
Bach's Temperament, Occam's Razor, and the Neidhardt Factor

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Source: *Early Music*, Vol. 34, No. 4 (Nov., 2006), pp. 625-633

Published by: Oxford University Press

Stable URL: <https://www.jstor.org/stable/4137310>

Accessed: 11-10-2026 18:49 UTC

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John O'Donnell

Bach's temperament, Occam's razor, and the Neidhardt factor

WITH understandable enthusiasm Bradley Lehman has trumpeted his interpretation of Bach's purported tuning diagram into the early music world.¹ Ideally his paper would have acknowledged the herald, Andreas Sparschuh, who in 1998 proposed that the diagram was indeed a key to Bach's temperament rather than mere 'border decoration', to which category it had previously been relegated; and Michael Zapf's subsequent work on the diagram might perhaps have been mentioned. Lehman has explained these omissions.²

Enthusiasm, however, is no guarantee of sound interpretation and, unbridled, can lead to unreliable results. It is hardly surprising, then, that there have been some well-considered responses to Lehman's proposals.³ Bach's diagram is shown as illus.1.

I see the following aspects of Lehman's interpretation as problematic:

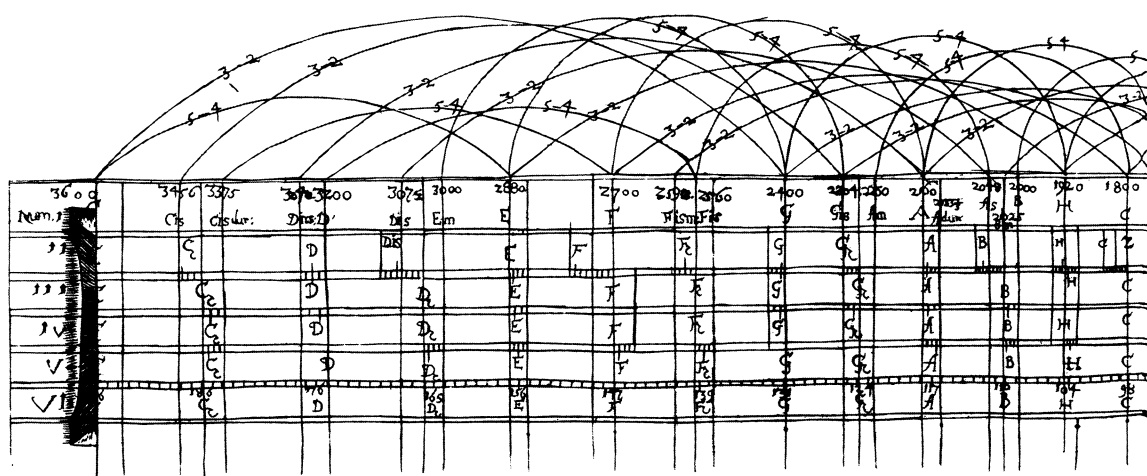
- 1 First and foremost, the diagram is to be read upside-down. According to Lehman: 'The solution, as students of drawing know, is to turn the

page upside-down to see if it might be easier to copy that way.'⁴ This may be so, but it is no argument as to how the diagram is to be *read*. Indeed, if it is easier to draw it this way and it is also to be read this way we have to ask why Bach didn't simply draw it the right way up. There is a failure of logic here.

- 2 The loops that enclose double coils and those that enclose single coils are treated as double and single versions of the one phenomenon, namely the narrowing of a 5th, whereas the fact that the single coils occur at the entrance to a loop while the double coils occur at the exit from a loop shows that they are not parallel phenomena.⁵
- 3 The 'C' identified by Lehman as the key to the position of the temperament has effectively been dismissed from the argument by Carl Sloan, who points out that this C 'is actually an ornamental hook on the "C" of "Clavier"'.⁶ Yes, it could be doing double duty, but if the diagram is to be read inverted why is this essential element now upside-down?



