Equal tension, equal feel and scaled tension

by Mimmo Peruffo

Introduction

The choice of the tension profile of a set up for bowed instrument for historical repertoires raises a number of doubts all concerning two fundamental questions:

a) what I choose will be historically correct?

b) is it going to cause problems of instrumental technique and / or quality performance?

Questions like these are by no means negligible, especially considering that the answer refers to a subject,- the survey on string setup for historical instruments -which is relatively young and therefore subject to potential and continuous updating.

A careful reading of already known historical sources and of those more recently discovered, the contemporary rediscovery of the French and Italian historical method to manufacture gut strings (method that produces results substantially different from those obtained following the modern techniques that are aimed, above all, to produce stiff modern harp strings, for tennis or for surgery) is allowing to fill, step by step, what until a few years ago was essentially an uncertain jigsaw puzzle full of gaps.

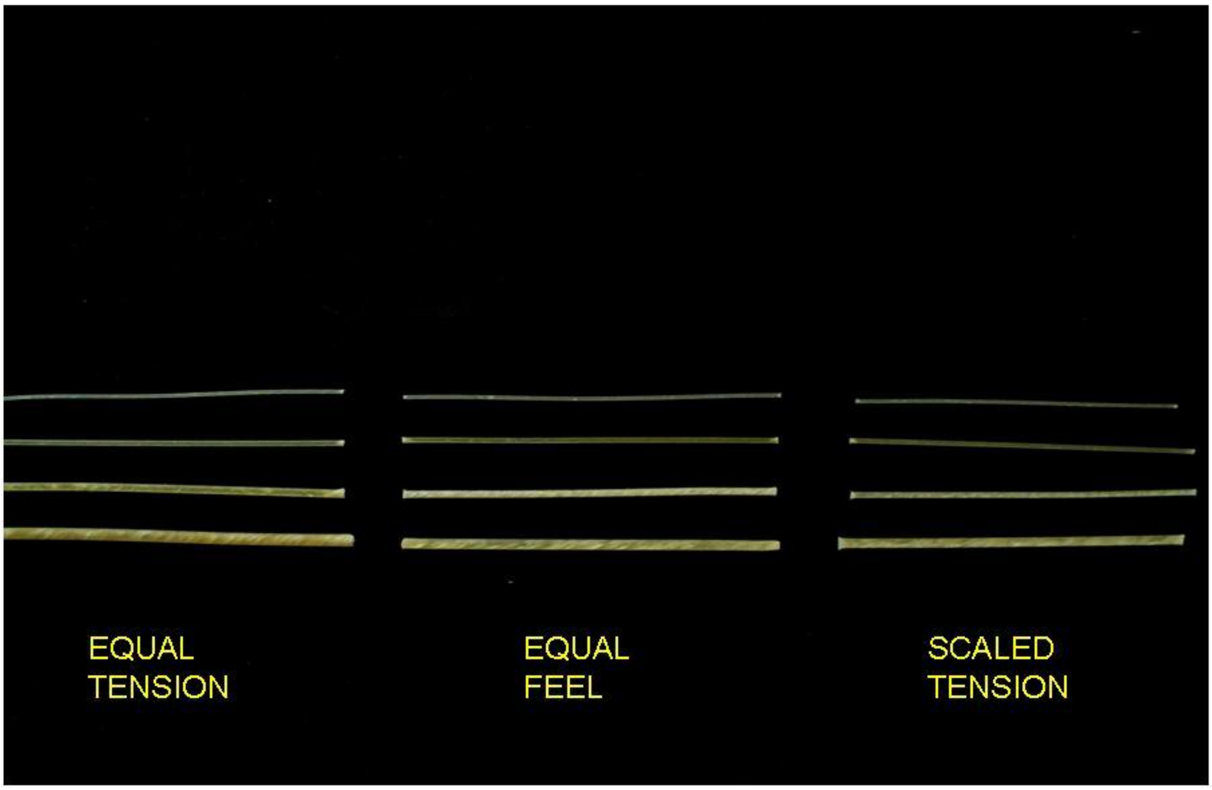
Is it possible nowadays to provide a convincing picture of the tension profile at different historical periods?

We shall first define some terms:

- Equal tension: the diameter of the strings of a set up is calculated all at the same value of tension, expressed in Kg

- Equal tactile feel of tension: the strings, pressed one by one at the same distance from the bridge (and in a state of intonation) express the same sensation of tactile "hardness" .

- Scaled or degrading tension: going from first thin string and passing to thicker strings they are calculated so that the tension is gradually decreasing.



Tension profiles of a Violin set-up

Equal feel and equal working tension

It is widely known that the rule to follow in set up for bowed instruments for repertoire of the sixteenth and seventeenth century is the one that leads to a profile in equal tension between the strings. (1) (2)
If we observe it more in detail, we will come to a different result.

It should be clarified first three basic elements:

1) In the seventeenth century treaties and methods that deal with music and / or musical instruments, tension is almost never expressed by a unit of measurement, the term used is what leads us to consider rather the 'tactile sensation' of tension. This, as it is stated on the same treaties, must be equal between all the strings of the set up ('equal feel'). From a historical point of view, the first document of our knowledge, in which the tension of each string (in this case of the Violin) is expressed in Kg dates only 1869. (3)

2) A second element to be remembered concerns the relative importance that has a speculative

document compared to other sources that report information obtained, instead, from stringmakers of that time or concerning methods for musical instruments such as lute, etc. We believe that daily practice is better described in these methods or by construction data of string makers than in scarcely accessible contemporary disquisitions focused only on theoretical speculation. It is the same even today: in most cases are indeed string makers that push market towards the use of certain gauges and certain tension profiles instead of others.

3) There is a third element: the treaties of the seventeenth and eighteenth centuries can easily lead to ambiguous situations. A typical example that brings to confusion between the equal tactile sensation of tension of the strings with the equal working tension is for example the following abstract from the Galeazzi: "

"*la tensione dev'esser per tutte quattro le corde la stessa, perchè se l'una fosse più dell'altra tesa, ciò produrrebbe sotto le dita, e sotto 1'arco una notabile diseguaglianza, che molto pregiudicherebbe all'eguaglianza della voce*".

('the tension must be the same for all four strings, because if one were more tense than another, that would create under the fingers, and under the bow, a considerable inequality very prejudicial to the equality of tone') (4)

By reading this passage with more attention is clear however that the 'equal tension' is actually referring to the feel of tension that you feel under the fingers or under the bow. Here's another one potentially misleading:

"*Quanto una corda è piu vicina al principio della sua tensione, tanto ivi e piu tesa. [...] Consideriamo hora una qualunque corda d' un liuto: ella ha due principj di tensione ugualissimi nella potenza, e sono i bischieri dall'un capo, e ' 1 ponticello dal1'altro; adunque per lo sopradetto, ella è tanto piu tesa, quanto piu lor s'avvicina: e per conseguente, e men tesa nel mezzo*".

('The closer a string is to the beginning of its tension, the tenser it is. [...] Just consider any lute string. It has two beginnings of tension that are absolutely equal in power: the pegs at one end, the bridge at the other. As a result, it will be tenser the nearer it is to those points and less tense in the middle') (5)

The concept of more or less tension is certainly related to a tactile sensation of tension and not to a real tension in Kg which, under static tension conditions of the string is obviously the same at any point on the string. From a tactile point of view it is more "strengthened" to touch as far as you move towards the fix-ends.

The evaluation criteria of tension: the case of Lute

The evaluation method of the string tension by finger pressure (or more exactly by right thumb) that tests their 'hardness' near the bridge was the universal criterion used for balancing set up of Lute Strings:

-John Dowland ('Variety of Lute Lessons', by Robert Dowland, 1610):

"*Of setting the right sizes of strings upon the lute. [...] But to our purpose: these double bases likewise must neither be stretched too hard, nor too weake, but that they may according to your feeling in striking with your thombe and finger equally counterpoyse the trebles*".

-Mary Burwell Lute Tutor (1670 ca.):

"*When you stroke all the stringes with your thumbe you must feel an even stiffnes which proceeds from the size of the stringes*".

-Thomas Mace ('Musick's Monument', London 1676):

:"*Another general observation must be this, which indeed is the chiefest; viz. that what siz'd lute soever, you are to string, you must so suit your strings, as (in the tuning you intend to set it at) the strings may all stand, at a proportionable, and even stiffness, otherwise there will arise two great inconveniences; the one to the perfomer, the other to the auditor. And here note, that when we say, a lute is not equally strung, it is, when some strings are stiff, and some slack*".

From these statements results the following:

1) the criterion for selection of the diameters of strings of a lute set up was carried out according to criteria of empiricism: the strings should not present too stiff or too slack but with a subjective right degree of tension feel.

2) that 'right' feel of tension should be the same across all the strings of the set up. If this does not happen then a serious mistake occurs.

It goes without saying that the judgment on the degree of tension can only be subjective. It is instead different the appearance of homogeneity of tension among the strings, which represents the true common criterion of lute players of the past.

We now are going to analyze in depth the issue of the tactile feel of tension.

The tactile feel of tension

When a string is moved laterally by means of a pressure practiced on it (by means of fingers, bow etc) it carries against the pressing element an equal and opposite action with the aim to counteract that pressure.
Such contrast, for a particular value of lateral shift, is going to produce a certain feel of effort on the part of the one who puts pressure on the string.

We talk about equal feel, when with the same lateral displacement, the sense of effort is the same even between strings of different type, diameter, etc., provided, however, that the point of pressure is always the same.
Trying to bring in scientific terms the notions of even stiffness, equally strung etc. described in the seventeenth century treaties like those above cited is something complex in itself, both because there is

no evidence to confirm that they all intended the same by “feel” and because the so-called feel can also be understood in a “broader” way.

There is meanwhile a first distinction to be made: whether to press the strings to evaluate the degree of 'tension' are directly the fingers of right hand or the bow. (9)

In the second case thicker strings (and therefore with more surface area in contact with horsehair), even if at the same working tension of thinner ones, can put up a higher resistance to friction thus making the player the feeling of a certain higher 'tension'.

In the likely hypothesis that the fingers and not the bow (as evidenced by the fact that treaties of the seventeenth century are practically always related to the lute) aimed to understand how stretched the strings are, we can understand the feel in **at least two different ways**:

The first one (commonly accepted and supported also by us): it considers the effort that must be done with a finger (usually the right hand thumb) to move laterally (usually downward) to a certain extent a string. This string will obviously create a resistance against the pressure. By substituting the finger with a weight acting at the same point, it can accurately be measured the extent of lateral shift for each string examined. The feel will therefore be the same, when the lateral displacement will be the same for all strings tested.

