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About the choice of tension for canvas paintings

How a stretcher works

1 The simplest traditional stretcher is made of a wooden perimeter onto which the tacking margins of the painting are fixed with nails, staples, strings or glue. This direct and unbuffered bond between the painting and its stretcher exposes both parties to the forces that each produces with dimensional changes related to environmental conditions. When Relative Humidity rises the wooden stretcher expands while the canvas may contract and hide glue swell and soften, as well as the paint layers.

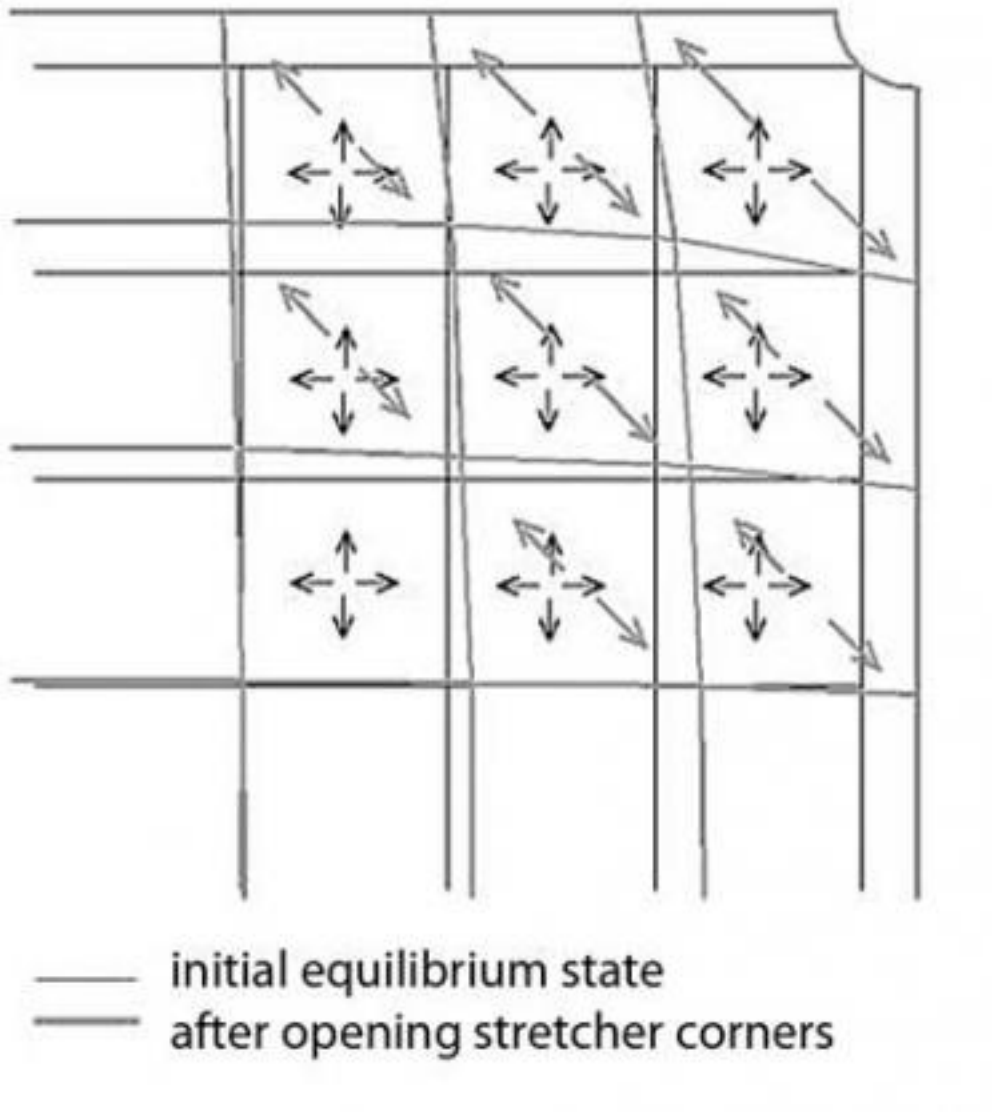
2 This causes stress concentration in the corners, where the proximity of the stretcher on two sides amplifies the problem, as Marion Mecklenburg demonstrated already in 1982 [25].

3 The painting's tension, that may considerably increase with canvas and/or hide glue contraction, is supported by the stretcher bars and corners, that need to provide adequate rigidity to the system.