1 The loops from the title-page of *Das wohltemperirte Clavier*

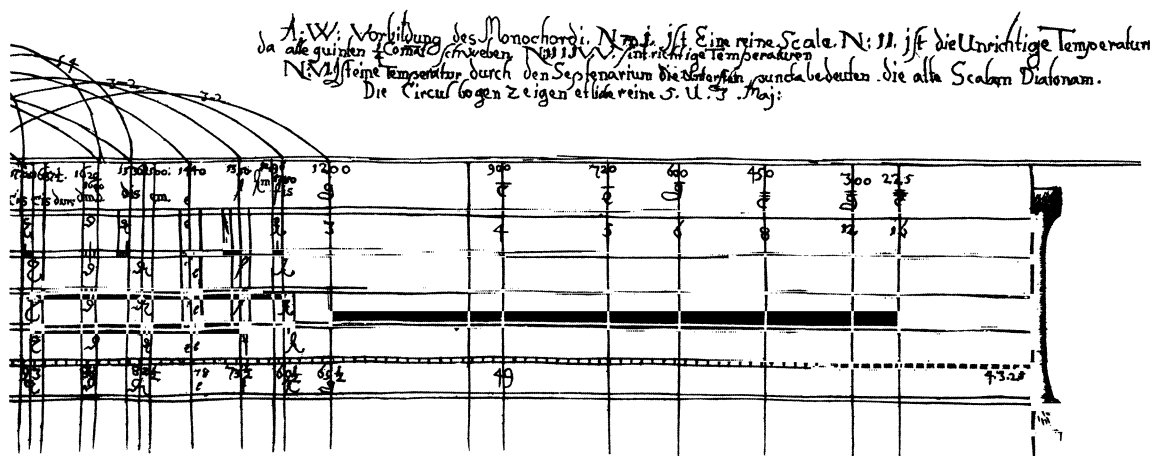


2 Andreas Werckmeister's monochord, from his *Musicalische Temperatur* (Quedlinburg, 1691), insert between pp.38 and 39

- 4 The failure to recognize the 'E♭/D♯' indication, discussed below, is a significant oversight.
- 5 The justification of the temperament's unusual contour through recourse to Sorge's temperament for organs tuned to *Chorton* pitch is a further failure of logic. *Das wohltemperirte Clavier* was, as we understand it, composed principally for harpsichord, which in Bach's day was generally a *Kammerton* instrument. The E–G♯ 3rd at which Sorge's *Chorton* temperament peaks will be F♯–A♯ for any *Kammerton* instruments performing with an organ so tuned, and there is no surprise element in a temperament whose widest 3rd is F♯–A♯. Sorge's solution is quite an ingenious one for a temperament that is required to do justice both to the solo organ repertoire and to ensemble music with *Kammerton* instruments. It may be that Bach intended his temperament for general use, but we have no information to support such an assumption.
- 6 If Bach's temperament included a wide 5th, and if this was indeed the temperament that C. P. E. Bach used, it is strange that the latter failed to mention this component. Wide 5ths are perfectly acceptable in themselves, but Emanuel Bach mentions only a majority of narrow 5ths, surely leaving us to understand that the remaining 5ths are to be tuned pure.

Let us begin anew, admitting at the outset that any interpretation of Bach's diagram must be hypothetical: certainly it is premature to be describing one reading as 'the Bach temperament' or 'Bach 1722'. But on the principle of Occam's razor, whereby an explanation that is simple and best fits the known facts is to be preferred to a more complicated one, the following interpretation may be deemed fit to supersede what has so far been proposed.⁷

Contributors to the discussion have been seeing Bach's diagram as a circle of 5ths: indeed one writer has made a plea 'for a Bachian circular diagram, rather than his wiggly horizontal line'.⁸ But what if Bach's intention is indeed horizontal rather than circular? Can it be that the loops follow the same order as the works in the volume of music that they precede? Temperaments in Bach's day were commonly notated chromatically from C, no doubt following the model of the monochord, but also because of increasing interest in measuring the equality or otherwise of successive semitones in the quest for equal temperament. It also happens to represent the order in which Bach chose to lay out the preludes and fugues of *Das wohltemperirte Clavier*. Yes, one tuned by 5ths and 4ths, as described by Carl Philipp Emanuel Bach⁹ and tabulated by Georg Andreas Neidhardt,¹⁰ but this is not the way in which temperaments were



2 continued

generally notated, and it is my proposal that Bach's is no different. Illus.2 is a diagram from Andreas Werckmeister showing a number of temperaments laid out on a monochord, above which are arcs showing perfect 5ths and major 3rds. It is my contention that this (or something akin to it) is Bach's model, though we are left to describe the arcs mentally.

The detail of Bach's diagram that triggered this realization is one not mentioned by Lehman. The letter 'D' of 'Das' includes a diagonal line that goes directly to the third loop and has 'Eb' on the left side of the line joined to the German keyboard tablature version of 'Dis' (D#) on the other side of the line.¹¹ How are we to interpret this other than as an indication that this loop represents Eb/D#? It may be that the choice of Eb/D# was made to symbolize the whole art of well-tempered tuning, wherein enharmonic notes are made one, and it is interesting in this regard that in the ensuing volume only the Eb minor Prelude and D# minor Fugue are notated as an enharmonic pair. But I think that it has a greater significance, as we shall see when we come to the tuning process.

