New Insights into the Conservation of Brass Instruments: Brass Instruments between Preventive Conservation and Use in Historically Informed Performance

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Introduction

Brass instruments have a relatively short lifespan, mainly due to corrosion. While modern instruments can be replaced when they are corroded, this is not the case with historical instruments. Those played by musicians in a context of historical performance practice may thus enjoy just a brief second life of musical use, while the instruments held in most collections and museums remain unplayed. Because they are part of our cultural heritage, they must be preserved in the best possible way. Playing them activates corrosion and is, in consequence, not intended in most collections. But playing them occasionally can provide us with more information on both the instrument and its musical background. This experience could in turn be used to produce replicas and to inform all other aspects of historically informed performance practice. Thus arises the fundamental dilemma of historical instruments: "to play versus display."[1]

Little is known about corrosion inside a brass instrument—a system of tubes of between one and ten meters in length.[2] As long as the inside remains unknown, every time an instrument is played this leads to an uncontrolled situation. And that is irresponsible. We need to carry out research into the insides of the tubes and into interior corrosion phenomena. This is a new field that embraces all aspects of the interiors of brass instruments. Why and how do brass instruments corrode on the inside? What are their corrosion phenomena and how do they affect the instrument? Can we protect the inside of brass instruments? Are there concepts for preventive conservation for the inside of brass instruments and, if so, can these be optimized?

Such questions have long been asked by musicians involved in historical performance practice. The authors therefore embarked on a multidisciplinary collaboration among leading Swiss research institutions, including natural scientists, musicians, conservators,

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and historians. Our goal was to be able to look beyond the dilemma of "play versus display" and find a third way of dealing with historical brass instruments, especially those in use by musicians. Our team aimed to acquire a better understanding of interior corrosion and determine measures to improve the preservation of brass instruments, both historical and modern. After engaging in initial studies of preventive conservation and materials, a long-term study of fourteen months was established in order to test a new, simple, preventive conservation treatment. For this, we used techniques such as electrochemistry, surface analysis, tomography, and endoscopy. At the close of the project, a sample set of twenty-one period brass instruments was assembled for a performance of Igor Stravinsky's *Le Sacre du printemps*; all these instruments were treated according to our tried and tested protocol of preventive conservation.

The present article reports on the procedures and results of all the different elements of the research project. We begin with the instruments used a hundred years ago in Stravinsky's *Sacre*: a set of playing instruments in the hands of historically informed performers (such instruments are still available on the historical instrument market). We continue with a discussion of preventive conservation, in which we investigate preventive measures inside the tubes and monitor their efficacy; then we close by offering a new concept of how to deal with historical brass instruments. For full details, see the specialized articles in the proceedings of the Symposium held in February 2017 in Bern.[3]

History: A brass section in Paris, a hundred years ago

For its musical reference point, the project decided to focus on the famous world première of Igor Stravinsky's *Sacre du printemps* by the Ballets Russes at the Théâtre des Champs-Elysées in Paris on 29 May 1913. It was scored for a large brass section, namely eight horn players (two of them temporarily switching to Wagner tubas), five trumpets (one playing an "alto" trumpet in D and one switching to a *trompette basse en mi♭*), three trombones, and two tubas. Few works have had a greater impact on music history and remain in our minds in such a legendary manner as this premiere by the famed company of the Ballets Russes. The riot at the performance has often been described—with Stravinsky's boisterous music conducted by Pierre Monteux, a choreography by Vaclav Nijinsky that was far removed from classical ballet, a primitive scenario and naïve stage sets by Nicholas Roerich, and last but not least, the impresario Sergei Diaghilev holding the threads in his hands.[4] However, aside from all the more or less credible reports of the riot, the actual orchestra in the pit was to some extent overlooked by most commentators. It has even been claimed that the orchestra for the performance was brought in from Russia. That was true for earlier productions of the Ballets Russes, but was no longer the case in 1913.

In fact, the ballet was accompanied by the expanded orchestra of the newly inaugurated Théâtre des Champs-Elysées, called the Société des nouveaux concerts. Admittedly, the printed program for the evening does not mention the name of the orchestra or the names of its members. But these are indeed listed on other programs of the same season. And further confirmation is offered by the business card of bassoon player Abdon Laus, held in the Stravinsky Collection of the Paul Sacher Foundation in Basel, with a handwritten addition to it: "Basson qui joua aux Champs Elysées à Paris pour la 1ère fois le Sacre en 1913" ("Bassoon that played at the [Théâtre des] Champs-Elysées in Paris for the first performance of Le Sacre in 1913").[5] Furthermore, "a small black composition tablet … was found in a closet beneath a pile of early financial records of the theatre" in the late 1960s, and this gives us many of the names of the brass section for the first performance of *Le Sacre*.[6] If we compare these names with the lists of the Paris Conservatoire, we can see that most of the players were rather young and had finished their studies only within a few years before or after 1913. Only the tuba section (all two of them) was devoid of any Conservatoire alumni—but this is no surprise, as there was no tuba class at the Conservatoire, and so they had probably trained in military bands. At least one of them, Eugène-René Vieulou, had a successful career as a conductor and tuba player with the Musique de la Garde Républicaine and later in the Orchestre Symphonique de Paris.