4 A key expandable stretcher makes it possible to increase dimensions through corner expansion, and therefore is a more complex construction that needs stronger wooden profiles in order to achieve the same overall rigidity even though the corners are weakened.

5 When corner expansion is operated, stress concentration is even more dramatic (Ill. 1).

Fig. 1 Painting nailed on a traditional stretcher.



Change in the distribution of forces upon expansion of stretcher corners or contraction of the painting. Only upper right corner is shown.

6 Actually, as this can be repeated any time the painting looses tension or shows some planar distortions, the effect is that of causing a progressive increase in the painting's dimensions along with those of the stretcher. The problem is amplified by the fact that, with corner expansion, tension reaches very slowly the central area of the painting, and only after overstretching the corner areas.

7 If corner expansion is obtained with springs the distribution of forces does not change, but much of its effects depends on the rigidity of the springs: if they are soft enough to be compressed by the contraction of the painting, they release some of the stress and provide better conservation conditions.

8 Still, very often the need of overcoming important frictions in the corner devices and the desire of providing a strong tension to the painting, lead to the use of springs that are much stiffer than the painting itself. This obviously increases stress concentrations, as the system behaves as a key stretcher in which someone is always pushing on the keys. The example of a very

old (1884) spring loaded stretcher that has progressively thorn the canvas along the tacking margin and caused extensive crack formation is very explicit (Ill. 2).

Fig. 2 Excessive stiffness

Excessive stiffness of springs in corner expansion stretcher (1884 Wright and Gardner elastic engaged stretcher) caused extensive crack formation and tears on the unpainted margin, as can be seen in this photo-collage. (David Johnson On the Unadilla, New York 25.110.135, The Metropolitan Museum of Art Bequest of Collis P. Huntington, 1900)

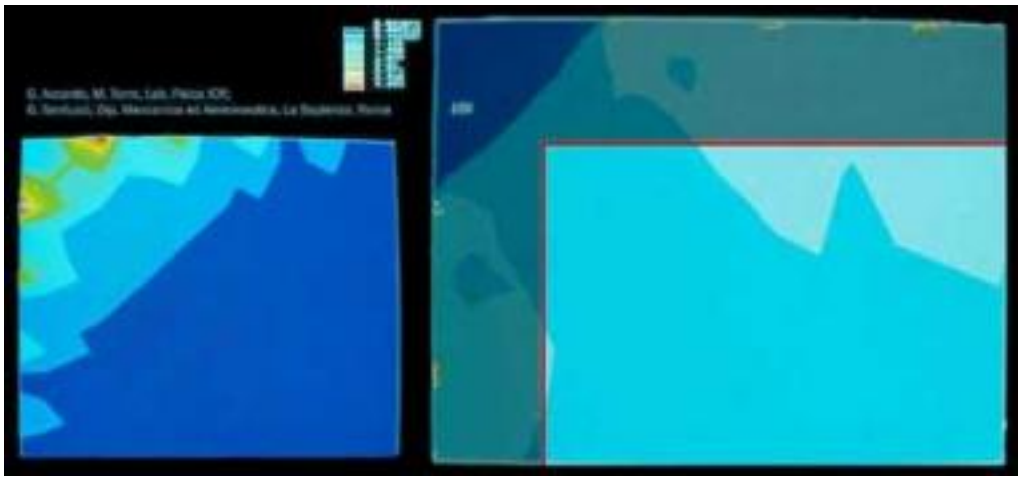
Photo credit - Dorothy Mahon

9 Separation between tension and support within a stretcher allows to obtain much better performances. This has been done for the first time in the stretchers developed at the Istituto Centrale per il Restauro (ICR) by R. Carità in the 1950s [13], letting the lining canvas slide on a smooth and rounded stretcher profile, and tensioning it with springs placed on the rear (Ill. 3).

Fig. 3 The stretcher developed by Roberto Carità at the Istituto Centrale per il Restauro, published in 1954.

10 The painting is as suspended within an in-plane elastic perimeter, pulling outwards simultaneously in all directions. A few decades later, it was demonstrated that this tensioning method allowed toh ave an even distribution of tensions within the painting and to avoid stress concentrations in the corner [2] (Ill. 4).