If Bach has identified Eb/D# we can simply accept C as the starting point, label the loops chromatically from C# to B (noting that the flourish of the letter 'D' passes, by accident or design, through the middle of the loop now being interpreted as D), and prepare to tune. And if we work within the

limits of the given octave we shall soon discover that each time we leap up a 5th we land on a loop enclosing a double coil, while each time we leap down a 4th we land on either a loop that encloses a single coil or an empty loop. I imagine that the interpretation of the empty loops as pure intervals will remain uncontroversial. How to divine the mind of Bach in relation to the loops enclosing coils is not immediately evident. But if we trace Bach's pen-stroke through each of our tempered 4ths it first describes a small coil then encircles it with another, which for the sake of clarity we are referring to as a loop: the process is one of enlarging. And after the empty loops we reach our tempered 5ths, for each of which the pen first describes a large loop, followed by two coils inside it: the process is one of reducing. So I am interpreting the single and double coils as widened 4ths and narrowed 5ths respectively. The difficulty is in explaining single versus double coils. Perhaps it is simply to ensure that the intervals of the 4th and 5th are visually distinct, and perhaps there is something in what C. P. E. Bach advises about tuning: 'The beats of 5ths can be more easily heard by probing 4ths, an advantage that stems from the fact that the tones of the latter lie closer together than 5ths.'¹² Hence clear single coils for the 4ths, convoluted double coils for the 5ths.

Let us proceed. C up to G is a narrowed 5th; G down to D is a widened 4th; D up to A is a narrowed 5th; A down to E is a pure 4th; and so on, until we

tune down a pure 4th from G $\sharp$ to D $\sharp$. And now the equivalence of D $\sharp$ and E $\flat$ comes into play, for at some point in the circle it is necessary to change from sharps to flats: thus we rename D $\sharp$ as E $\flat$. To our 21st-century minds this may be hardly worthy of note, but it was serious food for thought in the 18th century. In his *Grosse General-Baß-Schule*, in the annotations accompanying the tenth test piece of the middle class, Johann Mattheson refers to a deficiency (*Mangel*) in notation as he circumnavigates the complete circle of 5ths, 'which I, for the moment, do not know how to rectify'. He calls on 'the most experienced composers to offer me their thoughts about it and show a better way'.¹³ In a piece in F minor notated with three flats, Mattheson's notational deficiency involves a leap from f $\flat$ down to A $\flat$. He also refers the reader to an instance on p.200 of the book, where he has finished a phrase on d $\sharp$ and commenced the next phrase on e $\flat$ '. This is the last of his preliminary exercises, another three of which also involve similar notational deficiencies handled in a variety of ways. Bach's inscription, then, is an essential ingredient in the notation of his tuning system.

Continuing, we tune up a narrowed 5th from E $\flat$ to B $\flat$; and from B $\flat$ we tune down a pure 4th to F, which should leave us with a pure 4th from F down to our starting-point C or a pure 5th from F up to c, the small letter 'c' written with a new pen-stroke to the right of the diagram. The ensuing squiggle is presumably just that, perhaps meaning 'etc.', as in 'proceed to tune the octaves'.

If this interpretation is correct, it appears that Bach has omitted to give us one necessary piece of information, namely how much to adjust the various impure 4ths and 5ths, and this is where he would presumably have proceeded by verbal instruction. Lehman's solution is totally hypothetical on this point, though his interpretation of the single and double coils as two sizes of the one process gave him some relative information. It takes only a moment's calculation to realize that such an interpretation does not fit our case: for one thing five doubles and three singles means that we should be working in 13ths of a comma; for another, the major 3rd closest to pure in a temperament so tuned would be F $\sharp$ -A $\sharp$, inimical to

the principle of a circulating temperament, where the purer 3rds are required in the vicinity of C. But Bach's omission is really not as much of a handicap as might first be supposed, for we can already deduce a lot of information from the placement of the pure intervals. For example, regardless of the amount of the narrowing of the 5ths or widening of the 4ths, we can make the following statements about major 3rds

C-E and F-A will always be identical in size;

G-B will always be narrower than D-F $\sharp$;

A-C $\sharp$ will always be wider than E-G $\sharp$;

B-D $\sharp$ will always be wider than F $\sharp$ -A $\sharp$;

F $\sharp$ -A $\sharp$ will always be narrower than D $\flat$ -F;

D $\flat$ -F will always be narrower than A $\flat$ -C; and

B $\flat$ -D will always be wider than F-A.