The second one: it considers that the thinner string, sinking further into the tip of the finger that presses it, would produce a higher feel of tension of a bigger string, which having a larger surface does not sink in the finger in the same way. (10)

According to this second interpretation an equal feel requires a higher working tension in the thicker strings than in thin ones. However, there is no evidence that bass strings presented a tension in Kg higher than the trebles. There is evidence to the contrary, if anything.

We now investigate **the first hypothesis**, that namely considers as feel the sensation of resistance made by a string pressed by fingers, not considering its diameter, and as 'equal feel' the fact that the opposing force is the same (with the same displacement caused by acting finger) even for strings of different gauges or different manufacturing technology put into traction.

Physics has shown, by calculation, that equal feel as stated above corresponds exactly to an equal tension set up

But here comes something that has not been revealed so far: equal feel do correspond to an equal tension but under condition that the strings are already in a state of traction.

But this condition has nothing to do with the common practice where the diameters of the strings of the set up in 'equal tension' are obtained directly by mathematics calculation. In this way, the diameters are in fact those of the strings “packaged “, i.e. at rest.

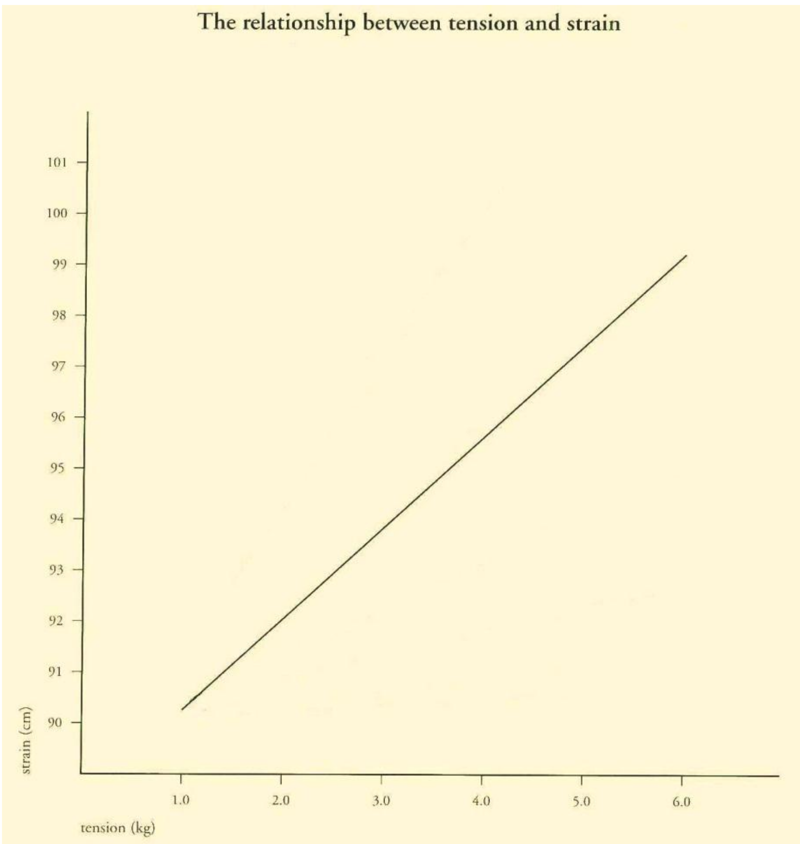
The difference between the two conditions is crucial: a string already in a state of tension is a string that has been subject to some stretching, then has no longer the diameter that had been calculated, but smaller.

In order to achieve the condition equal feel = equal tension in Kg, the strings should therefore keep unchanged their diameters even after being brought to tuning or at least that all gauges are reduced according to same percentage.

In practice (and this is evident in the gut more than in other rigid materials), this does not happen: once the strings are brought into traction, each of them will reduce its diameter to a certain percentage which is a function of the position in the instrument (in other words related to the Working Index) and how the string was made.

The Working Index is the parameter indicating the fraction of tensile strength used by the string compared to its maximum strength. This value derives from vibrating length multiplied for the frequency of the string. Its maximum value coincides with the breaking stress and is a function, as mentioned before, of construction parameters such as the amount of twist, the kind of twist used (similar to nautical line, high or low twist, etc.), quality of raw material, the use of specific chemicals which may contribute in increasing or reducing it, etc.. It goes without saying that the higher the working tension, the greater the strengthening of the string.

The tensile stress is highest for chanterelles (the Lute trebles exploit as much as 91-95% of their total available reservoir of tensile strength, which means that they undergo, among all, the greatest stretching under tension) and so on in smaller percentage on bass strings positions (lower Working Index). But this is not because the trebles are thinner but because their Working Index (the product of frequency and string length) is the highest among those of each string of the set up.



The explanation is simple: in a larger string the same tension is “spread” in a bigger section than a thinner string. Consequently, the applied tension-referred to single section will be lower. Hence a lower stretch of the string. A thicker string, in other words, is considered as composed by many hypothetical thin strings stuck together to make the diameter required. It is obvious that if full tension is applied to one of these hypothetical thin strings it will become much longer (it is the case of thin treble) but if the same tension is instead spread among this theoretical quantity of thin strings, here so that each of them shall be subject only to a fraction of the total tension thus producing a lower final stretch.

Summary

Between two strings of different diameter, constructed in the same manner and subject to the same tension, the thinner one will stretch much more than thicker one because of largest load insisting on the cross section. On gut strings in particular, longitudinal lowering is divided into recoverable lowering and not recoverable one, in practice a new string that has undergone initial tensioning, when placed to rest does not recover completely as the starting length. As the string stretches due to increasing stress (the difference will wrap around the peg) its diameter will gradually reduce. Well, the reduction in diameter will also result in a simultaneous decrease in operating tension (tension and diameter are indeed directly proportional)

As mentioned above, the strings that occupy the position of treble (because of higher traction per unit cross section) are those that decrease in a higher percentage than the others and so progression as we move to bigger ones (it is well known that in a violin many more turns of the peg for treble strings are required than for third string).
It follows therefore that their working tensions (which were formulated at the beginning from theoretical calculations as identical), in the final state of tune will no longer be equal but will take a new structure which will now be scaled: the treble strings will be, among all, the ones that will have the lowest working tension.

But if the string tension in a state of tone is different, here then also the 'feel' between the strings will no longer be the same. It will consequently have not a homogeneous tactile profile but a scaled one: the treble will be softer to the touch while the lower strings will need a greater pressure from the fingers.

At this point the equation equal feel = equal tension is no longer valid.

Conclusion

a set up in equal tension cannot be considered a historical set up: we would like to stress once again that the treaties of the seventeenth century for lute do condemn fairly clear a set up in case it has a not even feel. (Op. cit 8)

Experimental tests

Using a violin (but it would be fine also a guitar or a lute), we tested two gut strings calculated to have both the same tension (8.3 Kg pitch of 440 Hz) at required tuning ('E and D in our case). The string length is of course the same for both (33 cm).
The diameters we use are as follows: .65 mm for the 'E' and 1.45 mm for the 'D' measured 'in rest', i.e. not in tension. The thinnest string had a so-called 'medium' twist (45 ° approximately) while the thicker was 'high' twist. (<60 °).
Once tuned and stabilized we proceeded to verify by micrometer their diameters: E gauge dropped to .62 mm, while for D we did not find an instrumentally valuable decrease. The thin string has therefore experienced a reduction in diameter of 5% (.62 / .65 mm). While D string it was considered virtually unchanged (<0.1%), despite its degree of twist (and elasticity) is significantly higher than that of the treble.

It should be emphasized that these measures are derived from a single experimental test: strings manufactured differently than the samples examined by us may provide different percentages of reduction. In our case, the underlying tension of the strings on the instrument was reduced to 7.6 kg for the 'E' and 8.3 kg for the 'D' compared to the tension used for theoretical calculations and equal to 8.3 kg .

In order to have a 'E' and a 'G' in the state of tuning keep same kg then it will be necessary to increase the initial diameter of E only' (please note that the 'D' is virtually unchanged) of 5%.

In this state of tune then you are going to lose this "extra". In conclusion it will be required a diameter "packaged" of .68 mm while the 'D' shall remain equal to 1.45 mm.

Deriving tensions in this second set of strings in the resting state, there is therefore a scaling tension: 9.2 Kg for the 'E' and 8.3 kg for the string 'D'.

Unfortunately it is not possible to determine by mathematical calculation of how much string will reduce its diameter under load, because this parameter is the result of several variables specific function of the system with which it was built, the only valid method, then, is the experimental way starting from a set up in which gauges are known, provided that the type of strings are the same.

Summary

The experiment shows that the gauges of .65 and 1.45 mm in equal tension, in a state of tuning will reconvert producing some scaled in the working tension and consequently a lack of homogeneity even in the tactile feel. Using instead a compensatory diameter of .68 mm and 1.45 mm (according to a 'resting' scaled tension profile) operating tensions will then re-set so as to finally bring the hoped equal tension, or same tactile sensation (i.e. equal feel).

If you wish a set up in equal feel according to the historical criterion it is therefore necessary to start with a choice of diameters of string "packaged"" calculated according to a scaling profile.

What we expressed so far, gives finally an explanation of the relationship between the feel and tension of work. It can be applied easily to the family of the lute and plucked instruments, but what about the string instruments?

Criteria in the historical set up of bowed instruments

With the exception of the Lute treatises, we do not know indeed any treaty of Sixth -Seventeenth century able to provide some explanation about the criteria used in daily practice at that time. In practice, today - and missing better ones – are applied the criteria established for the Lute (even feel of tension) that is a plucked instrument. But are we sure that this operation is technically correct also on the bowed instruments?

The Lute is a fact quite different from the bowed instruments:

1) it must be plucked and not played with a bow.

2) it has courses in unison and octave, and not of single strings.

3) working tension are significantly lower than those of bowed instruments

4) it has a fingerboard and a bridge that are flat and not arched

5) it is provided of frets that go to determine with some accuracy the frequency of notes played

Only one of these criteria - the frets -is shared with the Gamba's family, while are excluded the violin, the Viola da braccio and the Violin Bass and some big Violoni.

Therefore, we now analyze in detail the historical sources in our possession that relate in some way with bowed instruments:

The Sixteenth century

There is no document (other than of essentially speculative nature) dealing with the tension profile of a string instrument in the daily practice of contemporary musicians and of the area in which its author lived.
On the other hand, we have the dimensions of the holes of the strings of two viola da braccio present the Ashmolean Museum in Oxford (we know that these tools were re-necked). Our measurements made in year 2008 have shown that the tailpiece's hole for the fourth string, considered an original of

Viola by Andrea Amati 'Charles IX' built around 1570 is 2.3 mm only: what explanation can we provide for this direct evidence?

