficient accuracy, we see the inanities of hundredths and thousandths of cents, as decimals.

10 The twelfth 5th, actually an enharmonic diminished 6th, absorbs whatever 'slack' remains as the circle meets the beginning note.

11 That is, the starting note and the direction of travel from each note to the next in the tuning process.

12 That is, how well does the twelfth 5th sound like a pure 5th or like any of the other 5ths? If it is reasonably near to those, enough not to offend the ear, the 'circle of 5ths' closes: and the temperament may be used for music in any key.

13 The series of 5ths is the normal method to tune keyboard instruments by ear, listening to the quality of each 5th and the quality of the resulting major 3rds.

14 *The Bach reader*, ed. H. T. David and A. Mendel (New York, rev. edn 1966), pp.390–93; *New Bach reader*, ed. David, Mendel and Wolff, no.214; *Bach-Dokumente*, iii, no.183.

15 *New Bach reader*, ed. David, Mendel and Wolff, p.436 (Forkel's biography, last page of chapter 3). Such a time limit is not an exaggeration; it is easily

within reach of an experienced tuner (as confirmed by my own practice, and by interview of colleagues), provided the bearing plan is simple enough to be set quickly.

16 See especially *New Bach reader*, ed. David, Mendel and Wolff, no.363; *Bach-Dokumente*, iii, no.815; *Bach reader*, ed. David and Mendel, pp.447–50; and 'Marpurg versus Kirnberger: the tuning controversy in Germany', in R. Steblin, *A history of key characteristics in the eighteenth and early nineteenth centuries* (Rochester, NY, 2/2002).

17 C. Wolff, *Johann Sebastian Bach: the learned musician* (New York, 2000), pp.218–30.

18 Christoph Wolff, 'Invention, composition, and the improvement of nature: apropos Bach the teacher and practical philosopher', *The keyboard in Baroque Europe*, ed. C. Hogwood (Cambridge, 2003), p.135.

19 This observation of the similarity of Bach's and Kuhnau's wording is from J. Lester, 'The recognition of major and minor keys in German theory: 1680–1730', *Journal of music theory*, xxii (1978), pp.65–103.

20 It also perhaps gave the Leipzig authorities an aural notice of the system he intended to install on the Leipzig organs.

21 Obviously, one must also come to this with a reasonable practical background in the listening techniques, and the knowledge of what was normal in Bach's milieu: the types of regular and modified-regular keyboard layouts in their everyday work.

22 I shall return to this in Part 2, in the discussion of Sauveur, Tosi *et al.*

23 Sorge also advocated such attention to 3rds of the octave, rather than any axis of duality C–F♯ (or elsewhere).

24 The SC interpretation of Bach's drawing is given in the supplementary materials on the website. I thank Ross Duffin and Debra Nagy for discussion of this, reading an early draft of the present work: they helped me to discard my own preference for the SC reading and to focus better on the PC reading.

25 Even without this information concerning the beat rate of F–A, the necessity of ⅙ comma as the basic tempering of the naturals can be inferred. It is obvious both from historical context and through trial-and-error experimentation with the pattern.

26 As noted above, C. P. E. Bach cited his father's dislike of 'dry, mathematical stuff'. Bach's dislike of written expression is also remarkable. We have already seen his thorough-bass remarks here. His treatise of counterpoint, *Die Kunst der Fuge*, has no explication in words; the points are made entirely by musical example. And, instead of trying to defend himself or his art against public criticism, he hired the university professor Birnbaum to represent him (*New Bach reader*, ed. David, Mendel and Wolff, pp.337ff.; Christoph Wolff, *Essays*, chapter 32; Wolff, *Bach: the learned musician*, pp.431ff.).

27 See the supplementary materials on the website www.em.oupjournals.org

28 A practical trick: it is easiest to hear and count this beat rate accurately using a major 10th, *F–a*.

29 For $a' = 440$ Hz: c'–e' has 4.5 and *f–a* has 3.0 beats (double the metronome speeds of 134 and 89). For $a' = 415$ Hz: c'–e' has 4.2 and *f–a* has 2.8 beats (double the metronome speeds of 126 and 84). 'Beats' are the audible interference patterns in the harmonics (overtones) of any two notes tuned almost to a pure interval. When a pure interval is made slightly narrow or wide, the beats increase in speed: and the interval's 'out-of-tuneness' can be calibrated precisely by listening to their tempo.