This already tells us a great deal about the profile of our temperament. But how do we decide the relative sizes of the narrowed 5ths? (To simplify the discussion I shall forthwith dispense with 4ths, and speak only in terms of 5ths.) Without recourse to narrowing smaller than a 12th of a Pythagorean comma the following possibilities present themselves: (1) $2 \times \frac{1}{4}$ comma and $6 \times \frac{1}{12}$ comma; or (2) $4 \times \frac{1}{6}$ comma and $4 \times \frac{1}{12}$ comma. A little practical experiment soon rules out the first option: no matter where the $\frac{1}{4}$ -comma narrowings occur one is simply unable to achieve a workable solution. The second option, on the other hand, fits very nicely, the pieces of the jigsaw falling into place effortlessly. Since the 3rds on F, C and G—those that we expect to be closest to pure in a circulating temperament—are each generated by three narrow 5ths and one pure 5th, and since the 3rd on F $\sharp$ —normally a wider interval—is generated by four narrow 5ths, it seems obvious, indeed virtually essential, to place the $\frac{1}{6}$ -comma narrowings in the region of C and the $\frac{1}{12}$ -comma narrowings in the region of F $\sharp$. The result may be displayed schematically as fig.1.

For those who prefer to contemplate temperaments in the systems devised by Eitz and Ellis, together familiar to many through Murray

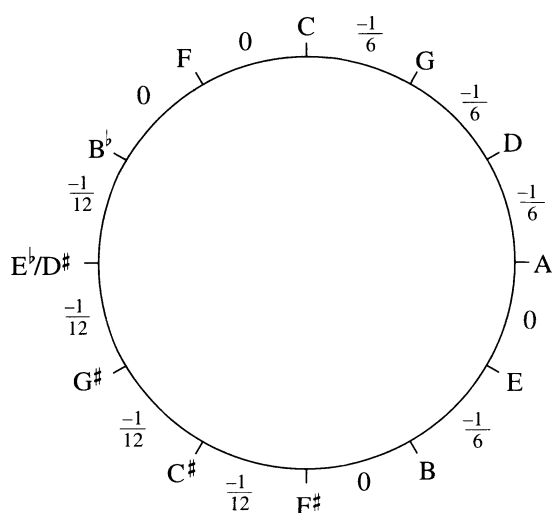


fig.1

Barbour's work,¹⁴ I give my proposed Bach temperament in this form also, noting in passing that we have returned to the linear form that I claim Bach also used:

C^0	$C\sharp^{-3/4}$	$D^{-1/3}$	$E\flat^{+1/12}$	$E^{-1/2}$	F^0	$F\sharp^{-2/3}$
0	96	196	296	396	498	596
$G^{-1/6}$	$G\sharp^{-5/6}$	$A^{-1/2}$	$B\flat^0$	$B^{-2/3}$	C^0	
698	796	894	996	1094	1200	

This will result in the following pattern of errors in major 3rds, each column totalling 21, representative of the 21 12ths of a ditonic comma that make up the lesser diesis.

A–C 9	D–F 8	F–A 7	B–D 8
E–G 7	A–C 8	D–F 7	G–B 5
C–E 5	F–A 5	B–D 7	E–G 8

This layout follows the model of Georg Andreas Sorge,¹⁵ used by Lehman in a website appendix to his article.¹⁶ A pure 3rd would be represented by 0, while 7 represents the error in an equal-tempered 3rd.

There is nothing extraordinary here. Three of the major 3rds, those on F, C and G, are a little

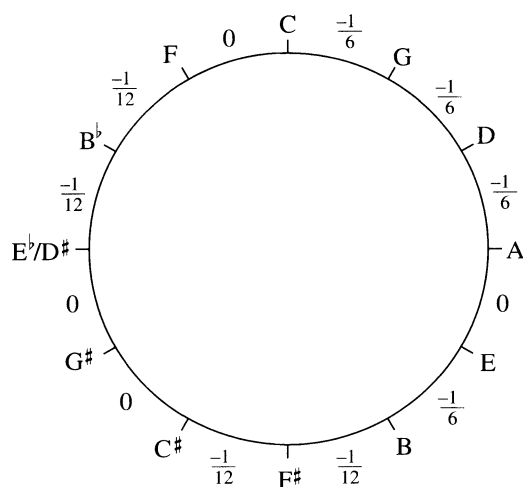


fig.2

purser than equal-tempered 3rds, four are exactly equal-tempered, a further four are just a step wide of equal-tempered, leaving the 3rd on A $\flat$ a further step wide. Our temperament accords with C. P. E. Bach's requirement that *most* of the 5ths be narrowed,¹⁷ with Kirnberger's statement that Bach had taught him to tune *all* the 3rds sharp,¹⁸ and with the obituary's observation that 'in the tuning of harpsichords he tempered them so purely and correctly that all tonalities sounded beautiful and pleasing'.¹⁹

