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Contents

SOME EVIDENCE FOR THE USE OF BRASS AND IRON STRINGING IN ITALIAN KEYBOARD INSTRUMENTS

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In separate pioneering studies by John Shortridge (1960) and John Barnes (1965), Italian harpsichords and virginals were investigated and described.[1] In the light of evidence then available, it appeared as if the short-scaled instruments must have been tuned to a higher pitch than the long-scaled instruments. Taking into account the differing keyboard compasses, with many short-scaled instruments ending on c^3 and long-scaled ones on f^3, an explanation was offered that instruments were pitched a fourth apart and were, in effect, "transposing" with respect to each other. Building on the foundation laid by Shortridge and Barnes, William Thomas and J. J. K. Rhodes suggested instead that the short-scaled instruments were intended for brass wire and the long-scaled instruments for iron wire, both at similar pitch.[2] Thus, by 1967 two opposing views had emerged to explain the available data. Empirical confirmation of *which* string lengths were used for brass and iron wire came from an unexpected source in the early 1980s when Grant O'Brien, and later Alfons Huber, showed that *both* kinds of string material were used in the same instrument and in an unusual way, with a separate bridge for each type of wire.[3] This evidence thereby corroborated

1. John Shortridge, "Italian Harpsichord-Building in the 16th and 17th Centuries," *United States National Museum Bulletin* 225 (Washington, D.C., 1960): 93–107; and John Barnes, "Pitch Variations in Italian Keyboard Instruments," *Galpin Society Journal* 18 (1965): 110–16.

2. William R. Thomas and J. J. K. Rhodes, "The String Scales of Italian Keyboard Instruments," *Galpin Society Journal* 20 (1967): 48–62, and "Brass Strings on Italian Harpsichords," *Galpin Society Journal* 23 (1970): 168–70. For a thorough review of the entire discussion, see Denzil Wraight, "The Stringing of Italian Keyboard Instruments c.1500–c.1650," (Ph.D. diss., The Queen's University of Belfast, 1997; Ann Arbor, Mich.: UMI, 1997 [UMI no. 9735109]), part 1, 13–21 (this source hereinafter cited as Wraight, diss.).

3. G. Grant O'Brien, "Historical Harpsichord Stringing Practice," January 1981 (a manuscript sent to me for comment, which has not been published). Alfons Huber, "Mensurierung, Besaitung und Stimmtonhöhen bei Hammerklavieren des 18. Jahrhunderts," parts 1 and 2, *Das Musikinstrument* 35, no. 7 (1986): 58–63; no. 9 (1986): 24–29.

Thomas and Rhodes's interpretation that short scales could be evidence of brass strings, and long scales of iron strings. At the time, this new evidence (which is probably still largely unknown) was particularly useful in dealing with a problem of interpretation where views had become strongly entrenched and polarized.

This article presents all known evidence for the use of brass and iron string scales in the same instrument, as indicated by the presence of separate bridges. Following a preliminary examination of definitions and design features, the study distinguishes five ways in which separate bridges were employed in several Italian instruments, that is, in three *spinettone,* six harpsichords, four clavichords, and one polygonal virginal. This information yields evidence of the use of the scales appropriate for brass and iron wire.[4] Finally, it is argued that this dichotomy of short scales for brass strings and long scales for iron strings is not sufficient to solve all problems of interpreting the pitch of Italian stringed-keyboard instruments.

A Means of Describing String Length and Pitch

In examining the length of strings in keyboard instruments, the somewhat vague term "scale" is often employed. Because it is easy to confuse the concept of "scale" with the *actual* string length, the precise concept of a "c^2 equivalent length" offers increased clarity, even if the phrase is somewhat cumbersome. This modern terminology suggested by Friedemann Hellwig expresses the string lengths in a way that renders the implications for the pitch and possible changes of material more readily apparent.[5] Thus, *any* string length in an instrument can be described in terms of its "c^2 equivalent length," and comparisons of the scale are more easily understood.

The reference point of c^2 in this expression comes from modern research into the old building practices, which has discovered the *later* practice in harpsichord building of using c notes to lay out an instrument. Until about 1600 in Italy, most keyboard instruments were laid out from the f notes, for which reason it would often more nearly reflect the designer's practice to

4. It draws on material already published in Wraight, diss., part 1, 181–86.

5. Friedemann Hellwig, "Die grafische Darstellung der Saitenlängen von Tasteninstrumenten," in *Saiten und ihre Herstellung in Vergangenheit und Gegenwart,* ed. Eitelfriedrich Thom, vol. 11 of Studien der Aufführungspraxis und Interpretation der Musik des 18. Jahrhunderts (Michaelstein/Blankenburg, 1991), 47–58.

refer to an "f^2 equivalent length." Thus, in the present study references to equivalent string lengths with certain instruments indicate that the maker either clearly or likely used f^2, not c^2, as a point of reference.