Whereas in fact an hypothetical Venetian pitch of 465 Hz at vibrating length of 36 cm, with a diameter of string equal to 90% of the hole (2.1 mm approximately) for a fourth note "C" you get a tension equal to 4,6 Kg only (range of working tension of a Viola da braccio today in equal tension is around twice to close to 3.0 mm in diameter of string). In this period of history according to some researchers (op. cit. 2) had not yet come into use in the low string made like a rope, from acoustic point of view this makes things even more difficult.

The Seventeenth century

Mersenne (Harmonie Universelle, 1636) (12): The 17th-century scholar **Marin Mersenne** (Harmonie Universelle, 1636) (12) is considered the first music theorist to present the concept of equal tension as a theoretical principle, in which he explains the mathematical relationship existing between diameter, vibrating length, string density and working tension. In other words, Mersenne enunciates for the first time what was subsequently referred to as the Mersenne-Taylor law, which is still applied in the calculation of strings.

However, on closer examination fundamental discrepancies emerge with respect to the rule of the proportions which he enunciated (and the concept of equal tension deriving from it) when the same is to be applied in a practical manner in a musical instrument.

On page 123 of the original work (Proposition VII, Book III, cfr. Chapman, pp. 176-77) we read the following:

First Rule
"*Si les chordes sont esgales en longueur & grosseur, & que l'une fasse le son grave qui est en C fa ut, quand elle est tendue avec le poids d'une livre, il faut tendre l'autre avec quatre livres pour la faire monter à l'octave, d'autant que les poids sont en raison doublée des intervalles harmoniques, ausquels on fait monter les chordes; or l'intervalle de l'octave est de 2. à 1. dont la raison 4. à 1 est double*."

("If the strings have the same thickness and length and one produces a low note, which is a C fa ut, when it is stretched with a weight of 1 pound, the other must be stretched with four pounds to make it rise to the upper octave, insofar as the weights are twice the harmonic intervals to which one makes the strings rise; now, the interval of the octave is 2 to 1, of which the ratio 4 to 1 is doubled.")

In the First Rule, Mersenne thus establishes the perfect proportionality that exists between tension and frequency at an equal vibrating string length and diameter (as seen from his trials on the Monochord).

He then writes the following in his second rule:

Second Rule
"*Il faut encore adiouster au susdit poids la seiziesme partie du plus grand poids, ou ¼ du plus petit, afin que l'accord soit iuste: par exemple, il faut adiouster quatre onces aux quatre livres precedentes pour faire l'octave iuste: par consequent 4 ¼ livres contre 1, estant suspendues à deux chordes esgales sont l'Octave parfaite.*"

("It is necessary to further add to the aforementioned weight the sixteenth part of the larger weight, or one fourth of the smaller, to achieve a proper or 'just' chord. For example, it is necessary to add four ounces to the preceding four pounds to obtain a perfect octave. Consequently 4 ¼ pounds against 1, being suspended on two equal strings, produce the perfect octave.")

PROPOSITION VII.

Vn homme ſourd peut accorder le Luth, la Viole, l'Epinette, & les autres inſtrumens à chorde, & treuuer tels ſons qu'il voudra, s'il cognoiſt la longueur, & la groſſeur des chordes: de là vient la Tablature des ſourds.

L'ON peut auoir de pluſieurs ſortes de chordes, qui ſoient eſgales en longueur & groſſeur, comme celle des Monochordes; ou ineſgales en lon-ueur & eſgales en groſſeur: ou ineſgales en longueur & groſſeur, comme elles des Harpes & de l'Epinette; ou eſgales en longueur, & ineſgales en groſ-eur, comme celles des Violes, & du Luth. Or de quelque maniere qu'elles oient differentes, l'homme ſourd les peut mettre à tel accord qu'il voudra, ourueu qu'il ſçache leurs differences tant en matiere, qu'en longueur, & roſſeur. Ce que ie demonſtre premierement aux chordes, qui ſont eſgales n toutes choſes, afin de commencer par les plus ſimples, parce que lors u'elles ſont tenduës par des forces eſgales, elles font l'vniſſon, puiſque cho-es eſgales adiouſtees à choſes eſgales, les laiſſent eſgales.

Or voicy les regles generales, dont il faut vſer pour faire toutes ſortes d'ac-ords, leſquels ſeruiront icy de preuue, & de Demonſtration, d'autant que ous auons fait voir ailleurs, qu'elles ſont veritables & infaillibles.

Premiere Regle.

Si les chordes ſont eſgales en longueur & groſſeur, & que l'vne faſſe le ſon raue qui eſt en *C fa vt*, quand elle eſt tenduë auec le poids d'vne liure, il faut endre l'autre auec quatre liures pour la faire monter à l'octaue, d'autant que es poids ſont en raiſon doublée des interualles harmoniques, auſquels on ait monter les chordes; or l'interualle de l'octaue eſt de 2. à 1. dont la raiſon e 4. à 1. eſt doublée.

Seconde Regle.

Il faut encore adiouſter au ſuſdit poids la ſeizieſme partie du plus grand oids, ou ¼ du plus petit, afin que l'accord ſoit iuſte: par exemple, il faut diouſter quatre onces aux quatre liures precedentes pour faire l'octaue iuſte: ar conſequent 4 ¼ liures contre 1, eſtant ſuſpenduës à deux chordes eſgales ont l'Octaue parfaite.

Oddly enough, Mersenne does not provide any motivation for this Second Rule, which contradicts the First Rule that he has just enunciated. In the first rule, confirmation is in fact provided of the perfect proportionality existing between tension and frequency in square terms. Why does it therefore become necessary to have an additional corrective coefficient if the proportionality is already mathematically 'perfect' as has been stated? The necessity for the compensation (for otherwise things don't quite add up) is also applied in the Third Rule, where it is established that to ensure two strings having the same diameter and different vibrating string length are in unison, the tension must be squared with respect to the initial value, plus a corrective coefficient equal to 1/16th of the increase in tension referred to. It is evident that Mersenne was aiming solely at solving the anomalies, but avoiding any explanation regarding the same. Nevertheless, in any case an explanation must exist.

However, this evident contradiction (requiring an act of faith on the part of the reader) was not missed by Bartoli (Op cit. 5) (Fourth Treatise, pp. 248-249), who says,

nè rallegrarmi d'hauer trouato chi me l'inſegni . Tanto piu
ſe ſi haurà in conto di vero quello che il Merſenno vuol che ſi
creda alle ſue mani , alle ſue orecchie, a' ſuoi occhi, adope-
ratiſi a farne la ſperienza : che la tenſione di quattro libbre, e
d'vna, non fà Ottaua legittima, e intera fra due corde pari-
menti lunghe, e parimenti groſſe; ma le quattro libbre ſi con-
uengono ingroſſare con la lor ſediceſima parte, cioè con di
piu il quarto d'vna libbra : con la qual giunta neceſſaria ad
hauere i numeri armonici dell'Ottaua; la Ragion duplicata
eſce de' termini, e perde la ſua ragione. Se poi queſto auuien
nell'Ottaua, chi ſaprà dirmi perche non ancor nella Quinta?
La cui forma conſiſtendo nella proportion ſeſquialtera, Tre,
e Due, e dandoci la ragion duplicata Noue e Quattro, ſe
quattro libbre non baſtano all'Ottaua, baſteran noue alla
Quinta? E pure ò io mal diſcorro, ò ſecondo ragion natura-
le, così le quattro libbre dell'Ottaua, come le noue della
Quinta, dourebbono riuſcire anzi ſouerchie che ſcarſe. Con-
cioſiecoſa che, chi puo dubitare, che due corde (ſien di mi-
nugia) tutto del pari lunghe e groſſe, ſe l'vna è tirata da vna
libbra di peſo, e l'altra da quattro, ò l'vna da quattro e l'al-
tra

Briefly, and with a discreet touch of sarcasm, Bartoli wonders why one should blindly believe Mersenne's statements regarding the fact one must introduce a correction coefficient as otherwise it is not possible to obtain the correct octave ratio. For Bartoli it is evident that Mersenne had committed an error. According to the law of proportions, everything should go smoothly; this means that the relation between the diameters must be equal to the square- ratio between the tensions. However, Bartoli later highlights the fact that a string subjected to traction will be stretched, meaning that it loses a part of its diameter and that such reduction is proportional to the weight bearing on the string in question, but goes no further.

CAPO QVARTO. 249

tra da noue, la piu tirata non ſi aſſottigli piu, e muti corpo,
baſe, e diametro al cilindro ch' ella è? dal che ſiegua, il ri-
chiederſi, come a piu ſottile, minor peſo, e minor tenſione, ad
hauerne due vibrationi per l'Ottaua, e tre per la Quinta, men-
tre la corda graue di quella ne fa vna, e di queſta due.

Like many others before him, Mersenne also used the monochord as a basis for his experiences. He then extends the acquired rules to keyboard instruments, the harp, the viol and the violin, introducing the concept of equal tension, which derives from the proportionality encountered between diameter, frequency, vibrating string length and string tension.

In another known example he uses the lute as his point of reference, illustrating the inverse proportion existing between the diameter of a string and its frequency (at equal tension, vibrating string length and specific gravity of the material). In his writings, however, he was evidently unaware of the gap existing between the proportion's law (found with the monochord) and what actually happens in reality with a musical instrument.

The strings in a tuned state are stretched in a different manner with respect to each other (in terms of a percentage) because the weight itself acts on different sections of a string, determining a new situation in the traction state.

Moreover, he appears not to conceive that the tension is perceived by the performer by means of tactile feel. In the case of the First Rule the final diameter of the string loaded four times with respect to the initial tension leads to the string's stretching, which causes a consequent reduction of its diameter. And herein lies the explanation for the need to introduce a corrective coefficient.

Thus, we are no longer dealing with a proportionality that is perfect but with a scaled type.

In another chapter of his work, Mersenne (Chapman, Book IV, Proposition I, p. 238) emphasizes that in his day neither the lutemakers nor musicians followed in their daily practice what he sustained.

This is certainly not a point to be overlooked as it means that equal tension, in the day-to-day reality of his time, was not a practice that was really followed but the result of a speculation on the part of those who trained their minds (just as he had done) by studying the Quadrivium (comprising also mathematics and music), of which ministers of the Church were the principle guardians. (13)

If his recommendations had been followed, the spinet and harp would have had serious problems of balance in the setup of the strings and under the total tension an instrument would be subject to. In the case of the harp, for example, it is common practice for the shorter strings to have a lower working tension with respect to the longer strings.