For comparison, the extremes of the table of 3rds (5, 9) are identical to those of Sorge's *Kammerton* harpsichord temperament of 1744 (fig.2),²⁰ which is also composed of three groups of four 5ths made up of four pure (two of them falling in the same positions as my Bach proposal), four narrowed by $\frac{1}{12}$ comma (two in the same positions), four narrowed by $\frac{1}{6}$ comma (all in the same positions), and whose 3rds on F, C and G are also identical with one another and with the interpretation of Bach's diagram shown as fig.1.

In Eitz/Ellis/Barbour notation:

C^0	$C\sharp^{-5/6}$	$D^{-1/3}$	$E\flat^{+1/6}$	$E^{-1/2}$	F^0	$F\sharp^{-3/4}$
0	94	196	298	396	498	594
$G^{-1/6}$	$G\sharp^{-5/6}$	$A^{-1/2}$	$B\flat^{+1/12}$	$B^{-2/3}$	C^0	
698	796	894	998	1094	1200	

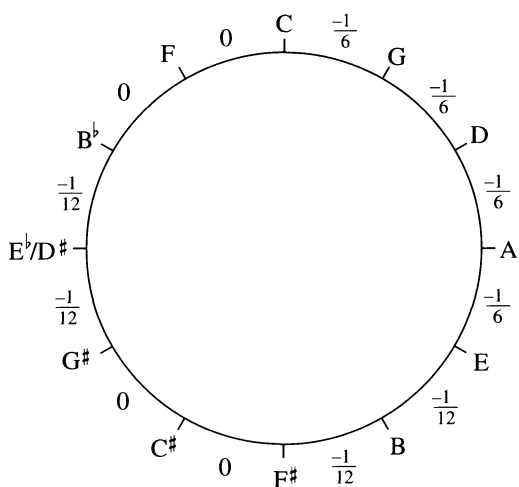


fig.3

This results in the following pattern of major 3rds:

A♭-C 9	D♭-F 9	F♯-A♯ 9	B-D♯ 9
E-G♯ 7	A-C♯ 7	D-F♯ 6	G-B 5
C-E 5	F-A 5	B♭-D 6	E♭-G 7

Johann Georg Neidhardt's Circulating Temperament no. 1 is similarly composed, and it shares with our temperament the positions of two pure, three $\frac{1}{12}$ -comma and three $\frac{1}{6}$ -comma 5ths (fig.3).

In Eitz/Ellis/Barbour notation:

C ⁰	C♯ ^{-3/4}	D ^{-1/3}	E♭ ^{+1/12}	E ^{-1/2}	F ⁰	F♯ ^{-2/3}
0	96	196	296	396	498	596
G ^{-1/6}	G♯ ^{-5/6}	A ^{-1/2}	B♭ ^{+1/6}	B ^{-2/3}	C ⁰	
698	796	894	1000	1094	1200	

The resulting major 3rds:

A♭-C 9	D♭-F 9	F♯-A♯ 9	B-D♯ 9
E-G♯ 9	A-C♯ 7	D-F♯ 5	G-B 4
C-E 3	F-A 5	B♭-D 7	E♭-G 8

But it is Neidhardt's 3rd-circle no. 4 that is virtually identical to our temperament, despite its different make-up of 5ths: one widened by $\frac{1}{12}$ comma, three pure, three narrowed by $\frac{1}{12}$ comma, and five narrowed by $\frac{1}{6}$ comma. In fact the only note that is not in an identical position is the note B♭, which Neidhardt has $\frac{1}{6}$ comma higher (fig.4).