Fig. 4 The Finite Element System



The Finite Element System analysis of tensions within a painting mounted with a corner expansion stretcher (left) and a painting on Carità's stretcher (right), where the lining canvas turned on the back of the stretcher is outside the red line.
photo – credit Mauro Torre, ICR Roma

11 As springs are placed all along the perimeter and not exclusively in the corners, it is possible to apply tension evenly on the canvas. Since the stretcher is not weakened in the corners by the insertion of keys, it can be made lighter and thinner. What is also interesting, the application of this method has permitted the re-use of original stretchers as the supporting structure for a new elastic tensioning system [20; 29].

The possibility of measuring tension

12 Measuring the elastic constant of the springs used with this kind of stretchers allows to calculate the value of the tension acting on the painting, through the ratio that exists between force and elongation in the spring: $F=k\Delta l$[1]. As early as 1955, R. Carità stated the tension value

he had chosen for a painting mounted with this method [12], nevertheless, tension values were never again declared until 1990 when the ICR [1] worked once again on the stretcher Carità had built for the S. Jerome of Caravaggio [13]. Gustav Berger had faced the problem in the same years [5] with a prototype of elastic stretcher, and gave some preliminary indications about the range of tensions he thought reasonable to work on. A few years later Alain Roche stated that a correct value of tension for an average unlined canvas painting would range between 1 and 2 Newtons/cm [31;32]. Still, there was too little for autonomous decisions.

The choice of tension: a story for a dilemma

13 During a traditional conservation process, after lining the conservator mounts the painting on a new key-stretcher with a tension that makes it "sound like a drum", in both paste and wax lining traditions. This is mainly because the new support is much more rigid and able to withstand strong tensions. Another good reason for doing so is that stress concentrations and creep due to tension and environmental changes lead to a progressive reduction of tension that will eventually show up as planar distortions of the painting that may not be appreciated by the owner: exceeding tension will postpone the appearance of distortions in time.

14 As a matter of fact, the evolution of consolidation and lining methods since the early 1970's lead to use lower tension values, as treatments became progressively oriented to the conservation of the characteristics of the original structures. This process has been described in two review papers, one written by B. W. Keyser [23] and another by P. Ackroyd [3], which outline the main points of discontinuity in the tradition.

15 Not only did the new attitudes in structural conservation reduce the need for high tension values, but even made them dangerous for paintings that had been treated with non traditional methods. This has led conservators to reconsider the traditional tendency to chose high tension values, particularly when dealing with unlined contemporary art. Furthermore, awareness of the tension-related origin of cracks [22; 32] and support deformations is becoming more and more widespread.

16 When the St. Jerome by Caravaggio was restored in 1990 at the ICR, it had already been mounted on an elastic stretcher by R. Carità in 1957 [13] and the presence of springs made it necessary to choose a definite value of tension for the painting[2].

17 The conservator that was responsible for the lining[3] was asked to select the tension value by adjusting the springs' elongation. In a first phase, he chose an unevenly distributed tension that was measured as considerably higher in the corner areas. The average value (4 N/cm) was then applied to all the perimeter evening out the forces produced by the springs. He considered this value too low, and decided that a correct value with an even distribution could be that of 6 N/cm. The average elastic constant of the springs was 2,6 N/mm.

18 One year later, I faced the same problem for a painting of similar dimensions and structure[4] I had mounted on the original stretcher using an elastic structure based on the same principle [20], and was challenged by the need of choosing a value of tension.

19 The "dilemma" was in the need of reading with a critical eye and an actualised perspective my teachers' work on the tensioning system of the St. Jerome by Caravaggio (I was still a student at the ICR), in a field where there seemed to be still insufficient data for a real debate.

20 First of all, I made up my mind for the choice of the springs, which I wanted to be as soft as possible in order to produce small changes in tension with the dimensional changes imposed by the painting in an uncontrolled environment. The average elastic constant was of 1,1 N/mm.

21 Then I found data in literature that allowed me to support the idea that the drum-like sound was not necessary after all, especially with an elastic tension obtained with soft springs. Gerry Hedley [19] found that his naturally aged samples of paintings equilibrated after 50-90 hrs at tensions that ranged between 1,2 and 2,7 N/cm. Gustav Berger and William Russell [5] had found that the maximum force that an heavy canvas without preparation was able to maintain

over time (resistance to creep) was around 1,75 N/cm. In this case, my own experience and that of a group of colleagues that supported me in the decision[5], guided me to the choice of a value of 2,6 N/cm.

