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Using Appropriate Pitches and Stringing Schedules

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Maintaining proportion and balance

For many centuries the goal in making any stringed musical instrument (lute, violin, etc.) has been one of finding just the right balance of making it light enough to be resonant yet not pull apart, but not so strong that it sounds dull and uninteresting. Another trend in musical instrument making over the centuries has been the desire to make them louder so that they would be useful in playing in progressively larger performance venues. More power required using heavier stringing which in turn required more strength in the case, but not too much or the balance that produced the desired vocal and tonal qualities would be lost. This progression can be seen in many instruments, but perhaps particularly in the evolution from the earliest harpsichords through fortepianos to the modern piano.

Continuing my "Tailoring the Sound of Your Keyboard Instrument" series from previous issues of *Harpsichord & Fortepiano,* this article will explore the effect that pitch level and stringing schedules play in determining the sound of a keyboard instrument.

What is "appropriate" pitch?

Much awareness and time go into developing and achieving a successful keyboard design: determining dimensions, positions, strengths, and weights of all the parts; adjusting how they interrelate with each other in order to produce a musically balanced distribution of resonance, tonal, and sustain characteristics; and considering tuning stability, evenness of volume, etc. for its intended purpose. In my experience the pitch is the starting point for designing, with the string band following from that decision, then the positioning of the case sides, and so on.

This pitch based designing can be seen historically in the Ruckers 6-foot and 5-foot virginal models which, as various evidence shows, were pitched a whole tone (two semitones) apart. Apparently they did not believe that the same string lengths could be satisfactorily used for this much difference in pitch, since they produced two different models to serve these two pitches: two models that differed by almost a foot in length, had different string lengths, and used different stringing schedules.

In fact, since the Ruckers also produced models that were pitched only a semitone apart (at quart and quint pitches) they apparently found even a semitone too much difference in pitch to play from the same length of strings – which indicates their level of sensitivity to pitch and string lengths. How much they would have felt a need to adjust for less than a semitone is not evident from this, but a semitone was definitely too much. And the Ruckers were not the only builders to produce different models for different pitches so close together. The fact that all of Europe was using the same wire gauge system and the same essential

manufacturing processes for that wire, and that Ruckers had customers all over Europe and beyond, makes it reasonable to think that other makers and players were aware of the consequences of pitch on the sound of an instrument.

I have met many clavichordists and fortepianists who are aware of where their instrument sounds and feels its best to within about a 1/4 semitone. When the pitch is lower than this sweet spot many of the owners say that the sound loses focus, sparkle, power, clarity. If the pitch is raised above their preferred zone, common observations are that the sound is too edgy and/or closed in.

Just how much an instrument's sound is influenced by pitch can easily be verified by taking any keyboard instrument and dropping it a semitone, or two, in pitch.[1] In fact, dropping the instrument's pitch in stages smaller than a semitone may allow you to hear just how much pitch change is needed for you to detect a discernible difference in various qualities of its sound. Some instruments that are lowered a semitone in pitch appear to "open up", becoming more relaxed, fuller in sound, and more vocal in speech qualities. Other instruments seem to become less focused. Some just seem different without a distinct judgment for better or worse being possible.

This pitch lowering experiment demonstrates only how much pitch level affects an instrument's sound. If one pitch level sounds "better" to somebody, that only establishes that person's preferences, not necessarily the pitch intended by the original maker/designer. If the intention of copying an historic keyboard is also to reproduce the sound intended by the maker, then using the appropriate pitch is obviously important since it is a key element of any instrument's design.

Breaking points and safety factors

One guideline often invoked in stringing discussions is that strings sound best when close to their breaking point. Another proposed guideline is to establish a practical "safety factor" of how far below breaking point the working pitch should be set so that there is reasonable longevity forthe strings.