The "c^2 equivalent length" is calculated by changing the *actual* string length according to the proportion its note has to c^2. For example, at c^1 the *actual* string length should be divided by 2; at c, by 4; and at C, by 8. The same ratios hold, respectively, for f^1, f, and F in relation to f^2 when calculating the "f^2 equivalent string length." The result of this calculation is a modern tool for further analysis. It is not suggested that old makers actually worked with this procedure.

When present, the evidence for the design orientation of an instrument is found as holes (often plugged) located at the bridges for the c or f notes, or sometimes as scribed lines on the baseboard used to lay out the case shape. Such indications have made it possible in some instances to reconstruct the original string lengths where original bridges are missing or to establish the original compass when the original keyboard has been removed or replaced.

String Materials and Their Expression in String Lengths

One of the essential features of instrument design is the choice of string material, which is then reflected in the string lengths. In the historical harpsichord-building tradition only three string materials were normally used: iron, yellow brass (about 25% zinc and 75% copper), and red brass (about 10% zinc and 90% copper). From stringing indications for the instruments of Blanchet, Taskin, Kirkman, Shudi, Wilbrook, and Ruckers, O'Brien has found that *in practice* the relationship of the lengths of yellow brass to iron strings is between 11:14 and 5:6, and that of red brass to yellow brass strings, between 5:6 and 8:11.[6]

These relationships can be regarded as firmly established for the eighteenth century, because they are observable in the *working practice* of the string lengths used. Furthermore, the relationships have been established

6. See table 1 in G. Grant O'Brien, "Some Principles of Eighteenth Century Harpsichord Stringing and Their Application," *The Organ Yearbook* 12 (1981): 160–76. This table provides a column for Italian instruments with the average scaling for c^2 as 285 mm. for brass wire but with a theoretical value, enclosed within parentheses, of 340 mm. for iron wire. At the time of writing this article, O'Brien had apparently not yet established the use of iron wire in the treble of some of Cristofori's instruments.

empirically by testing the breaking strength of old wire samples, the results of which have been documented by Malcolm Rose and Michael Latcham, to name but two researchers.[7]

As a practical guide it can be indicated that in Italy for a pitch of $a^1 = 415$ Hz a c^2 equivalent length of about 285 mm. for brass wire and about 340 mm. for iron wire *could* have been used. This estimate is based on the strength of both old and replica string materials, as I reported in the 2000 issue of this JOURNAL.[8]

Italian Scale Design and the Use of Separate Bridges

In most iron-scaled instruments from any tradition there is a changeover to brass strings (usually around the note c) where the string lengths become short enough to allow the use of brass wire at the same pitch level as the iron strings. It is not this practice that is referred to here but rather the employment of *separate bridges* for iron and brass strings. When the latter occurs in the treble of the instrument, with a separate bridge specially for the longer, iron strings, the necessity of a string-material change is rendered perfectly apparent to the informed examiner of these scaling issues (see fig. 1, an outline drawing based on the *spinettone* attributed to Cristofori, ca. 1720).[9] Five different ways in which brass and iron strings were used in the same instrument at the same pitch level are distinguished below.

1. Instruments strung mostly with brass wire but having iron wire in the upper portion of the treble. In the *spinettone* attributed to Cristofori (fig. 1) as well as in two similar instruments, the 8-foot bridge (often for

7. Much of Malcolm Rose's wire testing has not been published but was kindly communicated to me. A summary of some results of wire testing (mainly for brass wire) is found in Denzil Wraight, "Principles and Practice in Stringing Italian Keyboard Instruments," *Early Keyboard Journal* 18 (2000): 220–40. A recent and comprehensive source of wire data is Michael Latcham's "The Stringing, Scaling, and Pitch of Hammerflügel Built in the Southern German and Viennese Traditions, 1780–1820," *Musikwissenschaftliche Schriften* 34 (Munich and Salzburg, 2000), which includes descriptions of old iron and brass wire samples.

8. See Wraight, "Principles and Practice," 220–24.

9. Hubert Henkel, *Kielinstrumente: Musikinstrumenten-Museum der Karl Marx Universität Leipzig,* Katalog, vol. 2 (Leipzig: VEB Deutscher Verlag für Musik, 1979), no. 86.