The aim is for the entire string's setup to produce (at touch) an even feel of tension in the case of all of the strings, even though in fact it is obtained with a gradually increasing tension profile.

Following Mersenne's proportions, strings gradually decreasing in length would be progressively uneven, i.e. harder to the touch: the soundboard ought to withstand a very high global tension. The same would occur in the case of the spinets.

Mersenne was most certainly a great and ingenious scholar and remains as a precious source of information, however he occasionally commits a few errors in his calculation and evaluation, besides presenting evident conceptual contradictions. These appear even more evident when he leaves the theoretical dimension and moves on to proposing practical applications of his concepts.

Some examples:

1) In his second Proposition in Book II (Chapman, p. 78) he correctly states that smaller lutes must have proportionally thinner strings (so as to preserve the same 'right' feel of tension of the strings with respect to a larger instrument) but this affirmation then contradicts the law of proportion of the strings which he himself had enunciated. According to this law if the vibrating length decreases and one wants to maintain the same value of tension (deemed appropriate by the musician for a larger instrument), the diameters must increase. However, this is exactly the opposite of the contemporary recommendation proposed by methods and lute threatises. A smaller lute set up in this way would have (in tactile terms) excessively taut strings. (Op Cit 6,7,8)

2) The breaking load value of gut strings, according to his calculations, results in a value of just 19 Kg mm^2. In such conditions no lute, violin or instrument in the viola da gamba family of his time would be able to exist. The breaking load of a gut cantino necessary to withstand the vibrating length of a lute tuned to its own pitch in accordance with the data in the tables of Praetorius must be of the order of at least 34 Kg mm^2 (which, one should note, is also the average value of present-day gut cantini). In brief, with 19 Kg mm^2 a lute nominally in G should have a vibrating length of just 33 cm rather than approximately 60 cm. In a violin this should be just 15-16 cm instead 32-33 cms. With the right vibrating string lengths the 1st strings will breaks instantly. (14)

3) When discussing the strings of the theorbo, he points out that the thickest (which, in his example, is the 11th) is composed of 48-50 or 60 guts. Present-day string makers with 50-60 gut's strands (i.e. the whole gut cut into strips) produce a diameter between 3 - 3.5 mm. A diameter of at least 4-5 mm in the case of unsplit whole gut (as was the general case in Mersenne's time): this is the third string of a double-bass! An 11th string for a present-day theorbo has a diameter that is certainly smaller than 1.4 mm. On the other hand examinations of the diameter of apertures for the low strings of surviving theorbos have so far not shown anything of the kind. (15).

4) In providing the diameters and the proportions to be adopted for lute strings, there is absolutely no consideration that each string of the set loses its percentage of diameter when subjected to traction. The tactile feel of such a set of strings would in actual fact differ quite considerably from the recommendations of contemporary treatises on the lute (even tactile feel). Finally, his ideas are contradicted by the reduced dimensions of the holes for the lower strings in the bridges of surviving historical lutes, this being one of the few really unquestionable pieces of evidence we may refer to. (16) A practical application of his suggestions produces a set-up, the 'tactile feel' of which is found to be increasingly taut, proceeding from the treble to the lower strings with a brusque drop in the cantino, that is single (while the others are double). Moreover, it is quite a singular fact that in practice the diameter of the first and second strings cannot be effected at all; practical tests demonstrate that from a single, whole gut taken from a lamb of three months (the age-limit) produces a range of string diameters -with string that has been slightly polished- between .45 - .50 mm (while from Mersenne's data one obtains diameters which are a lot smaller and could not be produced in any way whatsoever).

5) Researchers have highlighted various clumsy calculation errors and discrepancies in the chapter where he describes metal wire strings and the string diameters for fingerboard instruments. (17)

6) He is never clear when he uses the term ‘Grosseur’. Occasionally he will be referring to diameters; however, at other times he refers to the square section of the string and even the circumference of the string in question. In some cases he uses two different concepts indifferently to express a measurement of a string also within the well-defined context and discussion of a single argument. (18)

7) In chapter […] Mersenne informs us that the Dessus 1st string (violin) is as thick as the fourth strings of the lute. On the basis of the measurements he himself provides in the chapter on the lute it is understood that the first string of the violin had a diameter of about 0.75 mm. Following the equal-tension rule which he upheld, the following diameters are established:

   1 E: 0.75 mm

   2 A: 1.12 mm

   3 D: 1.70 mm

   4 G: 2.50 mm

   We will leave it up to the reader to decide what the situation would be in terms of ease of emission and issues relating to fifths on the fingerboard etc with a set of strings of this kind.

Atthanasius Kircher (1650): In "Preludium 1" Kircher gives the number of fresh guts needed to produce the strings for Roman Violone:

“Est hic Romae Chelys maior, quàm Violone vulgò vocant pentachorda, cuius maior chorda consesta est ex 200 intestinis. Secunda ex 180. Tertia ex 100. Quarta ex 50. Quinta denique ex 30”. (19)

These data are very interesting as they set out in “directly” the number of guts to be used to make the strings of this great musical instrument, they were certainly given to Kircher by Roman string makers (Kircher indeed lived in Rome), who were the most active Europe.

Our goal is to check the tension profile so that is not important to know exactly the type of gut used, but only feel that all the strings have all been made from the same type of material. Assuming for example that with three whole sheep casing of about 8 months of age we get an average diameter of 0.70 mm, so by simple proportion it can be calculated as follows:

1: 2.21 mm (30 guts)
2: 2.85 mm (50 guts)
3: 4.04 mm (100 guts)
4: 5.42 mm (180 guts)
5: 5.71 mm (200 guts)

The author fortunately states how Chelys Maior is tuned : E treble, A, DD, low GG . The difference between the number of guts between fourth and fifth string can mean that there is only one interval of distance: so low FF

We calculate the tension considering a Roman pitch of 392 Hz and a fake vibrating length of 90 cm:

1: 35.50 kg for the first string E
2: 26.31 kg for the second string A
3: 23.54 kg for the third string D
4: 18.88 kg for the fourth string G
5: 16.64 kg for the fifth string F

As you can see the series of tensions of work leads to a scaled profile that probably also brings to an equal feel.

This figure can be considered direct evidence of the use of a scaled profile in the seventeenth century with data (the number of guts for each string) that refer directly to Roman string makers, i.e. at those who were certainly capable of imposing a certain line of conduct in the choice of commercially available diameters.

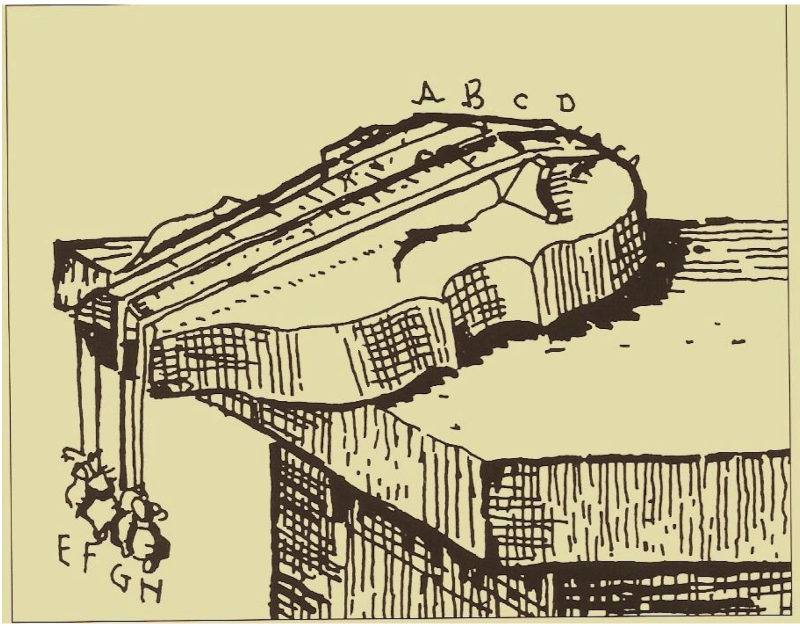
A final clarification: on page 486 of the Treaty there is a table on the strings of "Chelys exachorda" column II shows a series of numbers which do not indicate the diameter of string (which would remind a set up in equal tension) but the proportions between the frequencies of the strings played open (i.e. not fretted) . It is not a coincidence that the column is called 'propor'.

Serafino Di Colco (1692)

Serafino Di Colco (together with Mersenne and, as we shall see, also Leopold Mozart) is undoubtedly considered one of the main battle horses by those who support the equal-tension hypothesis.

Di Colco wrote, "*Siano da proporzionarsi ad un violino le corde […] distese, e distirate da pesi uguali […]. Se toccandole, ò suonandole con l'arco formeranno un violino benissimo accordato, saranno bene proporzionate, altrimenti converrà mutarle tante volte, sin tanto che l'accordatura riesca di quinta due, per due, che appunto tale è l'accordatura del violino*".

(The proportioning of the strings must be based on a violin [...], extended, and stretched by equal weights [...]. If, when touching them or playing them with the bow, they form an excellently-tuned violin, they can be considered as well-proportioned, otherwise you will need to change them as many times as necessary until the tuning is successful and fifths are obtained between pairs of strings, which is precisely the tuning of the violin).



The Di Colco case may indeed result in a certain ‘interpretational confusion’. In accordance with modern custom, one is in fact tempted to conclude that these are setups having equal tension, i.e. as if the diameters had been obtained starting from a calculation on packaged strings (i.e., not yet placed in a state of actual traction).

On closer examination things appear to be quite different however. It is true that the test indicated by Di Colco is carried out under an equal-weight regime (i.e., a real equal tension imposed by means of identical weights) but in a condition entirely different from the equal tension as it is sustained nowadays.

The modern equal tension is that which obtains - by mathematical calculation or from a chart – the string diameters (still ‘packaged’) not yet placed under a state of traction, while in Di Colco’s case the strings are actually already in a state of intonation, i.e., they have already undergone the process of stretching and loss of diameter due to tension imposed by the weights.

As this is a situation of equal dynamic tension (the weight always remains the same even though the strings are stretched), the strings thus reveal a condition not of equal tension according to the modern principle (i.e., obtained from a theoretical calculation) but of ‘equal feel’.

In other words, the method suggested by Di Colco achieves what we previously discussed in relation to the behaviour of strings of differing diameter subjected to the same tension but following an inverse path. The strings suitable for providing open fifth intervals must present diameters in the package relating to a moderately scalar tension profile, just like the other cases described.

 Once placed in a state of traction, these strings will be lengthened in a manner proportionate and suitable to obtain under the same working tension (given by the same bearing weight) the fifth intervals that are being sought.