Obtaining the correct value of elastic tension

22 The research I have undertaken at the Laboratorio di Restauro della Provincia di Viterbo [10] in 2001 has suggested a few elements that may have some relevance to the furthering of this line of thought[6].

23 The main goal was that of obtaining reproducible data about the process of "checking the value of tension" that a conservator uses at the end of the mounting on stretcher.

24 We worked on 7 paintings, mounted on their original stretchers modified with springs that had a low elastic constant and a long initial size (different solutions inspired to the same method as in [20]). The objective was to end up on a value based on new parameters, that were not determined by the "traditional approach," which in any case was no longer consistent with the new mounting conditions. The parameters were to be based instead on reliable and reproducible data.

25 To start with, we chose and measured a tension that was considered safe for the paintings.

26 The RH-related dimensional variations of the paintings were measured in a climatic chamber along with the total force acting in the system.

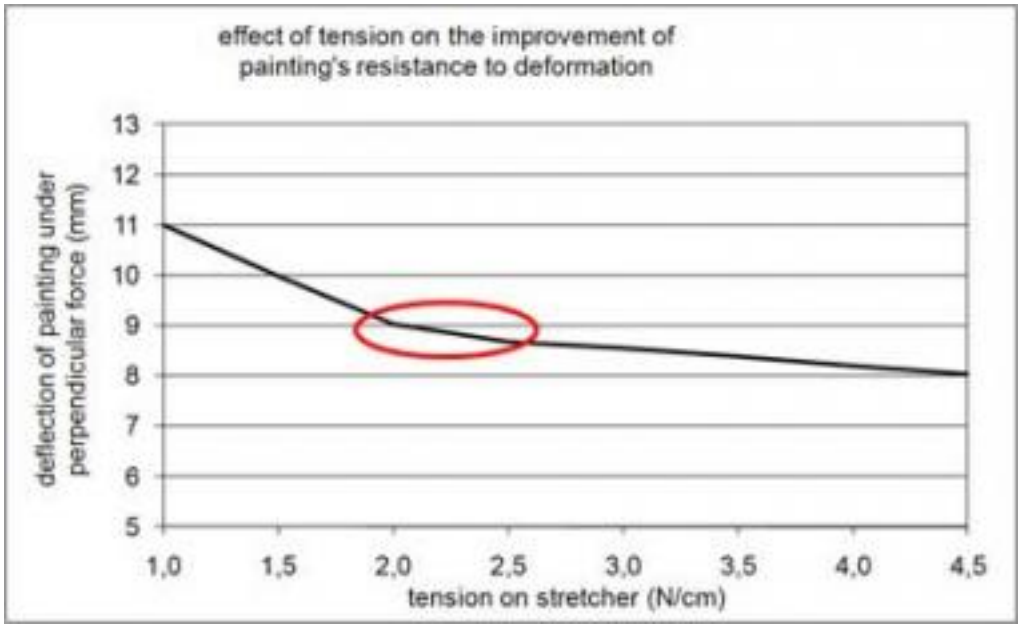
27 The following step was to measure the behaviour of the painting when the conservator applies a force on the canvas for testing its tension level. This had to be put in relation to the values of tension and RH, and was done in the environmental chamber[7] [11] by measuring canvas displacement when an orthogonal force was applied to the centre of the painting (in order to simulate the conservator's hand). The working group selected values that ranged around 2 Newtons/cm (approx. 198 grams of force for each cm of perimeter) for the 7 paintings, through accumulation of experience with the new tensioning method and keeping in mind that the chosen tension would not decrease in time.

28 At this point, some fruitful collaborations began: with the ICR, which was able to provide the expertise of Mauro Torre, Giorgio Accardo, Maria Enrica Giralico and Carla Zaccheo, along with some electronic equipment; and with Carlo Serino, that eventually led to establishing the firm Equilibrarte.

29 The new group of conservators[8] gave an experience-based anonymous evaluation of the tension of 5 more paintings, that had been exhibited in the museum of Viterbo for a few decades on their traditional stretchers, in order to start working on paintings that were not undergoing a conservation process. By means of an indirect method based on the same principle used so far (the relation between perpendicular force and displacement of the canvas) for three of them we were able to measure the tension they had on stretcher. Tensions had previously been judged as "correct" for two of them and slightly excessive for the third: measured values were 1,5 N/cm and 2,6 N/cm for the first two, and 3,4 N/cm for the last. This confirmed that a correct equilibrium tension (after decades of environmental stresses) is similar to that chosen for the paintings we had mounted on their elastic stretchers with a tension that was considered as a stable value.