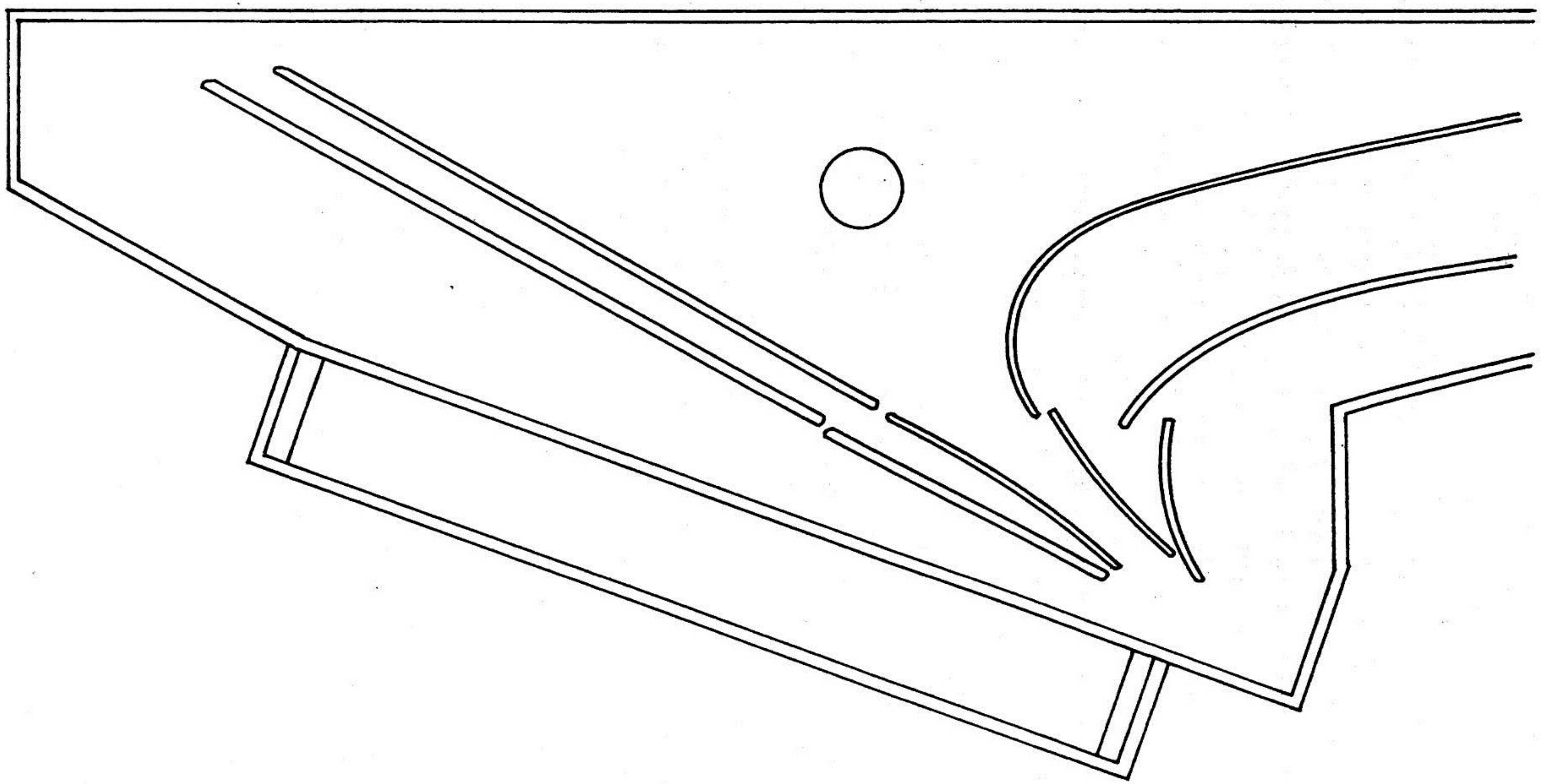

Fig. 1. *Spinettone* attributed to Cristofori (Leipzig no. 86).

c^2–c^3) is divided.[10] In these instruments the 4-foot treble strings would otherwise barely be long enough to span the jackslide. To avoid this difficulty, longer, iron strings have been used in the top octave.

When 8-foot and 4-foot registers are employed in a short-scaled harpsichord (c^2 = about 280 mm. or shorter) with a compass to c^3 or higher, it is advantageous to use a divided bridge and an iron scale in the treble, since the bridge on the soundboard is not placed so near to the bellyrail. Iron wire is used in the treble of the 4-foot register of the 1730 Solfanelli harpsichord for the notes c^2–c^3.[11] The layout problem in this instrument is similar to that in Cristofori's *spinettone:* the 4-foot strings of the Solfanelli harpsichord are barely long enough to straddle the jackslide.

The shortage of space in the treble is usually not so acute as to necessitate a change of string material.[12] It is unavoidable, however, in an unusual Cristofori harpsichord of 1726 that has 8-foot, 4-foot, and 2-foot registers and a divided bridge for f♯–f^2 of the 2-foot register.[13] Due to a lack of space, it is not possible for the 2-foot register to extend beyond f^2.

In all five instruments cited above, the length relationship between brass and iron strings is, or is close to, 5:6.[14]

10. The instruments are: Cristofori (attributed), Leipzig no. 86, Musikinstrumenten-Museum, about which both O'Brien and Huber have written (see note 3); the 1731 Ferrini, Pistoia, private collection (see Stewart Pollens, "Three Keyboard Instruments Signed by Cristofori's Assistant Giovanni Ferrini," *Galpin Society Journal* 44 [1991]: 77–93); and the undated instrument attributed to Solfanelli (W430; the "W" refers to instruments catalogued in part 2 of Wraight, diss.), Division of Musical Instruments of the National Museum of American History, Washington, D.C. Exact details of string lengths are given in Wraight, diss., part 1, 181–82.