The question now is: how many of the 'equal tension supporters' have actually gone to the trouble of checking the Di Colco test so as to see what really happens?

In any case we decided to do it ourselves:

For the pure sake of practicality we used a ukulele, from which we removed the head (i.e. pegbox) and added an arched bridge positioned at the violin's vibrating length, and finally adding the corresponding tailpiece (frankly speaking, we did not fully understand why the instrument drawn by Di Colco does not have a neck!

Was the test really carried out by him? And if it was in fact carried out, does it only concern half of the vibrating length? Rather than a musical instrument, what we have here is just a sound- box).

We checked the bearing weights (2.5 kg) on a balance to verify their adjustment. One was readjusted with an addition of 2.5 g.

The strings used were exactly .60 and 1.20 mm, measured with a micrometer and with a laser measurement device just for our safety. They were produced with a centerless grinding machine to ensure maximum precision and were both worked under the same conditions of ambient moisture.

The nut was extremely well-polished, with no grooving so as to avoid useless additional friction and treated with a graphite paste to ensure a maximum degree of string slide.

The knots on the side that had to bear the weights were produced in such a way that the strings would present the same overall length.

The two strings, placed under traction with the weights, presented the situation seen in the image above.
The thinner string was stretched more with respect to the thicker one.
This indicates that it had also become thinner in percentage terms with respect to the other string, thus altering the initial 1:2 ratio of the diameters (in the drawing by Di Colco you notice a particular absolutely unnatural and contrary to the laws of physics: the equal weights acting on the four different strings of the violin stretch each string of the same amount despite the fact that these gauges are very different among them: was it a mistake of the artist? Di Colco did not notice the error or actually never did this test?).

Consequently, when plucked, the strings did not show at all the octave interval as should have occurred according to the theoretical rules laid down by Mersenne; on the contrary we found an octave and two additional semitones.

But it could not have been otherwise. On the basis of the law applying to strings, having an equal vibrating string length and tension, the frequency and diameter are inversely proportional. The ratio existing between the two diameters - which in a state of non-traction reproduced perfectly the 1:2 ratio of the octave - in the traction state (the real condition in a musical instrument) on the other hand it is placed severely out of balance as the finer string is lengthened more than the other one!

To return to a situation capable of reproducing the exact octave interval in a state of traction, the initial diameter (obtained using the string formula) of the thinner string must be increased by a value exactly equal to that percentage of diameter it will subsequently lose under traction. This means that in the calculation using the string formula one must consider a tension of the scaled type. Once the equal weights have been applied to the strings, after having been securely lengthened, they will spontaneously assume a condition in accordance with the 1:2 diameter ratio.

We carried out the test referred to various times (also changing the weight value and string diameters) and demonstrated it in public during the course of a conference at a symposium held at Puurs in Belgium ('Corde Factum', 2012) (20)

So the truth emerges from this test and also from our own previous considerations. Di Colco's test (which, together with Leopold Mozart's, is nowadays considered one of the main proofs of the equal tension principle in which diameters are obtained by calculation using the string formula) is in actual fact the one that demolishes it, unquestionably demonstrating what really happens to two strings having different diameters submitted to the same working tension.

Thus, the only path forward to safeguard the 'equal tactile feel' rule, so widespread in the sixteenth and seventeenth centuries, is the use of a certain gradient of scaled tension in the calculation of initial diameters.

To conclude, Di Colco may in no way be considered a good battle horse for the 'equal tension' supporters but rather should be seen as one of the principle adversaries of this particular school of thought.

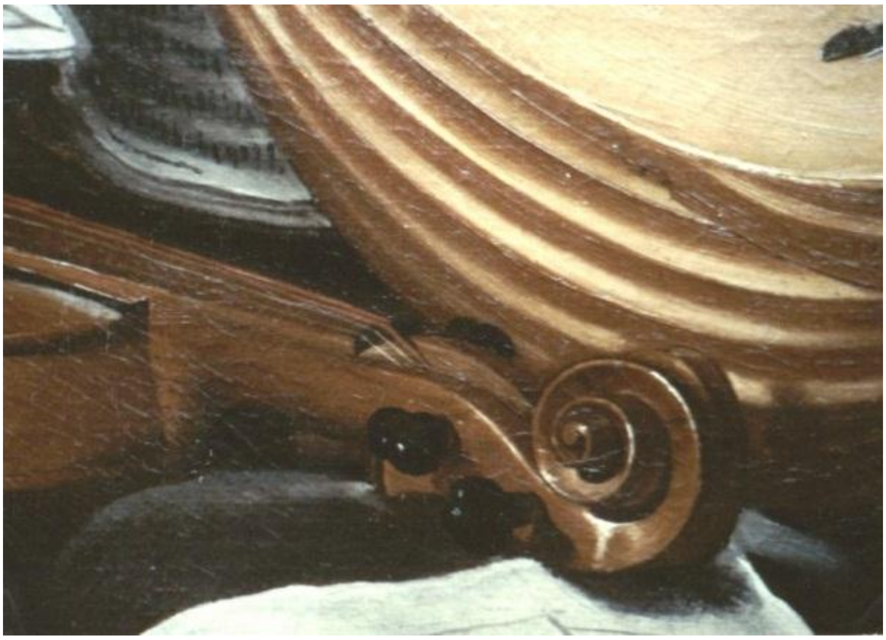
Iconographic investigation

The examination of the iconographic sources of the Sixteenth and Seventeenth centuries can provide valuable insights about the general profile of string gauges of the musical instruments represented, provided that they are made with certain criteria of 'truthful'.

Fortunately, in an equal tension profile, the difference in diameter between the first and last string is noticeably marked , so that is perceived to be easily 'visible'.

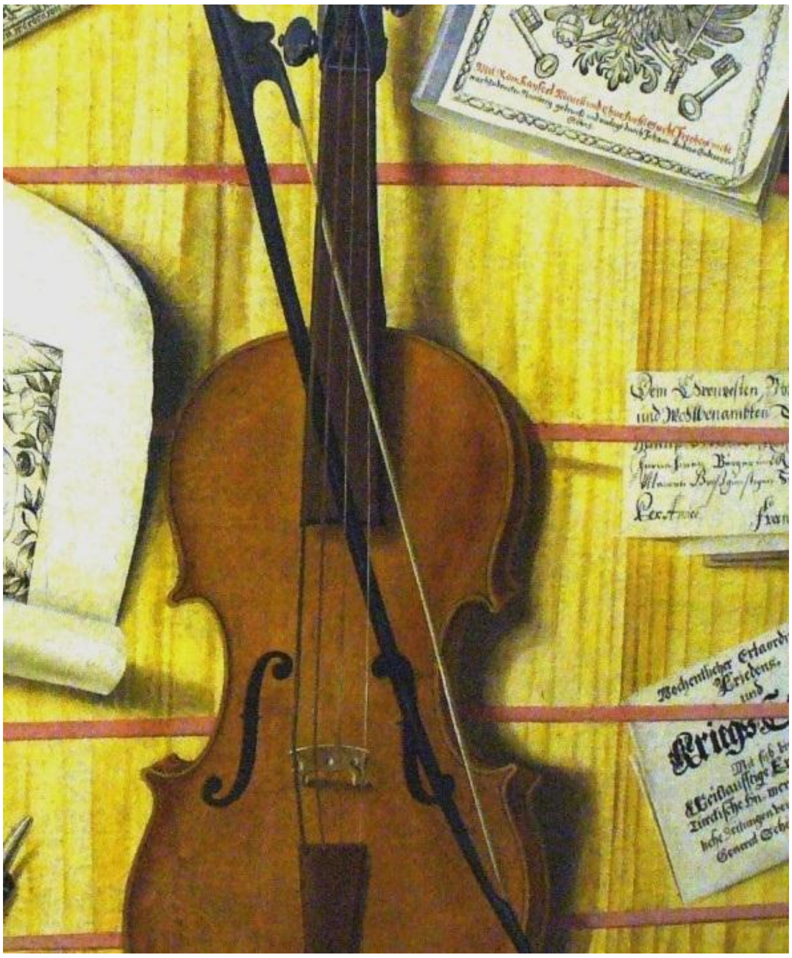
However, in the gallery of images that we show, most part of examples do deviate not only from what could refer to a profile of equal tension but, in some cases, that could draw to an even feel tension-profile:


CONTINUUS



Pictures in which the difference in diameter between the treble and the fourth string is not so evident (equal feel profile?)

Indeed the iconographic examples where you can find an interesting difference between the apparent diameter of the first string compared to lower strings are only a few:



Pictures in which the difference in diameter between the treble and the fourth string is more evident (equal tension profile?)

Even though we are dealing with painted images and not photos, what can be seen in the iconography of Seventeenth century (especially on one that reserves a great deal of attention in the reproduction of reality) draws a picture in which the possible explanations are more in the direction of a scaled tension profile than of equal tension, moreover there is also the possibility that the low strings are represented so thin not only because of a particular profile of tension but perhaps also because some manufacturing aspects of the strings (loaded gut?).