30 During the elaboration of the large amount of data that was gathered during the testing, one more relevant information showed up: it was possible to determine a threshold value in the tension on stretcher, beyond which there is no significant improvement in the resistance to deformation (Ill. 5).

Fig. 5 Increasing tension



Increasing tension on stretcher reduces the effect of a force that acts perpendicularly on the canvas, like the testing hand of a conservator. But, after a point that can be defined as "Maximum Useful Tension" this effect is so much reduced that one may wonder why to apply more tension to the painting.

31 This threshold value appeared to be between 2 and 2,5 N/cm for five paintings, regardless of their dimensions and weights.

A survey of the tension chosen by some Italian conservators

32 This data has been confirmed by 106 conservators from all over Italy who ended up choosing similar values during a survey we are carrying out with Carlo Serino[9]. Conservators are asked to stretch the same sample painting (80 x 80 cm) mounted on a stretcher equipped with strain gauges that can record the precise value of the chosen force. These range between 0,68 and 6,8 N/cm but after the elimination of the extremes, the average value, representing 75% of the group is of 1,8 N/cm. Interestingly, the conservators that deal with contemporary art choose lower values while a few more tradition-bound conservators chose significantly higher values.

Limits in mechanical research on tension for naturally aged paintings

33 As can be clearly observed, even though it was meant to overtake the burden of tradition, the research so far described is based on a mainly empirical and experience-based approach. The aim was that of working on the tension of real paintings, defining a value that would not be dangerous for them and still match the practical and aesthetical needs of conservators. So far, this seems to be the only way for producing useful answers to operational questions.

34 In theory, a correct approach to the determination of the ideal elastic tension for a painting would be that of obtaining a balance of the forces expressed within the painting with springs that are able to produce an equivalent response, in order to maintain a constant stress value. That is because if the stress is constant there is virtually no materials' fatigue.

35 Mechanical characterisation of the constituent materials of an actual painting can only be determined with a wide approximation because of their intrinsically discontinuous nature, resulting from both their use by the artists and the conservation history of each painting.

36 Test samples made from the same materials found in paintings seem to be the only alternative to submitting the actual painting to dangerous mechanical tests. But still, homogeneous and

not aged samples cannot be representative of the variability and the condition of the actual painting. Moreover, we are all aware of the unreliability of most artificial ageing procedures for mechanical testing.

37 It would be rather unsafe to simply rely on the data obtained with samples, as it would be impossible to detect all the weak points of the painting and the discontinuities of its ancient structure. Reducing this force to a "safe" level with an arbitrary decision would imply a level of approximation that could not be backed up scientifically. An intermediate approach may be that of testing samples of naturally aged paintings for their mechanical behaviour, and obtain from that reference data for the choice of springs.

Operational choices

38 The guiding criterion of my work and that of Carlo Serino (in Equilibrarte s.r.l.) is that of using an initial tension that will not become excessive at any environmental value, and keeping it as constant as possible by using springs with low elastic constant.

39 The uniformity of the distribution of tensions allows to apply tension values that in some cases may appear surprisingly low if compared to the traditional ones. A clarifying example is the "Assunta" by Domenico Morelli in the ceiling of the Chapel of the Royal Palace in Naples. This unlined canvas painting that measures 10 by 7 metres required only 2,2 N/cm of tension, and would not show relevant gravity-bound deformations in the central area.

40 We apply this method every year on a good number of paintings[10], very variable in dimensions and constitution. Decisions are often shared with colleagues that have commissioned our work on tension, and we are building up a data base.

The use of tension in antiquity and pre-industrial tradition.

41 Painting on canvas is a very old technique. Pliny writes of Apelles' canvases (4th cent. B. C.) and of a portrait of Emperor Nero measuring 120 feet, a size that was "unconceivable for the time" [28], that was presumably located outdoors, as it is said to have been destroyed by lightning. Its upper margin can be assumed to have been fixed to a support while the rest of the painting was left hanging, as was the case for the painted cloths documented in the Netherlands in the 14th and 15th centuries [27]. Its dimensions imply that it would have been solicited considerably by the wind, hence, it probably resembled a sail hanging more or less freely from a yard, and not so much a painting nailed on a stretcher. Fayum funerary canvas paintings [15; 38] were either held in place by the bandages or used for commemoration and buried along with the mummy.