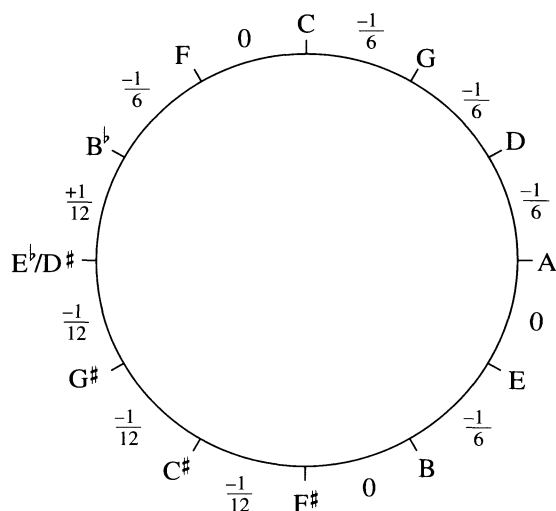


fig.4

In Eitz/Ellis/Barbour notation:

C ⁰	C♯ ^{-3/4}	D ^{-1/3}	E♭ ^{+1/12}	E ^{-1/2}	F ⁰	F♯ ^{-2/3}
0	96	196	296	396	498	596
G ^{-1/6}	G♯ ^{-5/6}	A ^{-1/2}	B♭ ^{+1/6}	B ^{-2/3}	C ⁰	
698	796	894	1000	1094	1200	

The resulting major 3rds:

A♭-C 9	D♭-F 8	F♯-A♯ 9	B-D♯ 8
E-G♯ 7	A-C♯ 8	D-F♯ 7	G-B 5
C-E 5	F-A 5	B♭-D 5	E♭-G 8

These temperaments of Neidhardt were first printed in 1724 and 1732 respectively,²¹ so Bach could have known them in 1722 only through a personal connection or through manuscript circulation. Or perhaps there was simply a culture of such temperaments in this area of Germany at this time, of which our hypothetical Bach temperament and those of Neidhardt and Sorge are examples.

In arriving at my realization of Bach's temperament I avoided any tempering smaller than a 12th of a Pythagorean comma. Some writers have suggested that since no one else was able to tune to Bach's satisfaction he must have been using smaller divisions of the comma,²² but there are simpler ways of interpreting this information in an era of tuning

by ear without beat-counting. The use of smaller intervals of tempering in one place will also mean larger intervals of tempering in another: one can certainly play around with such solutions as two 5ths narrowed by $\frac{1}{4}$ comma, one by $\frac{1}{6}$ comma and five by $\frac{1}{15}$ comma, but I wonder how practical this is to tune accurately by ear without counting beats and whether any musical advantage will be gained from it. At a time when finding accurate measurements for equal temperament was something of an obsession for many, the language of $\frac{1}{12}$ commas and $\frac{1}{6}$ commas was commonplace, Neidhardt even proposing what is in essence a poor man's equal temperament, tuning one pure 5th followed by one narrowed by $\frac{1}{6}$ comma right around the circle, resulting in equally tuned major 3rds.²³ And even the great Gottfried Silbermann, a conservative in terms of temperament, made $\frac{1}{6}$ -comma meantone, rather than $\frac{1}{4}$ -comma or $\frac{1}{5}$ -comma, his standard.

We have no evidence of any personal connection between Bach and Neidhardt. It is possible that they met; it is possible that they corresponded; but at this stage we lack documentation to confirm either of these possibilities. The following circumstantial evidence, however, may be relevant:

- 1 In 1706 Neidhardt was associated with Bach's cousin Johann Nicolaus Bach in Jena, perhaps as his student. The two men were involved in a temperament competition, each tuning a rank of pipes, Neidhardt setting his temperament by a monochord, Nicolaus Bach by ear. The latter was judged to have won the competition. The fact that this story is told by Jacob Adlung in 1758 shows that it was considered to be an event of some significance.²⁴ Even if Sebastian Bach was not in close contact with his cousin we should expect that he was familiar with it.
- 2 This competition took place at the organ in Jena's Stadtkirche, reconstructed in 1703–6 by the organ builder Georg Christoph Stertzing of Ordruf. This same man commenced the building of the organ of the Augustinerkirche in Erfurt, eventually completed by Johann Georg Schröter and examined by Sebastian Bach with the Arnstadt organ builder Johann Anton Weise in 1716.

All that we can say from this is that Neidhardt and Bach were moving in the same circles, and that it would be reasonable to assume that they would have known something of one another's work.

More important is the absence of any mention of Bach's name in discussions of temperament by Lorenz Mizler and members of his society and by such writers as Johann Mattheson and Jacob Adlung. From our perspective, as students of the '48', Bach was responsible for championing a modern approach to temperament, but among his contemporaries the big names in temperament were Werckmeister and Neidhardt, and within the Mizler Society Bümmler and Schröter also get an occasional mention.²⁵ Given that Mizler had been a student of Bach and remained an ardent admirer of him—Bach was one of the dedicatees of his doctoral dissertation at Leipzig University, and the Mizler documents repeatedly refer to him in such terms as 'our renowned Herr Bach'²⁶—the omission suggests that in mid-18th-century Leipzig Bach was not seen as having made any significant contribution to the development of temperament.