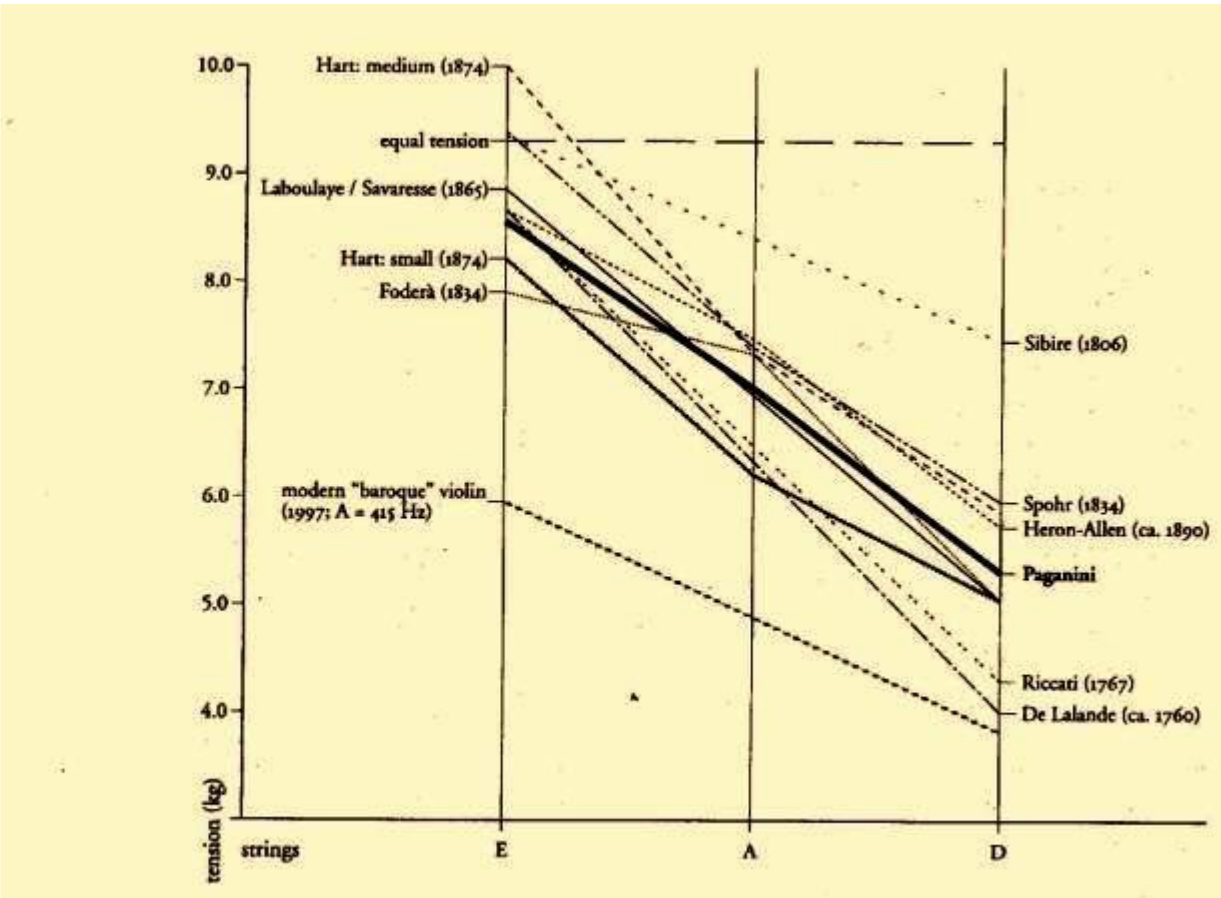
The Eighteenth century

Some researchers believe that in the Eighteenth (and also in the early Nineteenth century) there was a coexistence of the profile in equal tension and the strongly scaled. This view in our opinion is not historically sustainable. (Op. cit. 2).

Towards the middle of the Eighteenth century was beginning to define in practice some of the characteristics of the set up for stringed instruments of the time (mostly related to Violin):

1) the tension -profile reported in the documentation is scaled

2) the degree of scaling does not match with the one deriving from equal feel; the slope in the tension is in fact higher:



We do not know the reasons why the violinists of the time took that choice, unless this aspect was already part of the daily practice of the Sixth-Seventeenth century (see the iconographic aspect of and the measures of the holes of the strings of the Amati's Viola da braccio in the Ashmoleam Museum).

We cannot see any logic that could justify the abandonment of an eventual tactile equal feel profile to adopt a so scaled tension.

The adoption of wound strings indeed does not make this change necessary.

1) **Handwritten recipe** (probably early Eighteenth century): the number of guts suggested to make the top three strings of the violin leads to a very scaled tension profile (21).

2) **De Lande** (1765-6): he reported very interesting information on the activities of the most talented string makers in Abruzzo region (Italy) -Angelo and Domenico Antonio Angelucci-latter 's death in 1765 and that, in the first half of the Eighteenth century, had the most important works of strings of Naples, which numbered more than a hundred workers. In this document we learn that to make the first string of the violin they took three whole lamb intestines of eight to nine months of age, while for the last (ie last intending gut only, i.e. "D'", which is certainly not the fourth, which as we will see later, was a wound string) they took seven. The fourth string was a wound string. (22)

3) **Conte Riccati** (1767) The Count makes no new theory in regard to the tension profile compared to the past as some scholars argue. (23) He introduced a simple mathematical explanation to justify the reason of the scaling of the string tension of the commonly available strings that he finds on his violin. The book of Riccati was started around 1740: so in commercial sense, therefore, the violin strings available on the Italian market in the first half of the Eighteenth century showed a tension profile remarkably scaled (p.130):

'*Colle bilancette dell'oro pesai tre porzioni egualmente lunghe piedi 1 ½ Veneziani delle tre corde del Violino, che si chiamano il tenore, il canto e il cantino. Tralasciai d'indagare il peso della corda più grave; perchè questa non è come l'altre di sola minugia, ma suole circondarsi con un sottil filo di rame*'.

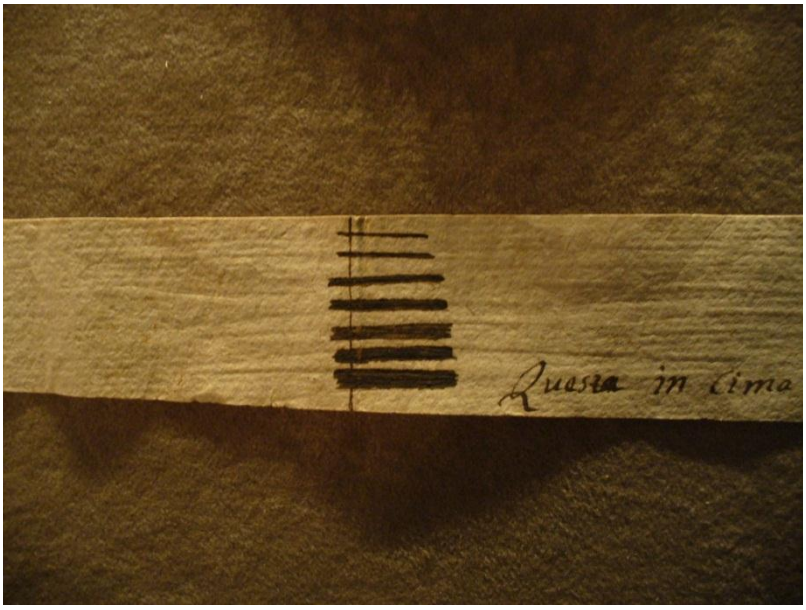
(Using gold-weighing scales, I weighed three portions, each 1 ½ Venetian feet long, of the three violin strings, those called the tenore, canto and cantino. I omitted the weight of the lowest string, because unlike the others this is not of gut only, but is usually surrounded with a thin copper wire).

If you consider an averaged specific weight of the gut of 1,3 gr/cm3 results to be respect .70; .91; 1.10 mm of diameter for "e'"; "a" and "d" respectively (24).

4) **Donato Vincenti** (1785): All data provided by this string maker in regard to the number of guts used to make the top three strings of the violin all lead to a very scaled tension profile. To be clear, the same kind as those mentioned by De Lalande. (25)

Let us now examine in detail some 18th C. sources which are considered equal tension profile evidence

1) **Stradivari** (early Eighteenth century): the hypothesis of a possible equal tension set up to the Stradivarius violin that he used to guide the type of string to use for its Theorbo Guitar born as a result of the traces shown on the figure marked with charcoal of the ' TheorboGuitar': next to one of these tracks is in fact wrote:"*Questa in cima deve essere una quarta da Violino…*" (the upper string must be like a violin 4th) (Op cit 2)



The track referred to the fourth string of the violin is of rather remarkable thickness: this was therefore not just a gut setup but also in equal tension. he was referring to, was in equal tension.

In conclusion it is not possible to determine anything about the profile of tension of that violin and we cannot conclude with certainty that it was set up only with gut strings Stradivari could in fact have wanted to suggest that for that theorbo guitar string it had to use the fourth violin wound string.

2) **Tartini (**1734): Fetis wrote that Tartini in 1734 found that the sum of the tensions of the four strings of his violin was of 63 pounds (op. cit 2). Apart from knowing how Tartini determined that value of tension (and if this data was then successfully converted into other units of measurement) it should be emphasized that the mere fact of being expressed in a single global value, this does not mean that we are witnessing the confirmation of a set up in equal tension. This same value can in fact also be obtained from the sum of completely different tensions. Through some tests we came to conclusion that we are perhaps in front of a scaled type set up

1. Being a violin we consider a vibrating length of 0.32 meters.
2. for standard "a" we can assume a theoretical Venetian pitch of the Eighteenth century equal to 465 Hz

Hypothesis of equal tension:
Assuming that 63 pounds are actually equivalent to 31 kg following the hypothesis of equal tension would result in about 7.7 kg per string that would bring to the following sizes:

e: .61 mm
a: .92 mm
d: 1.38 mm
g: 2.06 mm (expressed in equivalent solid gut gauge)

As you can see the treble has a diameter that is out of the calibration range which can be obtained with 3 or 4 lamb casings, that is, as we know, the typical constructive characteristic of that particular historical period. (Op. cit. 16, 19)

Starting instead from an average value of a supposed 'e' of .70 mm (obtained from 3 -4 whole lamb casings ...) with a set up still in equal tension it can be observed that things do not settle at all: it would have a total value of tension of about 42 Kg. Therefore this hypothesis is not plausible.

It should be emphasized how the sum of tensions of the three thinner strings only (about 30 kg) would be enough to nearly reach the value of tension indicated by Tartini for all four strings).

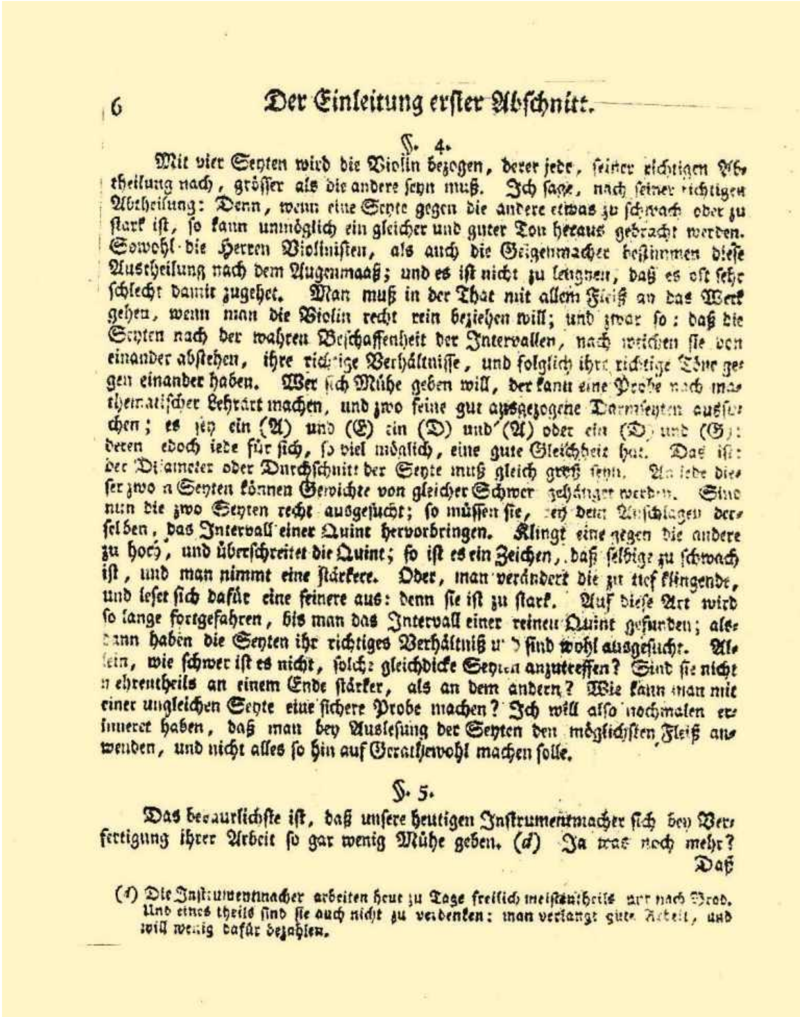
Hypothesis of scaled tension:
Starting with an average value of 'e' of 0.70-mm and using the sizes of 'a' and 'd' as found in the average historical sources close to him (Conte Riccati, De Lalande) leads to the following data :

e: .70 mm (9.9 kg)
a: .90 mm (7.3 kg)
d: 1.16 mm (5.4 kg)