42 The surviving processional banners of the Italian Renaissance often show a faithful adherence to Cennino's earlier technical prescriptions: a thin and tightly woven canvas covered by a thin gesso ground. These seem to be good examples of the first surviving canvas paintings of our era and some of them were also used as altarpieces, stretched on some kind of simple structure [7; 8]. In this case, the precise aim of tensioning seems to have been that of avoiding folds that could have disturbed a correct reading of the image.

43 Even though very few have survived, Renaissance distemper canvas paintings were extremely common [4; 16], as shown by the inventories of the Medici family at the end of the 15th century, where they are described as mounted on stretchers, on panels or as free hanging canvases [27]. Among the most ancient canvas painting in Italy is the paliotto with scenes from the life of Christ by Guido da Siena (1270-1280). It is painted on a very thin canvas[11] using a technique that recalls Cennino's prescriptions and Andrea Mantegna's works.

44 In the "Presentation at the Temple" by Mantegna the canvas is nailed on the front of a stretcher and the tacking margin is covered by the frame, also nailed through the front [26]. The stretcher, as in a category of paintings that have sporadically survived up to day with their original supports [24; 30; 36], is "engaged" with wooden planks and behaves like a stabilized panel, as the planks can move within the stretcher frame.

45 The presence of the wooden panel protects against mechanical shocks and dust accumulation in the fibres of the canvas. It also helps to stabilize the thermo-hygrometric values, given the presence of this considerable mass of hygroscopic material in an environment which is almost enclosed.

46 This mounting method does not allow for any corrections to the initial tension because of the reduced access to the tacking margin. In any case, it could not have been that strong to begin with. The painting was then subjected to a light tension, probably comparable to that given by its own weight.

47 Cennino [14] and Vasari [36] recommend using canvas as a support for painting when lightness and flexibility are needed, particularly when one needs to roll up the painting for transportation purposes. Another good reason for choosing canvas was economic: its price was considerably lower than that of wooden panels for painting [6].

48 During the 16th and 17th centuries thicker and rougher canvases were being used, especially for larger paintings with oil-based preparatory layers. In this case, the weight and thickness of the paint layers increased considerably and gained a more relevant mechanical role within the paintings' structure, also because the canvas weave was often more open. Flexible structures that could be rolled up were still desirable, but now flexibility was obtained through the adding of oil in the preparatory layers and thus making the more flexible and elastic than to the previous thin gesso grounds.

49 Even in presence of such dramatic transformations in painting techniques, painters did not need to modify the stretcher's structure. Wooden supporting panels were still used, but less so for the larger paintings, even though El Greco used them for a great number of his works, including the bigger ones like "El enterro del Conte de Orgaz" in Toledo [7].

50 Until the middle of the 18th century stretchers were extremely simple structures, as witnessed by the definition we find in the Encyclopédie: « L'on appelle encore châssis, les morceaux de bois sur lesquels l'on tend de la toile pour peindre. On en fait de toutes sortes de formes » (One calls stretcher the pieces of wood on which the canvas is stretched for painting. These are made in all sorts of shapes) [17].

Developments due to lining, consolidation treatments and corner expansion stretchers.

51 Within this historical overview, we find that the appearance of consolidation and lining treatments changed the mechanical behaviour of canvas paintings and made them more rigid and less suitable for rolling up.

52 This had already become rather common around 1754, when A. J. Pernety [26] mentioned key-expandable stretchers as a new invention. Since then, corner expansion methods have become commonplace.

53 Linings became more and more rigid[12] and techniques like marouflage, the wax-resin method and the use of double or triple lining canvases were introduced. All these treatments made the paintings heavier and able to sustain much stronger tensions. As lining includes flattening in order to correct permanent deformations, it became necessary to guarantee paintings' planarity after treatment. This concern dates back to the mid-18th century [9]. Increasingly stronger tensions became usual, in order to efficiently stretch canvases that were becoming more rigid and heavy. Once it had been stretched, the drum-like sound of the painting meant that it had reached a new level of stiffness (such as it had never had before). The progressive decrease in tension is due to repeated environmental stresses, that cause the insurgence of forces that exceed the yielding point of the canvas, particularly in the corner areas [25;2]. When such stresses are repeated over time, this leads to re-stretching the canvas by expanding the corners of the stretcher over and over again: a "stretching cycle" which usually results in the permanent progressive increase of the painting's dimensions.