If my interpretation is correct, it follows that Lehman's temperament does not derive from Bach, though, as he observes, it closely approximates a Sorge temperament of 36 years later designed especially for *Chorton* organs. At the subjective level I have been puzzled by Lehman's excitement over his sharp 3rds on E. For one thing a movement such as the E major Fugue of Book 2 of the '48', being of almost *prima prattica* purity, seems to call for just intonation as an ideal rather than something approaching its opposite; for another, the performance of the large setting of the Phrygian *Aus tiefer Noth schrei ich zu dir* from *Clavierübung III* that has given me the greatest musical fulfilment is one I played on a meantone organ. But this tells us only that while we need musical intuition to interpret Bach's diagram we also have to ensure that we balance this with objectivity: Bach's E–G# 3rd, according to my interpretation, is neither pure nor almost Pythagorean, but equally tempered.

I do not propose to analyse my Bach temperament at length, but the relative sizes of semitones

may offer some justification of my interpretation. We can observe, in particular, that D $\sharp$ /E $\flat$ is placed at exactly the midpoint between D and E, while G $\sharp$ /A $\flat$ is exactly halfway between G and A. These details seem appropriate, given that *Das wohltemperirte Clavier* includes movements in E $\flat$ major, both E $\flat$ and D $\sharp$ minor, A $\flat$ major, and G $\sharp$ minor; and indeed throughout the 17th century these pairs of enharmonic notes had been vying with one another for inclusion in the meantone system, many keyboard instruments employing split keys to accommodate both. On the other hand the temperament's C $\sharp$ remains closer to a true C $\sharp$ than D $\flat$, its F $\sharp$ closer to a true F $\sharp$ than G $\flat$, and its B $\flat$ closer to a true B $\flat$ than A $\sharp$; and Bach always chooses to write in the keys of which these truer notes are, respectively, the key-notes, despite D $\flat$ major's fewer accidentals than C $\sharp$ major, despite G $\flat$ major's similar number of accidentals to F $\sharp$ major, and despite A $\sharp$ minor's identical key signature to C $\sharp$ major.²⁷ The temperament is thus well on the way to the equal temperament that was the quest of many of Bach's contemporaries while retaining some subtle inequalities that allow tonalities to retain their individual characters.

But was Bach a one-temperament man? In practice this was never a possibility: throughout his life he played organs of a variety of temperaments, including meantone and (at least approximately) equal-tempered. And if he did have a single system for tuning his harpsichord, it seems that Emanuel Bach and Kirnberger were not aware of it, the former's instructions being very general, the latter mentioning only the sharpening of all major 3rds. We know that Bach was critical of Silbermann's use of meantone temperament, but he also criticized

the uniformity of the specifications of Silbermann's organs. One of the thrills of being an organist, after all, is the individuality of each instrument, often as peculiar to its location as the bread, cheese and beer. For a man whose head was always filled with new ideas, for a man who was always learning, it is difficult to accept that a temperament he designed or adopted in or before 1722 remained his only ideal for life. Nevertheless it is good to have one example of his tempering practices, if indeed this is what we have found.

Naturally it is my conviction that this is what we have found. My proposed Bach temperament takes into account all details of the diagram, in particular the identity of the E $\flat$ /D $\sharp$ loop and the contrasting orientations of the loops enclosing single and double coils. It reads the diagram chromatically, which was quite normal for the notation of temperaments in the 18th century and was subsequently the form adopted by Murray Barbour for his major work on temperament in 1951. It strongly resembles some of the temperaments devised by Bach's exact contemporary, Neidhardt, whose work in this area was recognized by such writers as Mattheson, Mizler and Adlung, all admirers of Bach, but none of whom mentions him in relation to temperament; it is therefore likely that our temperament owes something, either directly or indirectly, to Neidhardt. It shares several features with the 1744 temperament of Sorge, which was particularly designed for a *Kammerton* harpsichord. And finally, it requires a minimum of hypothesis, the degree of narrowing of 5ths and widening of 4ths, though not spelled out by the diagram, is easily provided by context or by calculation.

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1 B. Lehman, 'Bach's extraordinary temperament: our Rosetta Stone', *Early music*, xxxiii (2005), pp.3–23, 211–31.

2 <<http://www-personal.umich.edu/~bpl/larips/errata.html>>.