Historical lute (and guitar) documents often directed that the instrument should be tuned as high as the top course of strings can bear without breaking. This historical statement may have led to the idea, often repeated in articles of the last 60 years or so, that keyboard instrument strings sound best when close to their breaking tension. Inconveniently, there seems to be more evidence to doubt the appropriateness of this idea for metal strung keyboards than to support it.[2]

Some experiments done by myself and a composer/classical guitarist friend with excellent ears involved testing modern steel music wire on a clavichord copy designed for brass stringing to test the feasibility of a longer string scaling. The experiment was in regard to adding more treble notes to a future variation of the design. We figured that the extra strength of the high tensile music wire would permit even longer lengths than are possible with the usual modern "soft steel" substitute wires and longer lengths than would be possible with historical iron wire.

We experimented separately on different days, listening carefully while raising the pitch of several diameters of steel strings in stages until they were at breaking point. We kept separate notes. We were both surprised that while the pitch could certainly be

raised higher than with the other types of wire, the best sound from the steel was only some three semitones higher than for the brass, very much the same as for iron. And our notes showed we were in agreement within half a semitone for the range of best sound.

While the steel proved it could go to a higher pitch than iron, **the use of steel did not allow an appreciably higher pitch to be used when best musical sound quality was the criterion for pitch raising.** When the steel was pulled to a higher pitch than was intended for the original iron strings the tone began to sound strained, closed down, less clear, etc. It became worse the higher it was pulled, even though the wire was well below its breaking point.

This experiment demonstrated to us that steel wire did not sound its best near its breaking point, at least on that historical copy. It also highlighted the need for caution in using the modern brasses available and being tempted to run them to higher pitches or longer string lengths based only on their strengths and not judging the resulting sound quality as well.[3]

Even if it were discovered that most strings sound best relatively close to their breaking point when tested separately, the more important concern is how a string sounds in a certain position on a particular instrument, since we do not hear the strings by themselves but as part of a coupled, musical system.

If historical makers did use a particular safety margin below breaking point to determine the pitch of their instruments, it seems doubtful that they all would have chosen the same amount for safety, which would leave us having to figure out who used how much in order to establish what pitch they were intending. Even if all makers did happen to choose the same margin of safety, it would be difficult to establish that fact. Another possibility for setting their pitches is that they listened to the sound of the strings, as my colleague and I did, and determined optimum string length to pitch relationships in this way. If so, the amount of safety margin would not be what determined when a string sounded its best, but a consequence of listening to when a string sounded its best. Conducting listening tests with different sizes, types of wire, string lengths, and pitches could be musically useful.

Another limitation of the concept of safety factors is that it does not help in determining what gauge/diameter of string to use. Among the many modern Italian-type harpsichords I have encountered over the years, some started with an approximate gauge of #10 in the treble and then naturally increased towards the bass.[4] Others started with #9 in the treble, others started with #8, others started with #7, and several others started with size #6. The #6 size provides two and a half times the tension of the #10 size string for the same note, which is a tremendous difference – more than between the heaviest bass string and the treble strings of a typical 18th-century French double, yet all five schedules were essentially using the same pitch and the same two semitone safety factor. How these size choices radically change the sound of an Italian harpsichord will be described in the section on Appropriate Stringing Schedules.

Models of Hass clavichords use string lengths that are two semitones longer than a frequently copied model of Hubert, but copies made of models from both makers are often found tuned to the same pitch of a′ = 415. Obviously the strings of these two

different string scalings are not equally close to breaking point. Elsewhere, copies of the same clavichord model by five different makers can be found that use three different pitches (and at least three different stringing schedules). The range of these pitch differences indicates that we need to do more study on determining appropriate pitches so that we can have more confidence in which approach has the best chance of fairly representing the musical intentions of the original maker, and which approaches are more representative of the personal tastes of the copier and/or customer.

It is easy to focus on measuring breaking points and safety factors since it is so reassuring to have concrete numbers to several decimal points to look at, but the relative ease of gathering such data should not divert attention from the fact that more work needs to be done before we can be sure that these factors, and not others, were actually the criteria used by the historical makers. Otherwise, we will be leading ourselves further away from understanding these instruments.