30 David Gordon and Andrew Manze used this temperament in the English Concert's tour of the USA, and at the Wigmore Hall, during October and November 2004. They chose it for its all-purpose musical properties in the continuo, even though their tour repertory included no Bach! This, to me, is a particularly strong endorsement of its musicality.

31 Taylor & Boody Organbuilders, Staunton Virginia, Opus 41. Goshen College Music Center, Goshen Indiana, my undergraduate *alma mater*. I inspected this organ in November and December, playing the formerly problematic Bach repertoire (see Part 2). A recording will be available.

32 *Bach-Dokumente*, i (1963), no.152.

33 *Neue Bach-Ausgabe*, V/6.1 (*WTC* 1), Kritischer Bericht (1989), p.21.

34 *Neue Bach-Ausgabe*, V/6.1 (*WTC* 1), pp.xiv–xv.

35 *Bach reader*, ed. David and Mendel, p.85.

36 *New Bach reader*, ed. David, Mendel and Wolff, no.90.

37 *New Bach reader*, ed. David, Mendel and Wolff, no.88. Anna Magdalena, herself an excellent musician, of course knew how the home keyboard(s) *sounded* in her husband's everyday tuning. So did the children, hearing music all the time. To them, this would all simply have been the normal way that keyboards were to be tuned; there would have been no need to write the method down, and it would not necessarily have been a secret, anyway. When the tuning sounds so right all the time, so unproblematic, why ever

question how it's done, or why it works as well as it does?

38 J. M. Barbour, *Tuning and temperament: a historical survey* (East Lansing, 1951; new Dover edition, 2004), pp.195–6.

39 P. Hindemith, *Komponist in seiner Welt* (Zurich, 1959), p.114; cited in B. Billeter, *Anweisung zum Stimmen von Tasteninstrumenten in verschiedenen Temperaturen* (Berlin, 1979), p.12 (translation mine).

40 A good summary of Werckmeister's usage is provided in Rasch, 'Does "well-tempered" mean "equal-tempered"?', pp.293–300.

41 Wolff, *Bach: the learned musician*, pp.228–30.

42 P. Williams, 'Was Johann Sebastian Bach an organ expert or an acquisitive reader of Andreas Werckmeister?' *Journal of the American Musical Instrument Society*, xi (1985), pp.38–54, itself an expansion of P. Williams, 'J. S. Bach—Orgelsachverständiger unter dem Einfluss Andreas Werckmeisters?', *Bach-Jahrbuch*, lxviii (1982), pp.131–42.

43 P. Williams, 'J. S. Bach's *Well-tempered clavier*: a new approach', *Early music*, xi (1983), pp.46–52, 332–9, at pp.47–8.

44 P. Williams, *The organ music of J. S. Bach* (Cambridge, 2/2003), p.160. Even with Bach's temperament temporarily out of the picture, that analysis is questionable. In less suave temperaments there is a better chance that both D♯ (enharmonically E♭) and E major triads will be decent, for the E major version, than that both B and C major are.

45 P. Williams, 'The harpsichord acciaccatura: theory and practice in harmony, 1650–1750', *Musical quarterly*, liv (1968), pp.503–23.

46 Andreas Werckmeister recanting his previous work with unequal temperaments, in his (posthumous) *Musicalische Paradoxal-Discourse* (Quedlinburg, 1707), p.110; cited in Rasch, 'Does "well-tempered" mean "equal-tempered"?', p.299.

47 Werckmeister's own published harpsichord temperament of 1698 addresses those enharmonic concerns directly and explicitly, focusing on the qualities of major 3rds. Still, in practice, his D♭–F results as the worst 3rd of the 12. See the discussion in the excellent primer, P. Poletti, *Temperaments for dummies* (Utrecht, 2001), available as a PDF download from www.polettipiano.com.

48 Rasch, 'Does "well-tempered" mean "equal-tempered"?', pp.301–3.

49 D. Devie, *Le tempérament musical: philosophie, histoire, théorie et pratique* (Béziers, 1990).

50 The Barnes, Kellner and Kelletat temperaments are readily available in J. Barnes, 'Bach's keyboard temperament: internal evidence from the *Well-tempered clavier', Early music*, vii (1979), pp.236–49, which includes a lesser-known earlier temperament, as a footnote. The Bernhard Billeter temperament (in his *Anweisung zum Stimmen von Tasteninstrumenten in verschiedenen Temperaturen*) is probably the least known of any of these. The temperament he proposed is essentially a reverse-engineered version of Kirnberger II (the one with the especially narrow 5ths, D–A–E), slightly moderated to ⅓ syntonic comma, and then read hypothetically back into the practice of Bach as an alleged modification from Silbermann.