11. This harpsichord (W213) in the Musical Instrument Museum, Conservatoire Royale, Brussels, bears a faked inscription to Nicolaus De Quoco 1694. The maker's name, Solfanelli, is found on the underside of the soundboard (see Wraight, diss., part 1, 181–82).

12. Compare the scaling of the 1679 Giusti harpsichord in the Tagliavini Collection (see pages 64–74 in Luigi F. Tagliavini and John H. van der Meer, *Clavicembali e spinette dal XVI al XIX secolo* [Bologna: Cassa di Risparmio, 1986]), which has no divided bridge and a *shorter* scale (c^2 = 259 mm.) than encountered in the instruments mentioned with divided bridges, all of which have a c^2 of about 280 mm.

13. Musikinstrumenten-Museum, Leipzig. See Henkel, *Kielinstrumente,* no. 85.

14. For an exact statement of all the relationships, see Wraight, diss., part 1, 181.

2. Instruments that have 8-foot registers strung with different materials. In a "1615 De Quoco" harpsichord, different c^2 equivalent lengths are used for the two 8-foot registers, which is realized by having two nuts.[15] The length relationship of the two registers is 5:6 (at least in the treble) so that the use of brass and iron strings is possible in principle, even though it seems curious to implement this level of complexity in a two-register instrument.

In another instrument described by O'Brien (and attributed to Antonio Migliai either before 1695 or after 1702, but probably not between 1695 and 1702), it is clear, however, what the original purpose was.[16] Two soundboard bridges run nearly parallel to each other and thereby enable the provision of three 8-foot registers. The ratio of the c^2 equivalent lengths is between 5:6 and 4:5.[17] Other three-register Italian harpsichords were made using one stringing material, and thus the two-bridge strategy is not obligatory.[18]

It is possible that Cristofori learned about the practice of employing brass and iron strings in the same instrument from Migliai, who was active in Florence before Cristofori's arrival, but the date range of Migliai's unsigned harpsichord is ambiguous and cannot substantiate such a hypothesis.[19]

3. Instruments in which the 4-foot register is strung with a different material. In an unsigned harpsichord (W693, probably ca. 1700) with the compass GG/BB–c^3, it can be seen that, if brass strings were used for the 8-foot register, iron strings would be necessary for the 4-foot register. This necessity arises because the length relationship of the c^2 equivalent string

15. The evidence is the marks of nut positions that are not sufficiently clear to establish conclusively the maker's intention. The signature on the instrument is probably not original, and one molding is similar to that used by Pasquino Querci (see Wraight, diss., part 2, 243–44). The instrument is located in the Musikhistorisk Museum, Copenhagen.

16. O'Brien ("Historical Harpsichord") discovered the traces for the two bridges of this instrument, which is in the Rodger Mirrey Collection, London. The harpsichord's attribution is described in Wraight, diss., part 2, 215.

17. See Wraight, diss., part 2, 215; the precise original string lengths could not be established.

18. A list of other harpsichords having three 8-foot registers is provided in Wraight, diss., part 1, 138–44. Uncertainty regarding the original condition has not been eliminated for every instrument, but this matter lies beyond the scope of this study.

19. See also Donald H. Boalch, *Makers of the Harpsichord and Clavichord, 1440–1840,* 3d ed. by Charles Mould (Oxford: Clarendon Press, 1995), 40.

lengths of the registers (after correction for the octave pitch) is between about 4:5 (actually 0.79) and 5:6 (actually 0.82).[20]

In the case of a 1564 Franciscus Brixiensis harpsichord, O'Brien interprets the 4-foot string-length data as evidence of the intention to employ iron strings.[21] From the averaged string lengths given by O'Brien, the length relationship for the 8-foot and 4-foot registers is only 6:7, a ratio rather small in comparison with the other data presented here. The Franciscus harpsichord has, however, rather unusual scaling: the normal procedure in instruments *of this size* is to make the 8-foot scale *accurately* Pythagorean from f^3 down to f^1 (i.e., the string length doubles at each descending octave), which results in the 4-foot strings being Pythagorean from f^3 to f. By contrast, in the Franciscus harpsichord the f^2 equivalent string length *increases* in both registers toward the treble, but most noticeably in the 4-foot register. It is therefore not clear which measurements should be chosen to determine the length relationship. Depending on which f string lengths are compared, the length relationship ranges from about 7:8, 6:7, or even 5:6.[22]

Until we understand how the Franciscus instrument was designed, further interpretation of the data is speculative. Nevertheless, we can consider some possibilities:

a. The strength of brass or iron wire available to the builder did not correspond to the average strength indicated by the 5:6 ratio for brass:iron wire.
b. A pitch difference of a whole tone was intended between the two registers, that is, the nominally 4-foot register was pitched a whole tone lower than the true octave of the 8-foot register. This design

20. An unsigned harpsichord in the collection of Marlowe Sigal, Newton Centre, Massachusetts (see W693 in Wraight, diss., part 2, 375–77). The 8-foot register clearly has a Pythagorean scaling, but in the 4-foot register the slight lengthening of the scale between c^2 and c^3 may be the result of layout error. Thus, the c^2-equivalent-length scale ratio at c^3 is 277:354 mm. or at c^2, 277:338 mm., yielding ratios of 0.78 and 0.82, respectively.