Some simple indications that a pitch may not be appropriate for a particular instrument include when stronger-than-historical wire needs to be used in the treble to keep strings from breaking regularly. It is also sometimes apparent from reading a stringing schedule of an instrument and seeing that red brass or yellow brass strings do not go as high up the range as historically, or learning that "the top brass strings are always breaking". I once had to service one beautifully built Dumont/Taskin harpsichord 415/440 (transposing) copy that exhibited both very short lived treble strings and less use of brass strings than expected. The Taskin conversion had squeezed more strings onto the bridge and so had distorted the scaling somewhat, but string measurements showed that the instrument could be strung to the original stringing schedule, if the pitch were accepted to be 392/415. If 415/440 was needed, then the instrument was going to need a fair amount of steel and less brass in order to be dependable. The use of steel wire and 12% higher tension on the instrument for the needed semitone higher pitch of course guaranteed a different sound to that which the original would have had.

How pitch affects the sound of an instrument is all tied in with the reasons that the stringing schedule affects the sound, so we will go on to:

Why is an "appropriate" stringing schedule needed?

In the twentieth century many makers, including myself, tended to increase string thickness on small models of instruments so that string tension would stay closer to the tensions of the larger version, usually with the expectation of maintaining the same amount of power. Unfortunately for this idea, closer reading of the historical evidence points to quite the opposite practice.

Here again, the work of the Antwerp makers appears to demonstrate the historical stringing practice. In 1699 Klaas Douwes recorded the historical stringing schedules for five different sizes of Flemish virginals (6′, 5′, 4′, 3′, and 2 1/2′) that played at five different pitches: unison pitch, two semitones higher, a fifth above unison, an octave above unison, and an octave above the 5′ model. The model that is a whole tone higher than the unison model uses strings a whole size thinner for every note. The quint model is almost another gauge thinner, note for note, the octavino averages another

gauge thinner yet, and the smallest is almost yet another gauge thinner.

These historical schedules show no attempt to maintain tensions across models. Choice of string size correlates with size of instrument, not with tension matching. **String tension is a *consequence* of the gauge chosen, not the *criterion* for choosing the gauge.**

An observation that appears to confirm such a "**stringing-according-to-instrument-size**" principle is that the octave virginal averages a bit over three gauges thinner than the same key notes of the unison instrument, while many French, German, and Italian harpsichords with a 4' sharing the same case with 8's roughly average only one gauge difference in string size between unison and octave, above about tenor C.

This correlation of string sizes getting smaller as the size of the instrument gets smaller has been around for a long time and can be seen in the members of the bowed string family, as well as in string sizes of travelling instruments, whether pochettes, guitars, or harps, compared to the full size models. This basic stringing principle can also be seen within any keyboard stringing schedule, where strings get thinner as they get shorter and move a smaller amount of the instrument going into the treble of the range, and get thicker as they get longer and have to excite a larger proportion of the instrument for the lower notes.

To see what the historical criterion might have been for choosing the characteristic string size for a particular model, let us see what happens when Italian harpsichords are strung with known historical schedules, rather than the frequently heard sound of Italians strung with sizes typical of 18th-century Northern European (and heavier) schedules as many of us makers started doing in the twentieth century due to lack of information about Italian practices at that time.

Italian Brass Strung Schedules

Collecting data from inspections of more than 750 historical Italian keyboard instruments around the world, Denzil Wraight was able to publish 49 old stringing schedules for harpsichords, virginals, a bentside spinet, and a clavichord.[5] This compilation has been a huge boost for the understanding of Italian harpsichords. Wraight's article also explains the known data on the sizes of historical string gauges, which are in very close agreement. The approximately 30 Italian harpsichord schedules are very similar in approach. These schedules reveal that bass C strings in Italian harpsichords were typically three to four gauges smaller than most 18th-century non-Italian harpsichords, which means that Italian harpsichords would experience about half of the tension in the bass than if they were strung with the sizes that the other group used (and what is still commonly used today, unfortunately). This difference between the two types of stringing tapers off to about one gauge difference at the top, which still represents approximately 20% less tension for the Italian compared to using the typical Northern stringing size (and tremendously less tension than the heavier gauges that I mentioned earlier having encountered on copies of Italian harpsichords). Consequently, stringing with historical Italian schedules results in much less tension on these instruments than has been usual in modern times.