3 See correspondence from D. Ponsford, R. Maunder, C. Sloan,

K. Mobbs and A. Mackenzie of Ord, *Early music*, xxxiii (2005), pp.545–7.

4 Lehman, 'Bach's extraordinary temperament', p.6.

5 Attention was drawn to this distinction by E. Jobin, 'Bach et le clavier bien tempéré', <<http://www.clavecin-en-france.org>>.

6 Sloan, Correspondence, 2005, p.546.

7 I am familiar with the following alternative readings to Lehman's proposal: Jobin, 'Bach et le clavier bien tempéré'; Mobbs and Mackenzie, Correspondence, pp.546-7; D. Jencka, 'J. S. Bach's Well Tempered Clavier tuning script: a 1/18th PC interpretation', <<http://bachtuning.jencka.com/essay.htm>>; and J. C. Francis, 'Das Wohltemperirte Clavier: pitch, tuning and temperament design', <<http://www.eunomios.org/contrib/francis3/francis3.pdf>>. For their responses to my proposed interpretation I wish to thank harpsichord builder William Bright of Barraba, New South Wales, organ builder John Brombaugh of Eugene, Oregon, and organist Brett Leighton of Linz.

8 K. Mobbs, 'The "Bach temperament"', <<http://www.mobbsearlykeyboard.co.uk/KWMamplificationofEMAugs5letter.htm>>.

9 C. P. E. Bach, *Versuch über die wahre Art das Clavier zu spielen* (Berlin, 1753), tr. W. J. Mitchell as *Essay on the true art of playing keyboard instruments* (London, 1949), p.37.

10 J. G. Neidhardt, *Sectio canonis harmonici, zur völligen Richtigkeit der Generum Modulandi* (Königsberg, 1724), p.5.

11 Jobin recognized the E $\flat$, but not the adjoining D $\sharp$.

12 Bach, *Versuch*, p.37.

13 J. Mattheson, *Grosse General-Baß-Schule* (Hamburg, 1731), p.240.

14 J. M. Barbour, *Tuning and temperament: a historical survey* (East Lansing, 1951).

15 G. A. Sorge, *Der in der Rechnen- und Meßkunst wohlverfahrene Orgelbaumeister* (Lobenstein, 1773), pp.56-7.

16 Bach's Rosetta Sorge matrices, <<http://em.oxfordjournals.org/cgi/content/full/33/1/3/DC1>>.

17 Bach, *Versuch*, p.37.

18 F. W. Marpur, *Versuch über die musikalische Temperatur* (Breslau, 1776), p.213.

19 Lorenz Mizler, *Neu eröffnete musicalische Bibliothek* (Leipzig, 1739-54), iv, pp.172-3.

20 G. A. Sorge, *Anweisung zur Stimmung und Temperatur sowohl der Orgelwerke, als auch anderer Instrumente, sonderlich aber des Claviers* (Hamburg, 1744), p.25.

21 Neidhardt, *Sectio canonis harmonici*, der, p.12, and J. G. Neidhardt, *Gänzlich erschöpfte mathematische Abteilungen des diatonisch-chromatischen, temperirten Canonis Monochordi* (Königsberg, 1732), pp.37-39.

22 For example, M. Lindley, 'A quest for Bach's ideal style of organ temperament', *Stimmungen im 17. und 18. Jahrhundert: Vielfalt oder Konfusion?* (Stiftung Kloster Michaelstein, 1997), pp.45-67, and J. C. Francis, 'Das Wohltemperirte Clavier: pitch, tuning and temperament design', <http://www.bach-cantatas.com/Articles/Das_Wohltemperirte_Clavier.htm>.

23 Neidhardt's 5th-circle no.3: Neidhardt, *Gänzlich erschöpfte mathematische Abteilungen*, pp.29-31.

24 J. Adlung, *Anleitung zu der musicalischen Gelahrtheit* (Erfurt, 1758), p.311. Adlung claims to have had the story directly from Nicolaus Bach's mouth.

25 See especially Mizler, *Neu eröffnete musicalische Bibliothek*, vol.1, III, pp.55-6, and vol.3, pp.470-74, 579-80.

26 Mizler, *Neu eröffnete musicalische Bibliothek*, vol.1, V, p.75, and vol.3, pp.203, 235, 482.

27 Mattheson in his *Grosse General-Baß-Schule* notates the 24th test piece of his middle class in C $\sharp$ major but gives both D $\flat$ and C $\sharp$ major versions for the last test piece of his advanced class, indicating (pp.436-7) his preference for the former. In both classes he notates his 14th test piece in both E $\flat$ minor and D $\sharp$ minor, while for the 16th test piece he chooses G $\sharp$ minor in his middle class and A $\flat$ minor in his advanced class.

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