21. G. Grant O'Brien kindly communicated the manuscript of "Marco Jadra—A Venetian Virginal and Harpsichord Builder?" in *Gedenkschrift für Kurt Wittmayer*, ed. Silke Berdux (Munich, in press). The Franciscus harpsichord is kept in the National Museum of Ireland, Dublin.

22. The Franciscus harpsichord is clearly an f-oriented design, as can be seen from lines drawn on the baseboard for these strings. Thus, the f notes must be compared.

would effectively form two instruments in a single case pitched a tone apart, analogous to the whole-tone transposition arrangements of the 1537 Müller harpsichord and the 1559 Strobel organ.[23]

c. The instrument was designed for the use of iron strings in both registers, with the 4-foot iron strings being more highly stressed to add greater tonal brilliance to this register.

In neither the Franciscus instrument nor the W693 harpsichord is there an acute shortage of space that would make it either advantageous or necessary to use the longer iron strings.

4. Clavichords with separate bridges. The scale design of Italian clavichords is not identical in every known instrument; this should not surprise us since we do not find a single design for virginals used by every maker. In the following discussion I assume that the main part of the stringing is accomplished with iron wire, an assumption for which there is apparently now a consensus of several researchers.[24]

In the clavichord Leipzig no. 2 it is possible to use brass strings on the last fret (c–d) of the treble bridge, if we assume for the changeover criterion that the c^2 equivalent length has to be reduced to 5/6 at the changeover point,

23. Regarding the Hans Müller harpsichord (in the Collezione degli Strumenti Musicali, Rome), see G. Grant O'Brien, *Ruckers: A Harpsichord and Virginal Building Tradition* (Cambridge: Cambridge University Press, 1990), 20–23; and John Koster, "Pitch and Transposition before the Ruckers," in *Kielinstrumente aus der Werkstatt Ruckers: zu Konzeption, Bauweise und Ravalement sowie Restaurierung und Konservierung,* ed. Christiane Rieche (Halle: Händel-Haus, 1998), 82–86. Michael Strobel's organ (in the Churburg, South Tirol, Italy) transposed between a^1 = 466 Hz and a^1 = 521 Hz (see Egon Krauss, "Die Renaissance-Orgel auf Churburg," *L'Organo* 10 [1972]: 131–72).

24. See Denzil Wraight, "The Clavichord, 2. 15th and 16th Centuries," in *The New Grove Musical Instrument Series: Early Keyboard Instruments,* ed. Stanley Sadie (London: Macmillan, 1989), 151–52; Alfons Huber, "Konstruktionsprinzipien im Clavichordbau. Überlegungen zu Mensurierung, Stimmtonhöhe und Besaitung bei Clavichorden des 15.–18. Jahrhunderts," in *Musik muss man machen, eine Festgabe für Josef Mertin zum neunzigsten Geburtstag am 21. März 1994,* ed. Michael Nagy (Vienna: Vom Pasqualatihaus, 1994), 241–316; and John Koster, "The Stringing and Pitches of Historical Clavichords," in *De Clavicordio [I]: Proceedings of the International Clavichord Symposium, Magnano, 1993,* ed. Bernard Brauchli, Susan Brauchli, and Alberto Galazzo (Turin, Italy: Istituto per i Beni Musicale in Piemonte, 1994), 225–44. A possible exception is the clavichord Leipzig no. 3 (Musikinstrumenten-Museum, Leipzig), which in my opinion may have been conceived for the use of brass strings in the treble (see Wraight, diss., part 1, 215–20).

that is, reduced from 181 mm. to 150.8 mm.[25] It is questionable whether at the *change* of bridges the continued use of brass wire is possible since the c^2 equivalent length *increases,* the actual reduction yielding a ratio of only 8:9.[26] Similarly, we find that the 1568 Onesto Tosi clavichord also has only an 8:9 reduction at the bridge change.[27] This reduction might reflect the use of a different ratio between brass and iron, one that did not stress the iron as much, as in some Hass and other clavichords having 4-foot strings that complement the 8-foot strings in the bass octave.

Alfons Huber has made an interesting observation about the 4-foot stringing of a 1732 Hass clavichord, in which the length relationship of brass and iron strings at the changeover point is 8:9 and thereby obviously smaller than the 5:6 ratio described in this study for Italian instruments. As a result of this smaller 8:9 ratio, as Huber observed, and assuming the brass wire is stressed as much as practicable, the iron wire is stressed less than usual, with the effect that the tonal difference between the bichord (8′ + 8′) and trichord (8′ + 8′ + 4′) stringing is less obvious.[28] From data published by O'Brien and Lance Whitehead, one can see that the 8:9 length relationship in the 1732 Hass clavichord is not a unique occurrence.[29] The clear implication is

25. Hubert Henkel, *Clavichorde: Musikinstrumenten-Museum der Karl Marx Universität Leipzig,* Katalog, vol. 4 (Leipzig: VEB Deutscher Verlag für Musik, 1981), no. 2. See Wraight, diss., part 2, 117–28. Space limitations preclude describing other extant Italian clavichords here as well as investigating W678, the Italian clavichord depicted in an intarsia in the Montrefelto *studiolo* in Urbino.