Total 22.6 kg

In order to reach the 31 kg set by Tartini you must have a wound “g” string that produces about 6.5 kg of tension: this corresponds to plain gut string of 1.90 mm. Manufacturing such wound string as specified by Galeazzi (op. cit. 4) it is indeed in the required range and this would therefore confirm the hypothesis of scaled tension compared to equal tension.

3) **Leopold Mozart** (1756): Mozart (26) considers the same concepts of Di Colco. He suggests to bring equal weights to each pair of adjacent strings, and a change of the diameter ("a" comped to treble"e") until we succeed in obtaining open fifths. We proceed in this manner with the third and apparently also with the fourth strings.



6 Der Einleitung erster Abschnitt.

§. 4.

Mit vier Seyten wird die Violin bezogen, derer jede, seiner richtigen Abtheilung nach, grösser als die andere seyn muß. Ich sage, nach seiner richtigen Abtheilung: Denn, wenn eine Seyte gegen die andere etwas zu schwach oder zu stark ist, so kann unmöglich ein gleicher und guter Ton heraus gebracht werden. Sowohl die Herren Violinisten, als auch die Geigenmacher bestimmen diese Austheilung nach dem Augenmaaß; und es ist nicht zu leugnen, daß es oft sehr schlecht damit zugehet. Man muß in der That mit allem Fleiß an das Werk gehen, wenn man die Violin recht rein beziehen will; und zwar so: daß die Seyten nach der wahren Beschaffenheit der Intervallen, nach welchen sie von einander abstehen, ihre richtige Verhältnisse, und folglich ihre richtige Töne gegen einander haben. Wer sich Mühe geben will, der kann eine Probe nach mathematischer Lehrart machen, und zwo feine gut ausgezogene Darmseyten aussuchen; es sey ein (A) und (E) ein (D) und (A) oder ein (D) und (G): deren jedoch jede für sich, so viel möglich, eine gute Gleichheit hat. Das ist: der Diameter oder Durchschnitt der Seyte muß gleich groß seyn. An jede dieser zwo n Seyten können Gewichte von gleicher Schwer gehänget werden. Sind nun die zwo Seyten recht ausgesucht; so müssen sie, bey dem Anschlagen derselben, das Intervall einer Quint hervorbringen. Klingt eine gegen die andere zu hoch, und überschreitet die Quint; so ist es ein Zeichen, daß selbige zu schwach ist, und man nimmt eine stärkere. Oder, man verändert die zu tief klingende, und leset sich dafür eine feinere aus: denn sie ist zu stark. Auf diese Art wird so lange fortgefahren, bis man das Intervall einer reinen Quint gefunden; alsdann haben die Seyten ihr richtiges Verhältniß und sind wohl ausgesucht. Allein, wie schwer ist es nicht, solche gleichdicke Seyten anzutreffen? Sind sie nicht mehrentheils an einem Ende stärker, als an dem andern? Wie kann man mit einer ungleichen Seyte eine sichere Probe machen? Ich will also nochmalen erinneret haben, daß man bey Auslesung der Seyten den möglichsten Fleiß anwenden, und nicht alles so hin auf Gerathewohl machen solle.

§. 5.

Das bedaurlichste ist, daß unsere heutigen Instrumentmacher sich bey Verfertigung ihrer Arbeit so gar wenig Mühe geben. (d) Ja was noch mehr?

Daß

(d) Die Instrumentmacher arbeiten heut zu Tage freilich meistentheils nur nach Brod. Und eines theils sind sie auch nicht zu verdenken: man verlangt gute Arbeit, und will wenig dafür bezahlen.

Our conclusions are therefore the same as those made with Di Colco, we are talking about a tension profile that if it is calculated in accordance with the current practice leads to a tension profile of tension (derived from calculation) moderately scaled, not to an equal tension according to the current concept. (Op. cit 1, 2)

Here now some Nineteenth century sources supposed with the equal tension profile

1) **Fetis and Savart** (1840 and 1856): both show the total value of the tension of the violin specifying better how the tension was divided between the treble and the other strings. If the strings were in equal tension, for what reason it was specified that the treble took 20-22 pounds and the rest of the strings up to a total of 80 pounds? It was enough to define a single value of tension. We lean to the conclusion of a scaled tension profile also as a result of the contemporaneous scholar Delezenne. (27) (28)

2) **Delezenne (**1853): first, he formulated the theoretical hypothesis of equal tension but when he had to deal with a dozen sets of strings present in the market given to him by luthier Lapaix he realized that all all of them followed a strong scaled tension profile . (29)

3) **Maugini & Maigne / Savaresse** (1869): The tension values indicated in the text for the four strings are unreliable, they are fully in contradiction with the number of guts necessary to procuce them, which leads instead to a scaled tension profile similar to all other examples.

It should be noticed of the text a mistake in calculation or typing : the treble has a working tension lower than the second string (7, 5 kg compared to 8.0 kg of "a'"), probably the correct value is 8.5 kg.

After deriving it from an estimation of the diameters (and a vibrating length of 33 cm and a pitch of 415 Hz), relating to the same breaking tension for each string in the text, there is a fundamental inconsistency: the breaking index of gut is too low, out of any acceptable standard: 33-36 Kg/mm2 for "e" (and this is fine) and only 21 Kg/mm2 for 'a' and 17-19 for Kg/mm2 ' d '. This makes it unreliable to draw any definitive conclusion in favor of equal tension. If we start instead from the number of guts in the text by string maker Savaresse (for a scaled tension profile) the breaking index are again fully reasonable. (Op. cit. 3)

4) **Huggins** (1883): After having calculated the diameters according to an equal tension profile he realized that they did not work as expected. Afterwards he understood the validity of commercial gauges with strongly scaled tension as those produced by string maker Ruffini in Naples. Afterwards Huggins argued that theoretic gauges in equal tension do not give open fifths as well as a satisfying acoustic performance and he made all his efforts to understand why this happened. (30)

248 *On the Sound-post and Strings of the Violin.*

It will be seen that the 1st string is thicker, and the 3rd thinner, and the 4th much lighter than the theoretical values. Therefore the tension of the 1st string would be greater, and that of the 3rd and 4th strings less than they should be in relation to that of the 2nd string. The greater flexural rigidity of the 4th string will have a small effect in the direction of making the vibrations quicker, and therefore of making the tension required less.

By means of a mechanical contrivance I found the weights necessary to deflect the strings to the same amount when the violin was in tune. The results agreed with the tensions which the sizes of the strings showed they would require to give fifths.

A violin strung with strings of the theoretical size was very unsatisfactory in tone.

The explanation of this departure of the sizes of the strings which long experience has shown to be practically most suitable, from the values they should have from theory, lies probably in the circumstance that the height of the bridge is different for the different strings. It is obvious, where the bridge is high, there is a greater downward pressure. By this modification of the sizes of the strings there is not the greater pressure on the 4th string side of the bridge, which would otherwise be the case. On the contrary, the pressure is less, which may assist the setting of the belly into vibration. There is also the circumstance that the strings which go over a high part of the bridge stand farther from the finger-board, and have therefore to be pressed through a greater distance, which would require more force than is required for the other strings, if the tension were not less.

What might be the explanation of so marked scaled tension?

Huggins considers two hypothesis : the first takes into account the pressure done by each individual string on soundboard .

He points out that in the condition of equal tension (but also in equal feel, we might add) the pressures in Kg exerted by the first three strings on the below soundboard are by no means equal, and this depending by the angle of the string on the bridge moving towards bigger ones that gradually becomes more acute. It is determined in this way a higher pressure on the soundboard. In order to obtain equal pressures acting on the table by each individual string it is therefore needed an additional scaling compared to the condition so far considered.

The second hypothesis considers the fact that the strings gradually that are thicker , in practice, are placed gradually at a greater distance from the keyboard: therefore the fact that the fingers of his left hand in a position of equal tension / equal feel should do an extra effort to press on the keyboard. Hence the reduction of tension in order to recover consistency in the feeling of the fingers of his left hand.

A third and final hypothesis that weighs in favor of a (marked) scaled profile in tension consists on aiming to the maximum possible uniformity of friction to horsehair bow, as advocated by Riccati already in the Eighteenth century and again later by the second half of Nineteenth century by Pleissiard (31):

'Egli è d'uopo premettere, che quantunque l'arco tocchi una maggior superficie nelle corde più grosse, nulladimeno la sua azione è costante, purchè si usi pari forza a premer l'arco sopra le corde. Questa forza si distribuisce ugualmente a tutte le pasrti toccate, e quindi due particelle uguali in corde differenti soffrono pressioni in ragione inversa delle totali superfi cie combacciate dall'arco.' (Giordano Riccati 'Delle Corde…' op. cit, p. 129).

eguali forze vive rendono ſuoni egualmente forti. In fatti i ſuoni del violino prodotti da corde animate, come vedremo, da eguali forze vive rieſcono di pari vigore, quantunque le forze tendenti non ſerbino la ragione delle groſſezze delle corde. Ho abbracciata la nominata ipoteſi, perchè queſta dee verificarſi almeno proſſimamente negli ſtromenti più perfetti, ne' quali le ſpeciali circoſtanze non obbligano gli artefici a regolarſi diverſamente.