51 For example: $^{161}/_{160}$ and $^{162}/_{161}$ approximate the square root of $^{81}/_{80}$ from opposite sides.

52 O. Jorgensen, *Tuning* (East Lansing, 1990), p.9.

53 'Well temperament' is ungrammatical, but has become common usage.

54 Jorgensen's references to 'harmonic waste' in *Tuning* are too numerous to mention individually.

55 M. Lindley, 'Well-tempered clavier', *New Grove II*.

56 By 'workmaster' I mean the Werckmeister/Neidhardt/Vallotti shape: temperaments that preserve the expectation from mean-tone layouts that F♯ major or C♯ major will have the most discordant major 3rds. My pun on Werckmeister's name also implies that something is not quite right about the shape, like trying to use a cheap set of imported tools that do not quite fit the job requirements.

57 See, for example, Lindley's 'Grosvenor' temperament in the supplementary materials on the website.

58 M. Lindley, 'Stimmung und Temperatur', *Hören, Messen und Rechnen in der frühen Neuzeit*, ed. F. Zaminer (Darmstadt, 1987), pp.109–331.

59 M. Lindley, 'J. S. Bach's tuning', *Musical times*, cxxvi (Dec 1985), pp.712–16.

60 M. Lindley, 'A quest for Bach's ideal style of organ temperament', *Stimmungen in 17. und 18. Jahrhunderts*, Michaelsteiner Konferenzberichte, lii, (Michaelstein, 1997), pp.45–67.

61 M. Lindley, *Lutes, viols and temperaments* (Cambridge, 1984); Lindley, 'J. S. Bach's tuning'. Also, the previous incarnations of Lindley's *New Grove* 'Temperaments' and 'Well-tempered clavier' articles included similar observations.

62 Notably, the F minor Sinfonia employs A and B𝄫, B and C♭, E and F♭; and the E major pieces call for well-placed extreme sharps, far beyond E major itself.

63 M. Lindley, 'Temperaments', *New Grove II*.

64 Lindley himself has taken a strong and consistently firm scholarly stance against the adoption of equal temperament for J. S. Bach's music. Therefore, any notion that C. P. E. inherited equal temperament from his father must be handled carefully. The present article offers a third way out of that particular dilemma.

65 Carl Philipp Emanuel Bach, in *Versuch über die wahre Art das Clavier zu spielen* (Berlin, 1753), paragraph 14 of the introduction, writes that only 'most of' the 5ths ('meisten Quinten') are tempered. Is this perhaps a description of the same temperament he learned from his father, his only teacher: with nine tempered 5ths and three pure? All the keys are musically usable, equally, without any startling anomalies; could that be what he meant as *gleich rein*? His own compositional style, with its bold harmonic surprises and cross-relations, is well served by the key colours and subtleties of his father's temperament. In the *Versuch* it appears that C. P. E. is merely contrasting the modern system (*Wohltemperirt*) with earlier ideals of regular mean-tone. In light of this, and on the musical evidence of playing through his compositions, I do not believe that C. P. E. ever abandoned this in favour of equal temperament.

66 Again, there is no way to describe this adequately in words. It must be experienced at the keyboard.

67 Kellner's temperament is at its best in the music of Buxtehude, Scheidt and Scheidemann.

68 Kellner promoted the mathematical truism that among regular ⅕ PC 5ths, the resulting major 3rd beats at the same rate as the 5ths. But this is of no value when listening to music, since it would be audible only if the three notes of a triad were played *exactly* simultaneously, and if nothing else were happening during such a sustained triad. It is useful information during the tuning process itself (by ear), and perhaps also to mystics; but, the 2:1 proportional beating of regular ⅙ PC has just as much (or little) significance. Kellner's over-promotion of the 6/1 proportional beating in the B major triad of his temperament is more of the same: it is all salesmanship, the assignment of spiritual meaning to mathematical truisms, and inaudible during musical practice.

69 Rasch, 'Does "well-tempered" mean "equal-tempered"?', p.308.

70 *The well-tempered clavier, Part I*, ed. R. Jones (London: ABRSM, 1994).