26. See Wraight, diss., part 2, 117–28, for the corrected string lengths that are the basis of this discussion.

27. Ibid., 275–88 and 22–26. The Tosi clavichord is kept in the Museum of Fine Arts, Boston.

28. Alfons Huber, "Überlegungen zur Besaitung eines Clavichordes von H. A. Hass, Hamburg 1732," *Arbeitsblätter für Restauratoren* 2 (1992): 151. The Hass clavichord is in the Museum für Kunst und Gewerbe, Hamburg. A similar procedure is sometimes employed in organ building. An organ builder who has too little space for an open 8-foot pipe, for example, can combine an 8-foot Gedakt with an open 4-foot pipe, which would supply some of the missing overtones of the Gedakt. For this combination to be effective tonally in lieu of an open 8 foot, it is important to have the correct blend of 8-foot Gedakt and 4-foot tone. The organ builder achieves this by adjusting the height of the mouth of the 4-foot pipe and the strength of the pipe's sound.

29. G. Grant O'Brien, "Stringing Materials and Gauges for Clavichords by I. C. Gerlach and H. A. and J. A. Hass," in *De Clavicordio [I]* (cited above in note 24), 123–35; and Lance Whitehead, "The Laying-Out of Hass Clavichords," ibid., 111–21.

that string materials were not always stressed to their highest practical working point, but that other tonal factors played a role in guiding the maker's decisions and, as Huber has argued, depended on the *type* of instrument the maker was creating.[30]

In the 1543 Dominicus Pisaurensis clavichord, brass strings are possible at the third-to-last fret (g–a) on the treble bridge, following the 5:6 (equivalent to 0.833) criterion.[31] At the last fret on the treble bridge (e–e♭) the f^2 equivalent string length is reduced to almost 3:4 (equivalent to 0.75). As in other Italian clavichords, the f^2 equivalent string length *increases* again at the change of bridges, resulting in a reduction of nearly 5:6 (precisely 0.856). It should be noted that the basis of this analysis is an f^2 equivalent string length derived by *calculation* from the highest strings f^2–c^3, where the scale is Pythagorean. If one takes the *actual* c^2 string length as the basis of comparison, the calculated reduction will be less, because the c^2 string is shorter than implied by the f^2 equivalent string length.

This feature of clavichord scaling, that only part of the treble is Pythagorean, is a significant detail of the early clavichord design. It enables us to calculate the correct position of the treble bridges, which in these early Italian clavichords are not glued in place. *All* catalogue information on the early Italian clavichord bridge positions and the resulting string lengths is, according to my analysis, slightly inaccurate, for which reason I draw attention to this matter here.[32]

If Dominicus designed his ruler for the 1543 clavichord so that the *theoretical* f string length was used for the note d (the highest note on the second bridge), one would find an exact 5:6 ratio at the bridge change. This hypothesis is an explanation of his design procedure and, if correct, a way of determining the intended location of the second bridge.

5. Instruments strung mostly with iron wire but having brass wire in the lower portion of the bass. Although instruments using iron strings from the highest note downward change over to brass between about c♯ and A, it is unusual for a separate bridge to be provided for the brass strings. This is exactly what we find, however, in a unique virginal from about 1530 that can be attributed to Francesco Antegnati, who was well known as an organ

30. See Huber, "Mensurierung," part 1, 59–61.

31. The Dominicus clavichord is in the Musikinstrumenten-Museum, Leipzig. For additional information about the instrument, see Henkel, *Clavichorde,* no. 1; and Wraight, diss., part 2, 143–45.

32. For the calculation, see Wraight, diss., part 2, 143. The calculation method is discussed further on pages 25 and 275–76.

builder in Brescia.[33] The changeover is at e/f, resulting in an f^2 equivalent length relationship of nearly 5:6 (exactly 0.823) between the first string on the small bass bridge and the treble strings (see fig. 2).

We can only speculate as to the reason for this practice, there being no apparent necessity for two bridges. If we compare this virginal with the 1543 Dominicus clavichord discussed earlier, we see a similar progression of the f^2 equivalent length: this is shortened to a similar extent at the end of the treble bridge (e♭), that is, 0.77 for Antegnati and 0.76 for Dominicus. Furthermore, in both instruments the f^2 equivalent length then becomes *longer* at the highest note of the bass bridge and a ratio of 5:6 (i.e., 0.833) is then reached. Given these correspondences, one could consider whether Antegnati's virginal scaling is derived from a clavichord design and therefore whether the bass bridge section is analogous to the separate bridges of the sixteenth-century Italian clavichords.[34]

What Information Does the Brass-to-Iron String Ratio Reveal?