54 The effects of these cycles were noticed very soon after the invention of key-expandable stretchers, and as early as the second half of the 19th century, some had the idea of placing springs in the corners of the stretcher to automatically correct this process (as in the Wright and Gardner patent).

55 Nevertheless the system did present some problems when dealing with unlined canvases, as the springs needed to be very strong and rigid in order to effectively expand the stretcher in the presence of high levels of friction. Quite simply, if the painting was not able to withstand this force, or if it produced a stronger force upon contraction, it would incur damage. In some cases, as we have already seen in fig.2, this may lead to crack formation and eventually tears in the canvas.

56 After Wright and Gardner, numerous other elastic stretchers based on corner expansion were patented. Some were more effective than others since they used softer springs (as the Giorgio Staro patent) or because, in the large formats, used a flexible perimeter that played its part in the tensioning system because springs were loaded also in the crossbars (as the Giorgio Rigamonti's stretcher).

Conclusion

57 The use of high tensions on stretchers is typical of the “Age of lining”, when canvas paintings became very strong and rigid. We are now heading back to a time when the canvas support is flexible and needs a careful handling, and therefore attitude is changing in stretching practice.

58 It is now possible to measure the value of tension chosen for a painting, thus it has become possible to compare individual choices and results over time.

59 There may be now enough data for starting a new level of confrontation between professionals involved in the decision.

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Notes

1 Hook's law of elasticity.

2 Even though they would have considered more appropriate to work on the elastic modulus of the painting in order to choose the correct value of tension [1], the short time available and the need of reaching a consensus among the members of the working group oriented the choice on a completely tradition-based approach.

3 Giorgio Fioretti, a liner that worked at ICR for a few decades, now retired.

4 I had lined the painting with the same paste-glue procedure, the painting dates to the early 17 c. and has similar characteristics and sizes.

5 In particular Lola Porro Caballero, with whom I shared the conservation of the painting.

6 I thank Alain Roche, who has supported generously my effort in that period.

7 It is possible to build a low precision but reliable environmental chamber with a small budget. In this case we used ultrasonic humidifiers, a dehumidifier, a heater, an air conditioner and a couple of fans. For technical improvements see [11].

8 Linda Bernini, Giorgio Capriotti, Ottavio Di Rita, Maria Enrica Giralico, Antonio Iaccarino Idelson, Geltrude Missori, Carlo Serino, Carla Zaccheo.

9 With the participation of Giorgio Capriotti and Mauro Torre. This work will soon be published.

10 From the establishing of the firm in 2002, we have tensioned some 250 paintings.

11 The painting has a 20th century lining that apparently over-lines a previous ancient one. Preparation and paint layers are extremely thin and canvas very thightly woven. Approximately 180 per 80 cm, it is in very good state of conservation. I thank Marco Ciatti for letting me observe the painting, which is currently undergoing restoration treatment at the Opificio delle Pietre Dure in Florence.

12 With the exception of those made with sturgeon glue and honey in the Russian tradition, very often thin and flexible.

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Abstract / Résumé

The choice of the value of tension for a canvas painting is crucial for its future life, but tradition has handed us methods based on intuition that do not allow us comparing the results of different choices. Since the 1950es it is possible to measure the force used for stretching a painting, but

this is very rarely done. This paper describes the evolution of the approach to the problem and points out the results of recent research and changes in attitude.
Keywords : stretcher, tension, stress, elasticity, canvas painting

Le choix de la valeur de tension pour une peinture sur toile est crucial pour sa future conservation, mais la tradition nous a transmis des méthodes fondées sur l'intuition qui ne nous permettent pas de comparer les effets des différents choix. Depuis les années 1950 il est possible de mesurer la force de tension choisie pour une peinture, mais ce la est fait très rarement. Cet article décrit l'évolution de l'approche à ce problème et souligne les résultats de récents recherches et changements d'attitude.
Mots clés : tension, contrainte, élasticité, châssis, peinture sur toile