A couple of years ago a harpsichordist from the Chicago area, Mark Shuldiner, restrung and revoiced a used Zuckermann Italian model harpsichord

using historical Italian stringing that was much lighter than the typical schedule that had originally come on the instrument. The change in sound qualities was very obvious when he subsequently used it in a staged performance of Monteverdi's *Tancredi e Clorinda* and Charpentier's *Actéon*: the sound was much more open, fuller, deeper, and sustaining. The blend of the sounds of harpsichord and gamba was seamless and produced the effect of a single continuo sound. This quality was commented on by several audience members, and even the harpsichordist said that it was "eerie" since he and the gambist often could not tell whose sound they were hearing – him supporting her or her supporting him – but they loved it. The de-emphasis of the pluck sound allowed the tone simply to appear, much as it does with other baroque instruments.

Since the keyboardist did not have a convenient way to shift registers when he played the lute parts and the harpsichord parts on the keyboard, he played with just one 8' for the whole concert and was easily heard by the musicians and the audience in the solos and the tuttis, so one can safely say that the lighter stringing did not appreciably reduce volume or projection. In fact, the sound was far clearer and more lute-like and virtually without any of the tizz or fuzz of the original stringing, exhibiting far more case resonance than previously. Similar results have occurred with four other examples of two different Zuckermann Italian models that were reworked similarly in Germany and the US, so this result does not seem to be an anomaly.[6]

Using the lighter, more historical approach to Italian stringing appears to establish a more favourable balance between the power of the strings and the strength and mass of the soundboard and case. The improved balance shifts the speech formation and sustain to qualities more closely resembling those of the later heavier iron strung Northern European schedules balanced with their more massive soundboards and cases. Thus, an appropriately strung Italian harpsichord produces a tone that is more likely to "bloom" than "pop", and confirms the comments from the 1791 Encyclopedie, "Since these instruments were almost entirely destined for composers and were used especially to accompany the voice, a sweet sound was all that was sought." This type of sound is quite different to the, "loud transient and a quick decay" that characterizes most 20th-century descriptions of Italian harpsichords.

17th-Century French Schedules

Another step along from the Italian approach in both stringing and case construction appears in the 17th-century French design approach. The case walls were taller and somewhat thicker than the Italians, while their string lengths required iron for most of their range. I often encounter copies of these models suffering distortion of the soundboard and/or case, almost always in association with 18th-century style stringing being used on them, despite their lighter internal and external dimensions, smaller bridges and nuts, and other differences associated with less tension. Usually, restringing them with a lighter, more Italian style schedule, although mostly in iron rather than brass, relieves the distorting strain and produces a smoother, more blooming sound than before. Like the Italian result, this approach gives the 17th-century French instrument a more open and lute-like

sound (again, with appropriate voicing) which is more supportive of the idea that the 17th-century French harpsichord music derived from the lute literature. The relationship to lute repertoire is not as noticeable with heavier stringing, which gives a quite pronounced and edgy transient to a thinner sound and a rather short decay that makes it much more difficult to link tones together convincingly. It makes more sense for an instrument to take over another instrument's literature when they share sound qualities. A mandolin sharing flute literature, or vice versa, seems a highly unlikely transfer.

18th-Century French, German, Scandinavian, Italian, English
Many of the currently popular keyboard models from these design traditions have stringing schedules for them which are pretty reliably known (with minor variations), or are similar enough to models that do have schedules that schedules can be pretty safely adapted for them. This makes it rather surprising how often copies are encountered that use significantly different, often heavier, schedules, usually with questionable sound qualities and reduced tuning stability.

18th-century English
The Shudi and Kirckman models seem an under represented approach to harpsichord making at present, considering the number of them that were made and the awe with which they were viewed on the Continent. They also seem to represent a further extension along the path of increased case mass balanced with somewhat increased string tensions, mainly in the treble. The heavy oak cases and heavier stringing, along with the disposition, and jack tongue details that point towards increased projection, would seem to make this model the best choice for concert hall use, then and now. I suspect that their current lack of popularity might be due to them often being approached and set up from a French perspective, which does not fully exploit their possibilities, but I have not had an opportunity to prove or disprove this impression. However, the various factors of these late English models appear to form a system intended to fill a significant role, and seem definitely worth more study.