As the simplified discussion of Italian string scales in the introduction indicates, there have been two main hypotheses for explaining the different string scales encountered in Italian instruments:

1. Short and long scales reflect pitches separated by a fourth (Shortridge and Barnes).
2. Short and long scales with a ratio of about 5:6 reflect the use of two different string materials (Thomas and Rhodes).

Expressed in this way, the evidence of the separate bridges for the 5:6 ratio described in this study apparently supports Thomas and Rhodes's interpretation that long and short scales were intended for brass and iron wire, respectively.

33. The virginal (Division of Musical Instruments of the National Museum of American History, Washington, D.C.) bears a faked inscription to Artus Gheerdinck. See Wraight, diss., part 1, chap. 5, II, and part 2, 37–39.

34. Relevant to the question of the development of early virginal and clavichord design is John Koster's observation that the 1548 Joes Karest virginal (Musical Instrument Museum, Conservatoire Royale, Brussels) has the same 14:11 proportion for the longest case side to longest string as does the Arnaut de Zwolle *clavicordium.* See "Toward the Reconstruction of the Ruckers' Geometrical Methods," in *Kielinstrumente aus der Werkstatt Ruckers: zu Konzeption, Bauweise und Ravalement sowie Restaurierung und Konservierung,* ed. Christiane Rieche (Halle: Händel-Haus, 1998), fig. 6 and p. 31.

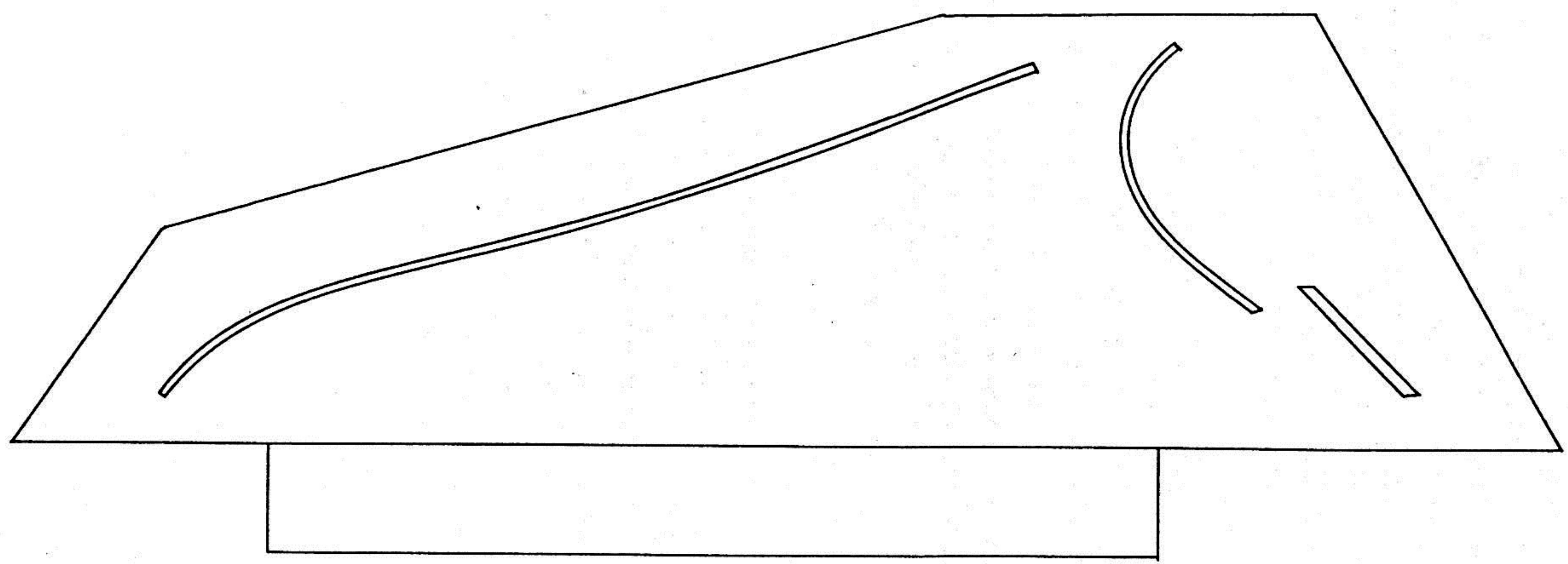

Fig. 2. Plan view of W533 Antegnati showing two separate right-hand bridges.

The evidence of the separate bridges in the treble (e.g., in the *spinettone* attributed to Cristofori, Leipzig no. 86) was initially and remains a particularly clear expression of the use of brass and iron scales; this evidence is not heavily dependent upon interpretation, since the alternative explanation that a single stringing material was employed is too unlikely to be correct. Antegnati's virginal design with separate bridges for brass and iron strings provides the clearest evidence to date that virginals of this type should be strung with iron wire in the treble.[35]

Remaining Problems

1. Today, some forty years after Shortridge's original publication, we have a much better idea of what was produced in Italian workshops and, importantly, of how instruments were altered to reflect changing musical taste. For sixteenth-century harpsichords this often involved a change of compass and sometimes of string lengths as well. In many instances the pitch was thereby altered. Barnes contributed significantly in drawing attention to these factors, which had obscured our understanding of the instruments' original condition.