XV. Faccio ritorno al violino, e giacchè il noſtro ſtromento è guernito di quattro corde ugualmente lunghe, e variamente groſſe, ſtimo opportuna coſa l' indagare qual proporzione debba aſſegnarſi alle diverſe groſſezze, acciocchè paſſando da corda a corda ſi conſervi la legge $V:u::\frac{1}{\sqrt{T}}:\frac{1}{\sqrt{t}}$, e ritenendo i ſuoni la ſteſſa indole, l' orecchio non s' accorga, che il ſuono piuttoſto da una corda che dall' altra provenga.

Egli è d' uopo premettere, che quantunque l' arco tocchi una maggior ſuperficie nelle corde più groſſe, nulladimeno la ſua azione è coſtante, purchè ſi uſi pari forza a premer l' arco ſopra le corde. Queſta forza ſi diſtribuiſce ugualmente a tutte le parti toccate, e quindi due particelle uguali in corde differenti ſoffrono preſſioni in ragione inverſa delle totali ſuperficie combacciate dall' arco. Facendo l' arco ſuonare le corde col mezzo del fregamento, ed eſſendo queſto in proporzione compoſta della preſſione ſoſtenuta da particole uguali, che ſta reciprocamente come le intere ſuperficie, e del numero d' eſſe particole, che ſta direttamente come le intere ſuperficie; ne ſegue che il fregamento è pari riſpettivamente a tutte le corde, e che l' azione dell' arco è coſtante.

Ciò dimoſtrato, egli è chiaro, che le diverſe corde concepiranno eguali forze vive MV^2, mu^2, onde s' abbia $V:u::\frac{1}{\sqrt{M}}:\frac{1}{\sqrt{m}}$: ma ſi vuole parimente, che ſi verifichi l' analogia, $V:u::\frac{1}{\sqrt{T}}:\frac{1}{\sqrt{t}}$; dunque $M:m::T:t$. E poichè nel caſo preſente le maſſe delle corde, che ſono della ſteſſa materia, ed egualmente lunghe, ſerbano la ragione delle groſſezze, troveremo, che queſte debbono riferirſi nella ragione dei tempi delle vibrazioni.

R Due

Conclusions

The examination of different historical and iconographic sources in our possession might possibly allow to draw a sufficiently clear criteria for choosing a set up for stringed instruments in the seventeenth, eighteenth and nineteenth century (as seen in everyday practice, and not at the level of pure theoretical disquisition). If you cannot say with certainty which were the criteria used in the Seventeenth century , we can emphasize with some certainty which ones were not.

In first place there is the concept of equal tension 'by calculating' so prevalent today: despite the writings of Mersenne, seems not having been followed as common practice in the Seventeenth century.

Moreover, equal tension 'derived from calculation' unfortunately, is based on an error of scientific evaluation of the proper relationship equal tension= equal feel. The tension of this equivalence is that the string which is already tuned, not the one you set by the known formula for the calculation of the diameters.

It must be emphasized that this criterion of equal feel is still derived from the treaties for plucked instruments only like the lute and not for stringed instruments, for which we do not have actually anything really exhaustive. The first useful practical information date back only to the late Eighteenth century.

Our point of view, summarizing the existing corpus of information examined, aims to suggest in practice a scaled -type tension for most of stringed instruments: Kircher, moreover provides a real test. To determine how scaled it could be is unfortunately impossible to determine. It remains an open question on the open Fifths of fingerboard, which was for some researchers of the Nineteenth century, a topic to explain the need of scaled tension in stringed instruments. But if the problem of having the fifth in tune in the Nineteenth century was a real problem (32), was it a problem even in the Seventeenth century?

Bibliography

1) OLIVER WEBBER: “Rethinking Gut strings: a Guide for Players of Baroque Instruments”. Ed: King’s Musik. London, 2006.

2) EPHRAIM SEGERMAN: "Strings thorough the ages", The Strad, part 1, January 1988, pp.54-55".

3) MAUGIN - MAIGNE: Nouveau manuel complet du luthier, pp. 168-181 (the string's section was added in the 1869 edition).

4) FRANCESCO GALEAZZI: ‘Elementi teorico-pratici di musica con un saggio sopra l’arte di suonare il violino’, Pilucchi Cracas, Roma 1791, p. 72.

5) DANIELLO BARTOLI: Del suono, de' tremori armonici e dell'udito, a spese di Nicolò Angelo Tinassi, Roma 1679, p. 157.

6) JOHN DOWLAND: "Other necessary observations belonging to the lute", in ROBERT DOWLAND: Varietie of lute-lessons [...], Thomas Adams, London 1610, paragraph "Of setting the right sizes of strings upon the lute".

7) Wellesley (Mass.), Wellesley College Library, "The Burwell lute tutor", manuscript ca. 1670, facsimile reprint with introduction by Robert Spencer, Boethius Press, Leeds 1973, the chapter 4 "Of the strings of the lute [...]".

8) THOMAS MACE: Musik's monument [...], the author & John Carr, London 1676, pp. 65-6.

9) At present it seems that only historical source that describe the bow's feel on the strings instead fingers is Galeazzi, p 72.

10) EPHRAIM SEGERMAN: “Modern lute stringing and beliefs about gut”, Fomrhi Quarterly, bull 98, January 2000, p.59.

11) SERAFINO DI COLCO: Lettera. prima (Venezia, 7 gennaro 1690), in Le vegghie di Minerva nella Accademia de Filareti: per il mese di gennaro 1690, Venezia 1690, pp. 32-3.

12) MARIN MERSENNE: Harmonie universelle [...], Livre quatriesme, Cramoisy, Paris 1636. Mersenne was the first that expained the relationship that exist between tension, gauge, string's scale and the string- density.

13) MARIN MERSENNE: Harmonie universelle [...], Livre quatriesme, Cramoisy, Paris 1636. Quoted by Stephen Bonta in 'Further thoughts on the history of strings'; The Catgut Acoustical Society Newsletter n° 26, November 1 , 1976, p 22.

14) EPHRAIM SEGERMAN: “String tension on Mersenne Lute”, Fomrhi Quarterly, bull 11, April 1978, p.65 .

15) MIMMO PERUFFO: 'Il Chitarrone e le corde di metallo', Bollettino della Società Italiana del Liuto, Anno VII, N°2-4, vol 24, February 1999, pp. 8-15.

16) MIMMO PERUFFO: "The mystery of gut bass strings in the sixteenth and seventeenth centuries: the role of loaded-weighted gut", Recercare, v 1993, pp. 115-51.

17) EPHRAIM SEGERMAN & CARY KARP comm. In Fomrhi Quarterly of 12 July 1978 p. 25; 14 January 1979 pp.44-46; April 1979, pp. 56-57 .

18) EPHRAIM SEGERMAN: "String tension on Mersenne Lute", Fomrhi Quarterly, bull 23, April 1981, p.79-83 .

19) ATTHANASIO KIRCHER: "Musurgia universalis […]", Lib V, 'De musica Instrumentali', p.440: " …diversa soramina deducta in tantam deveniant subtilitatem, ut subtilissimi Capilli crassitiem adæquent", Roma 1650.

20) SEE: http://www.cmbpuurs.be/cf12_mimmo_peruffo.php

21) Libro contenente la maniera di cucinare e vari segreti e rimedi per malattie et altro, manuscript, Reggio Emilia, Biblioteca Municipale Panizzi, Mss, vari E 177: "Corde da violino, modo di farle. Si prendino le budella di castrato o di capra fresche [...] volendo fare cantini se ne prende tre fila e si torgono al mulinello…"

22) Francois De Lalande, Voyage en Italie […] fait dans les annés 1765 & 1766, 2a edizione, vol IX, Desaint, Paris 1786, pp. 514-9, Chapire XXII "Du travail des Cordes à boyaux…: " .

23) EPHRAIM SEGERMAN: "Review: Italian violin strings", Fomrhi Quarterly, bull 98, January 2000, p.26-33 .

24) GIORDANO RICCATTI. Delle corde, ovvero fibre elastiche, Stamperia di San Tommaso d'Aquino, Bologna 1767, p. 130.

25) PATRIZIO BARBIERI : Roman and Neapolitan gut strings, 1550-1590, GSJ, May 2006, pp 176-7.

26) LEOPOLD MOZART: Versuch eine gründlichen Violinscule [...], Verlag des Verfasser, Augsburg 1756, p.6.

27) For Savart see SEGERMAN: "Strings through the ages", part 2, p. 198.

28) FRANCOIS-JOSEPH FETIS: Antoine Stradivari luthier celèbre connu sous le nom de Stradivarivs [...], Vuillaume, Paris 1856, p. 92: acording to Jean-Baptiste Vuillaume' datas, from him we know that, 20 years before, the Violin's 1st was at 22 French pounds (11 kg ca.) of tension while the other strings were a bit less. The total tension was of 80 pounds (quoted by BARBIERI: "Giordano Riccati", p. 29)

29) CHARLES-EDOUARD-JOSEPH DELEZENNE: Experiences et observations sur les conies des instruments à archet, L. Danel, Lille 1853 (quited by BARBIERI: Acustica, accordatura e temperamento nell"illuminismo veneto, p.48). Folowing Barbieri, Delezenne at the beggining considered the equal tension idea but when he examined "ten different assortments of strings of commercial violin strings provided for him by the luthier Lapaix, finding instead average ratios [between the strings] noticeably lower than 1.5 [which was equal tension]": the Violin string gauges commonly available in the market measured by Delezenne: e" = .61-.70; a' = .82-.96 mm; and d = 1.01-

1.39 mm.

30)WILLIAM HUGGINS: "On the function of the sound-post and the proportional thickness of the strings on the violin", Royal Society proceeding, xxxv 1883, pp. 241-8: 248:

‘ The explanation of this departure of sizes of the strings which long experience has shown to be practically most suitable, from the values they should have from theory, lies probably in the circumstance that the height of the bridge is different for the different strings. It is obvious, where the bridge is high, there is a greater downward pressure. There is also the circumstance that the string which go over a high part of the bridge stand farther from the finger-board, and have therefore to be pressed thorough a greater distance, would require more force than is required for the other strings, if the tension were not less.’.

31) JOSEPH-ANTOINE PLAISSARD: "Des cordes du violon", Association fracaise pour I'avancement des sciences. Congres del Lille, 187487 (quoted in BARBIERI: Acustica, accordatura e temperamento, p. 46.)

32) WILLIAM HUGGINS: "On the function of the sound-post", p. 248: "By means of a mechanical contrivance I found the weights necessary to deflect the strings to the same amount when the violin was in tune. The results agreed with the tensions which the sizes of the strings [i.e. corresponding to Ruffini's gauges] showed they would require to give fifths".