The Parts Reflect the Whole

The overall size of strings used in a stringing schedule interacts with so many other factors (strength and mass of the frame and case; dimensions of the bridge; distance of bridge to bentside; size, number, and arrangement of ribbing; bridge pin details; string side angles; plucking distance; type of voicing; damper arrangement, etc.) that if stringing, or any other single factor, is different from another design approach then it is almost certain that this difference will be reflected in some other factors being different as well. Conversely, if it is proposed that an instrument type is just like another design approach except that the stringing is significantly lighter or heavier, the absence of any other differences makes the assumption highly unlikely.

Examples:

1. Light stringing on a muselar virginal would be unlikely to work well because the strings over much of the range would travel too far for the jacks reliably to pluck the strings so close to their centres; the framing would be stronger than needed; the relatively

large dimensions of the bridge would not be as easily excited by light strings.

2. The factors of thinner cases, less framing, smaller bridge dimensions, etc. found in 17th-century French harpsichords compared to 18th-century French harpsichords all point in the direction of lighter stringing being used, which is underscored by how frequently these instruments distort when mistakenly fitted with inappropriate 18th-century schedules.

3. Late Antwerp harpsichords (by Dulcken, Bull, Van den Elsche) are almost a foot longer than their French and German counterparts and some also have heavier framing. Couchet, of the earlier Antwerp builders, used the lowest normal pitch of his time for his harpsichords, and this has been measured to be no lower than a′ = 392, and probably half a semitone higher.[7] There appears to be no evidence that the pitch in Antwerp dropped significantly by the time of Dulcken, yet his string lengths cannot possibly be safely used with historical wire above about a′ = 350. (The Van den Elsche might be barely able to go a semitone above that, but not to 392 either.) This combination of factors would seem to indicate historical use of a lower pitch than is used today with these instruments, even though there is no known evidence of such a low pitch being used in that region. However, a continuation of the earlier Flemish practice of making different models for transposing pitches seems possible, perhaps a fourth below organ tone. (It is interesting to note that the last extant Couchet harpsichord was nearly a foot longer than their previous models – about 8′ 6″ for a single manual.)[8] More study of this problem is definitely needed so that a more accurate idea of these harpsichords' original sounds can be heard as opposed to the sound now produced from the restored originals and copies that have to use modern high tensile music wire in order to play at the usual expected pitch of 415 or 392, which surely cannot represent the sound intended by their historical makers.

4. It was hypothesized late in the twentieth century that 17th-century Flemish four octave, two register, harpsichords used strings that were one to three sizes thicker than the same gauge numbers used by other European makers. This would seem highly unlikely since the resulting total tension on the instrument would be approximately equal to that of an 18th-century five-octave French double while the smaller instrument has weaker framing and smaller bridge dimensions not designed to support those tensions. All historical evidence yet uncovered indicates only one gauge size system in all of Europe (the English ran their numbering in reverse of the Continental system, but the sizes were all the same). Additionally, if the Ruckers and Couchet models actually did use heavier strings per gauge when that design approach was chosen to replace the native 17th-century French design approach, one would expect that such an important sound feature would have been preserved in the new derivative French designs, and that it also would have been preserved when these prized Flemish harpsichords were enlarged by the French. No indications of either of these practices seem to exist. The sound of instruments strung this way appears unrelated to the qualities of other harpsichords, or other baroque instruments, and would seem to misrepresent the intended

sound of these instruments unless some very convincing evidence to the contrary can be brought forth.