71 D. Ledbetter, *Bach's Well-tempered clavier: the 48 preludes and fugues* (New Haven, 2002), chap.2 'Well-tempered'.

72 Ledbetter, *Bach's Well-tempered clavier*, pp.1–2.

73 R. Steblin, *A history of key characteristics in the eighteenth and early nineteenth centuries*, covers the Marpurg–Kirnberger debates, and Mattheson and many others, but provides nothing about Sorge.

74 S. Isacoff, *Temperament: how music became a battleground for the great minds of Western civilization* (London, 2002), p.249.

75 Isacoff, *Temperament*, p.6; the form of words is horribly ironic.

76 *New Bach reader*, ed. David, Mendel and Wolff, no.394; *Bach-Dokumente*, iii, no.801.

77 I have tuned numerous continuo organs and maintained small church instruments, and I assume that other professional organists of the 17th and 18th centuries probably had more practised skill at this than I do.

78 The most drastic changes of temperament require trimming or addition of pipe material.

79 See C. Wolff, 'Bach's personal copy of the *Schübler* Chorales', in *J. S. Bach as organist*, ed. G. B. Stauffer and E. May (London, 1986), pp.121–32. Also C. Wolff, *Bach: essays on his life and music* (Cambridge, MA, 1991), pp.178–86. For C*lavierübung III*, see the remarks in Williams, *The organ music of J. S. Bach*, p.387.

80 The preservation process is described in Ledbetter, *Bach's Well-tempered clavier*, p.6.

81 *Grove's dictionary of music and musicians* (London, 1904–11), i, p.152.

82 See Spitta.

83 Devie, *Le tempérament musical*, p.142.

84 Devie, *Le tempérament musical*, pp.142–3; Lindley, 'Stimmung und Temperatur', pp.272–6.

85 Also, the tetrachords and hexachords are not absolutely unique any more, as Bach's are (see Table 1 and Part 2 of this article), but *most* keys are melodically different from one another.

86 Another possibility: Bach himself may have refined the temperament thus in practice, between 1722 and any encounters with Sorge in the 1740s.

87 Johann Joachim Quantz, *Versuch einer Anweisung die Flöte traversiere zu spielen* (1752), trans. E. R. Reilly as *On playing the flute* (Boston, MA, 2/1985), pp.257–8.

88 See especially Ross Duffin's web essay, 'Why I hate Vallotti' at http://music.cwru.edu/duffin/Vallotti/, and B. Haynes, 'Beyond temperament: non-keyboard intonation in the 17th and 18th centuries', *Early music*, xix (1991), pp.357–81.

89 The extant parts are listed in the appendices of L. Dreyfus, *Bach's continuo group: players and practices in his vocal works* (Cambridge, MA, 1987).

90 B. Haynes, 'Questions of tonality in Bach's cantatas: the woodwind perspective', *Journal of the American Musical Instrument Society*, xii (1986). The article is an excellent presentation of these specific issues, including commentary about the available editions and the transpositions that have been done in them.

91 Facsimile excerpts of the autograph score from the cantata BWV49 (1726, Leipzig) appear in Dreyfus, *Bach's continuo group*, pp.65–6. I have performed this cantata in an ensemble where the keyboards were tuned to Vallotti's temperament, and the organ part was transposed to E instead of Bach's notated D. The orchestra had difficulty matching pitches in this situation, especially where the music ventures into double sharps. If Bach's temperament had been available to us at the time, the orchestra would have been tuning to the sound of Bach's D major, which is considerably easier.

92 In the standard modern performance materials for Bach's vocal works, this has already been done. Bach's normal transposing situation is now *abnormal* for modern players! As Haynes remarks in 'Questions of tonality in Bach's cantatas', this transposition in modern editions sometimes makes performance of these pieces more difficult than it should be.

93 This is a subtle distinction, to be sure, but the aim here is to restore the expected *sound* of Bach's ensemble overall, as closely as possible, in the artificial situation where the organ is no longer a 'transposing' instrument.

94 This is equivalent to the observation (in Part 2 of this article) that the subset E♭, G, A♭, B♭, D♭ in the untransposed version is a set of five notes from equal temperament. The comfort of singers and orchestral players is a commodity not to be underestimated! Musicians need a familiar terrain on which to do their best work, being most freely expressive.

95 In Bach's church services, the orchestra tuned quietly *during* an organ prelude in an appropriate key.

96 See also Sorge's 1758 temperament, referenced above.