After the reconstruction of many original compasses and scales, it has become clear that there was a *range* of scales in use from about 350 mm. to about 270 mm., in apparently semitone steps.[36] Thus, a hypothesis that merely equates short scales with brass wire does not explain the evident complexities of Italian scalings. Some original scales are short enough to have been used for brass at "normal" pitches but, when strung in iron, could also have been used at higher pitches.[37] It need not concern us to study this problem further here, but we do need to be aware that the evidence of the separate bridges does not provide the solution for all problems of interpretation.

2. We have seen that several Italian instruments used a brass-to-iron ratio for the c^2 equivalent lengths of, or close to, 5:6. It is revealing that of the ten *plucked* Italian keyboard instruments mentioned (three *spinettone,* six harp-

35. See Wraight, "Principles and Practice," 193–95, for the evidence of stringing indications and O'Brien's finding of the use of brass and iron bridge pins as a possible indication of stringing intention.

36. Denzil Wraight, "The Pitch Relationships of Venetian String Keyboard Instruments," in *Fiori Musicologi, Studi in onore di Luigi Ferdinando Tagliavini nella ricorrenza del suo LXX compleanno,* ed. François Seydoux, Giuliano Castellani, and Axel Leuthold (Bologna: Pàtron, 2001), 573–604.

37. Wraight, diss., part 1, chap. 5 (especially 209–12).

sichords, and one virginal) six were produced in Florence. Thus, the phenomenon of mixed brass-and-iron scale design is clearly linked to instrument making in Florence and may derive entirely from Cristofori and his influence on other makers.

That this 5:6 ratio was consistently employed in the instruments made by Cristofori (and his known worker Giovanni Ferrini) would hardly surprise us because instruments coming from a given workshop tradition would probably adhere to the same design procedures.[38] It is perhaps more surprising that we should find this ratio used in an early sixteenth-century virginal (attributed to Antegnati, who worked in Brescia), for we might suppose that over the course of 200 years the quality of the available string material might have changed. This finding tells us that, whatever Cristofori's influence in Florence may have been, the principle of employing separate bridges for iron and brass strings in plucked keyboard instruments was known in Italy well before his time. Furthermore, the Antegnati instrument establishes the possibility, but does not prove, that the 5:6 ratio was widely used in Italy for brass and iron string lengths.

3. Although 5:6 is the most common ratio found in instruments with separate bridges, it may not have been the only ratio in use for brass and iron strings. It is possible that the Dominicus clavichord was also designed to reflect the same 5:6 ratio. The clavichord Leipzig no. 2 may indicate a different tradition, using a smaller ratio of 8:9, which could imply that the highest possible stress for all the strings was not the design intention.

Several analyses have been published recently that describe original instrument design procedure. John Koster has suggested a significant and practical criterion for such studies, namely, that we should apply any proposed design principle to a *number* of instruments in order to test its explanatory power.[39] Undoubtedly, there is still much to discover and interpret

38. See note 10 and David A. Sutherland, "The Florentine School of Cembalo-Making Centered in the Works of Bartolomeo Cristofori," *Early Keyboard Journal* 16–17 (1998–99): 7–75.

39. Koster, "Ruckers' Geometrical Methods." Other sources of immediate relevance to the analysis of the clavichord design are: Herbert Heyde, *Musikinstrumentenbau* (Wiesbaden: Breitkopf & Härtel, 1986); Thomas Friedemann Steiner, "Clavichords No. 2 and 3 in the Leipzig Collection: Some Complementary Thoughts about Their Origins," in *De Clavicordio [I]* (cited above in note 24), 41–46; G. Grant O'Brien, "The Use of Simple Geometry and the Local Unit of Measurement in the Design of Italian Stringed Keyboard Instruments: An Aid to Attribution and to Organological Analysis," *Galpin Society Journal* 52 (1999): 108–71; and Wolfgang Strohmayer, "Traditional Design Principles in the Early History of Keyboard Instruments," *Clavichord International* 6, no. 1 (in press).

in early instrument design: it will be our challenge to wrest the maker's intention from each surviving instrument in order to shed further light on questions of pitch and instrument-making practice.

Conclusion

The material presented in this brief survey of the use of separate bridges is of a most interesting type because it clearly reveals the employment of both brass and iron strings in Italian keyboard-instrument making, with the length relationship generally being 5:6. Most instruments thus designed were made in Florence, but an early virginal from about 1530 by Antegnati of Brescia shows that this brass-to-iron ratio was applied elsewhere. This documentation not only emphasizes the possibility that the ratio was widely used in Italy but also confirms the provision of iron and brass strings in a virginal design. It is possible, however, that under some circumstances other ratios were used for brass and iron scales. Only a better understanding of the design principles of such instruments will improve our ability in analyzing the design intention.