Summary

Fitting thicker strings or using a higher pitch on a keyboard instrument beyond what was used on the historical model changes the balance between the mass and strength of the strings and the mass and strength of the instrument. The resulting new balance makes the transient sound more prominent and reduces the formerly blooming sound to a quicker more straight line decay, which reduces the sound's ability to link and suspend tones (imagine the sound of a thick plucked string moving a banjo diaphragm). Using strings lighter than originally intended, or a lower pitch, reduces the string energy compared to soundboard/case strength, which smoothes the start of the sound even more and lengthens the sustain, but can result in too little sound strength and resonance (imagine the sound of a thin plucked string trying to move a metal plate). Reproducing the appropriate historical balance between strings and soundboard/case is a necessary element in order to reproduce the vocal speech qualities, sustain, and colour that the historical makers intended for their designs.

With clavichords and fortepianos it seems that too much string strength results in little to no ability to affect speech qualities by changing the strength or speed of tangent or hammer impact. The result is reduced colour change across the dynamic range of the instrument (although this is not the only reason for lack of colour). When string and soundboard/case design are in better balance, lighter impact will allow smoother speech and longer sustain, while stronger impact will shift the balance to more declarative speech and quicker decay rate. Harpsichords have less ability to shift this balance during playing, but voicing approaches can make a significant difference to the ability to elicit colour and dynamic differences from the plucked strings (to be discussed in a future section).

I believe the type of sound produced by Italian harpsichords using appropriate stringing and appropriate pitch is very similar in musical effect (speech and singing qualities) to 17th-century French models appropriately strung and pitched. Both styles are very similar to the larger Northern European harpsichords appropriately strung and pitched. The resulting sound qualities – smooth, mellow, resonant and vocal – are also more similar to, and so blend better with, other baroque instruments. In my experience, using appropriate stringing schedules and pitches on well made copies also results in better tuning stability, probably because that was naturally one of the factors considered when designing the system.

Yes, there are some differences in power and "accent" between the various periods and regions of keyboard making, but not enough to impede or even diminish the satisfying musical realisation of music composed for the instruments by contemporary composers from any region of Europe. I have not encountered any historical evidence that historical players chose the regional style of keyboard they played to match the regional origin of the music's composer. My impression is that this approach was not a typical historical practice for any instrument of the time, but if any historical documents ever surface that reveal the existence of such an approach it would

certainly be worth considering them. I believe that musicians historically were more interested in instruments that provided the most satisfying musical qualities for them to realise their music, regardless of where the instrument was made, or where the music they were playing at any one time originated.

Ruckers and Couchet harpsichords, as well as their rebuilt versions, were historically shipped to Spain, France, Italy, England, and even Peru. I find it difficult to believe that it was because those customers wanted an "appropriate" harpsichord on which to play Flemish music. Did Chambonnieres buy a Couchet harpsichord for playing Flemish music, or to use primarily for composing French music?

How much can an instrument's sound be changed by using non original pitches, stringing schedules, scaling, and wire? Consider what happens when present day violin makers take a Stradivarius design and reinforce it somewhat so they can use slightly longer, modern-material strings at a higher pitch and different sizes than the original design. The result of these changes is a modern violin, which does not sound as Stradivarius intended his violin to sound, and which does not blend well with other baroque instruments because of that.

By not paying attention to using appropriate stringing schedules, pitches, and wire in keyboard copies and restored antiques we produce inaccurate impressions of what any of those instruments sounded like. From those impressions I believe we have created kinds and degrees of differences between harpsichords, and types of harpsichords, and playing practices, that likely never existed historically.

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Endnotes

1 It should be noted that changing the pitch of an instrument offers at least three possible sources for any perceived impression of changed sound:

a. The string itself sounds different because it is working under different tension.

b. The string's frequencies at the new pitch couple differently at that location with the instrument's resonance patterns for those frequencies.

c. The change of overall tension on the instrument changes the frequencies of the instrument's characteristic resonance modes.

The first factor is a quality of the string itself. The other two factors are qualities of how the string and instrument work together as a system. This point will be encountered again in discussing Stringing Schedules.