Learning about the musicians led us to our next question, which is even more relevant for the project under discussion: What instruments did these musicians play? Generally, one can say that the French market for musical instruments at this time was rather closed, so it is quite likely that these young musicians used state-of-the-art French instruments. But what type of instruments exactly? The upper horn parts might have been played on instruments with the French system of ascending valves. But did the horn players doubling the tenor tubas play these parts on saxhorns, cornophones, or really on German Wagner tubas? Did Stravinsky have slide or valve trombones in mind (the latter replacing the former in opera pits as late as 1913)? Was the D-alto trumpet a Russian model (as letters by Stravinsky seem to suggest), or a French instrument? Or—given that a wide range of tubas exists in different sizes (sometimes listed as saxhorns)—what bass and contrabass instruments did they use? In C or B♭, with three, four, or even six valves? While tubas in B♭ with three valves were regularly used in wind bands, the tuba in C with four or six valves was more common in orchestras.[7] As the tuba parts range from low *EE♭* to *g♭* (the first part begins at *AA*), the six-valve tuba—a French specialty—seems the best option for *Le Sacre*. It is relatively small, more the size of a euphonium today, and this means its sound blends somewhat better with the rest of the orchestra than does the giant contrabass tuba, though it is still perfectly capable of providing the entire range needed for the part. Once we have decided on which instruments were most probably used in 1913, we can proceed to the next step of our project.

Preventive conservation

Preventive conservation aims to avoid or, at least reduce, all risks incurred during the use and storage of cultural property items in order to ensure their long-term survival. Besides the risk of damage during the handling and transport of historical wind instruments, playing them also creates corrosion, not to mention wear and tear. In consequence, most museums and collections do not allow their wind instruments to be played.

The main focus in the present research project was on the internal corrosion that is related to high interior humidity during and after playing.[8] Tests showed that the climatic effects caused by playing are comparable for all instrument types examined. Within the first few minutes of playing, the levels within the instruments rise to over 90% relative humidity (RH). The air inside is saturated with moisture and condenses on the inside walls, forming droplets and local patches of water. The result is that the relative humidity values remain exceedingly high for several days.[9] Even when all slides are emptied after use and left out to dry (a common practice among musicians), the relative humidity within the instrument does not go below 70% RH within the first 24 hours, nor below 60% within twenty days (see Figure 1). An instrument that is played every day thus stays wet inside all the time. And for an instrument that is rarely played, a short period of playing results in long-term humidity on its interior surfaces.[10]

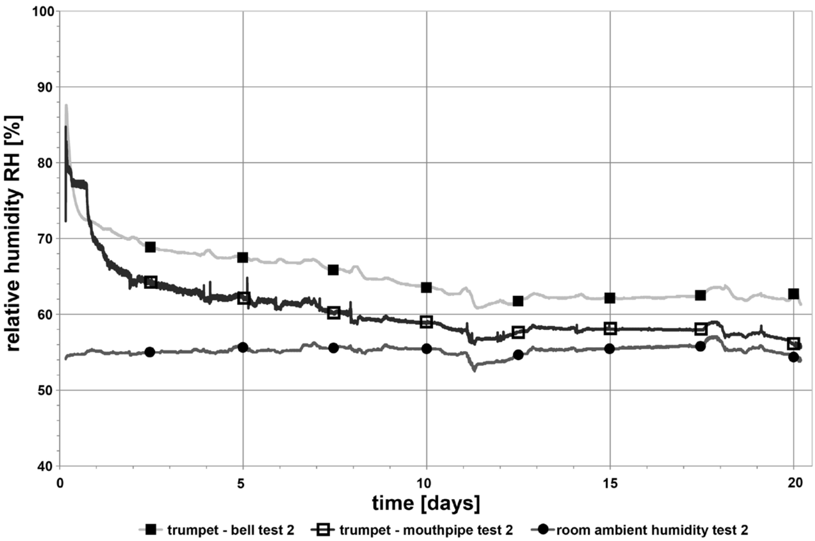

Figure 1: Typical changes to relative humidity (RH) within a brass instrument over a period of twenty days. After being played for five minutes only, the inside of a brass instrument stays wet for many days, regardless of its size.