2 a. Gut-strung plucked instruments such as the lute and guitar are often designed so that the highest treble string and the lowest bass string have the same length, so satisfying both tone and playing characteristics can only be achieved by manipulating how thick their plain gut strings are (apart from using wound or braided strings). If the top course is tuned too slack, the subsequent tension of the bass course will be too low to produce a well-focused and controllable musical note. Metal strings cannot be tuned to allow anywhere near the range of pitches as work with gut strings and still produce acceptable tone, which is why metal-strung keyboard instruments are designed to have different lengths of strings to achieve most of their changes in pitch.

b. Common theory is that a string sounding an octave higher than another string will be half of the lower string's length. Iron (and steel) strings become stronger the thinner they are made (owing to tensile pickup). This increase in strength of thinner strings would allow a thin string to be more than half as long as the thicker string pitched an octave below it. This can be seen in some historical 16th- and

17th-century designs, but not usually in 18th-century designs, even though these later designs added more treble notes and could hate gained more distance across the gap if they had taken advantage of longer strings. Thus, the longer strings could offer an advantage to instruments that used four registers of jacks in their gaps, but not so much in those that used only three registers in their gaps. If the sound was better when the strings were closer to breaking tension, why weren't these stronger, thinner strings used to that advantage?

c. In harpsichords with 8' choirs and a 4' choir, the lengths of the 4' strings in the treble range are usually half the length of the shorter choir of 8' strings, and not of the longer 8' strings. This is curious since if the 4' notes would truly sound better pulled to higher tension, one would expect that they would be half the length of the longer 8' strings. Actually, since ferrous strings are stronger the thinner they are drawn, one would then expect that the thinner 4' strings would be made relatively longer than the strings of either 8' for that note, if pulling them closer to their breaking tension was, historically, ever used as a principle to make strings sound their best. I am not aware of any extant 18th-century antique harpsichords that display this practice.

3 If instruments that are designed around such modern wires do not exhibit a similar result, then our observations might be because our model was designed around the historical iron wire. If instruments designed around modern wire still demonstrate that their best sound occurs well below their breaking points, then it might be that historical makers were primarily using the wire's best sound to determine the pitch and string length relationship. In either case, this seems a relationship worth more exploration.

4 Denzil Wraight, "Principles and Practice in Stringing Italian Keyboard Instruments", *Early Keyboard Journal* 18 (2000): 175-238.

I am referring to historical gauge numbers, the actual sizes of which varied by about + and – 1/4 of a gauge size due to manufacturing procedures and industry acceptance. Using the average sizes published in Denzil Wraight's article, p.212, #12 would be 0.154mm/0.0061", #11 0.172mm/0.0068", #10 0.193mm/0.0072", #9 0.215mm/0.0085", #8 0.241mm/0.0095", #7 0.269mm/0.0106", #6 0.301mm/0.0118", #5 0.336mm/0.0134", #4 0.375mm/0.0148", #3 0.420mm/0.0165", #2 0.469mm/0.0185", #1 0.524mm/0.0206", #0 0.577mm/0.0227", #00 0.629mm/0.0248", #000 0.689mm/0.0271".

The different historical gauge sizes proposed by both Kenneth Bakeman and Grant O'Brien from pioneering work in this field in the 1970s, using a limited number of historical wire samples, do not appear to be confirmed by the substantial amount of information which has been uncovered since then.

5 Wraight, 238.

6 It should be noted that since stringing is only one element of the musical system, changing it will also change other relationships. Generally, more benefit from this lighter original stringing approach is achieved by an approach to voicing that supports its "singing" quality. A typical modern conception of a light "French" voicing may not excite the case resonances as much as can happen with a fuller pluck that incorporates a smooth release. What may work best with the light stringing on lighter soundboards like these may not please most people on a French instrument with its heavier stringing moving a heavier soundboard. How angled the plectra are in a jack tongue also affects the type of voicing approach. The overall point when working with a musical system is to get all parts of the system in optimum balance, not just to focus on one part at a time.

7 Bruce Haynes, *A History of Performing Pitch; the Story of "A"*, (Lanham, Maryland, and London: The Scarecrow Press, Inc., 2002), 85.

8 Edward L. Kottick, *A History of the Harpsichord*, (Bloomington, Indiana: Indiana University Press, 2003), 123.