The high humidity, far above the values measured for the ambient air, suggests that there is a high probability of corrosion occurring in the instruments. This fact led to the hypothesis that reducing the period of wetness after playing will substantially reduce the risk of further corrosion. From a conservation perspective, rapidly drying the instruments after use to avoid corrosion damage thus has the highest priority. To this end, the use of moisture absorbers or solvents or heated and compressed air might be considered. But these measures were deemed inappropriate outside a museum context, since they could not be applied by musicians every time after they have played their instruments. Actively drying the instrument with the help of fans, however, meets all our requirements. It is easy to do and poses no risks either to the instrument or the musician. We therefore carried out experimental tests. After playing, the tuning slides and valve slides were emptied and then reinserted; the valves were fixed in a position in which all tubes were open (the trombone slides at the seventh position), and a fan positioned at the bell or mouthpiece end of the instrument. Crooks were dried separately. The results show that the continuous stream of air completely dries an instrument within three hours at most. The values matched that of the ambient climate (see Figure 2).

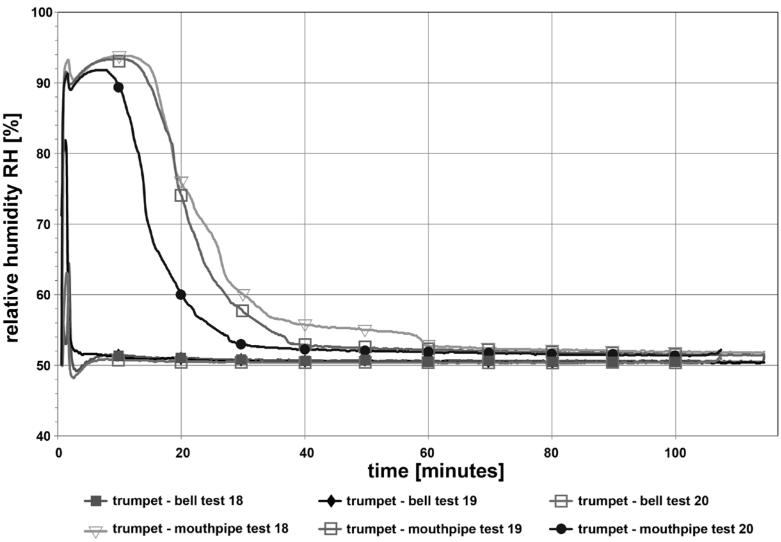

Figure 2: With the help of a fan, humidity inside the tubes is reduced to ambient values in one to three hours' time. Valves have to be fixed in an open position for drying as do the valve slides.

Long-term survey

The preventive conservation protocol was evaluated during a fourteen-month study of sixteen instruments[11] (five trumpets, eight horns, one trombone, one Wagner tuba, one tuba). These were divided into two groups. In the first group, the musicians treated the instruments according to our newly developed preventive conservation protocol, which relies primarily on actively drying an instrument with a fan after each time it is played.

The second group served as a control group. The musicians treated these instruments in the usual way—in other words, all slides were merely emptied after use. In order to prevent overall damage, all the players were instructed on preventive conservation treatment. They had to wear gloves, and any oil or grease used on the instrument had to be deemed safe in terms of conservation.[12]

The musicians of both groups were asked to play their instruments for at least five minutes a day over a period of fourteen months. In order to correlate any changes found in the instruments, the musicians were also asked to keep a diary specifying how long they played their instrument each day. On average, the instruments were played 275 times for 6.2 minutes, resulting in a total average playing time of 28.3 hours. Three testing methods were applied to ascertain whether the instruments had undergone any changes and to assess the effectiveness of the preventive conservation measures: electrochemistry, neutron tomography, and endoscopy. This was done before the start of the long-term study, after seven months, and at the end of its fourteen-month period. For practical reasons, all the investigations were carried out on just thirty tuning, valve, or trombone slides taken from the sixteen instruments.

Electrochemistry and surface analysis

As described above, a thin film of water remains for several days on the inside surface of instruments that are regularly played, governing the intensity of corrosion.[13] As corrosion is an electrochemical process,[14] electrochemical techniques were our methods of choice to monitor it. An initial but merely qualitative indication of corrosion can be based on the open circuit potential (OCP) or corrosion potential that can be measured between any metal or alloy in a given environment and a reference electrode (see Figure 3). More quantitative information can be obtained from the polarization resistance (Rp) that can be measured in any system alloy/environment by potentiodynamic polarization in a narrow range around the corrosion potential. A small Rp value indicates a high corrosion rate, a high Rp value indicates a low corrosion rate.

For this reason, an electrochemical sensor was developed that could take rapid, non-destructive measurements of the polarization resistance inside the instruments. This sensor consists of a tubular tool mounted on a thin plastic tube that allows it to be inserted into the tubes of instruments, and a balloon whose expansion/contraction enables it to contact the brass surface.[15] The sensor was initially tested on two model brass alloys (CuZn18 and CuZn37) with different surface states. In order not to alter the surface being tested, a non-aggressive phosphate buffer solution (pH 7) with a small amount of NaCl was used. The results were comparable to measurements in a traditional electrochemical cell.[16]

The results of the Rp measurements of an initial test series (nine tuning slides or valve slides from four instruments) showed a great variation within individual slides and—even more so—among different slides. Overall, we observed no influence on the part of the alloy composition or of any prior cleaning procedure. Thus the po-

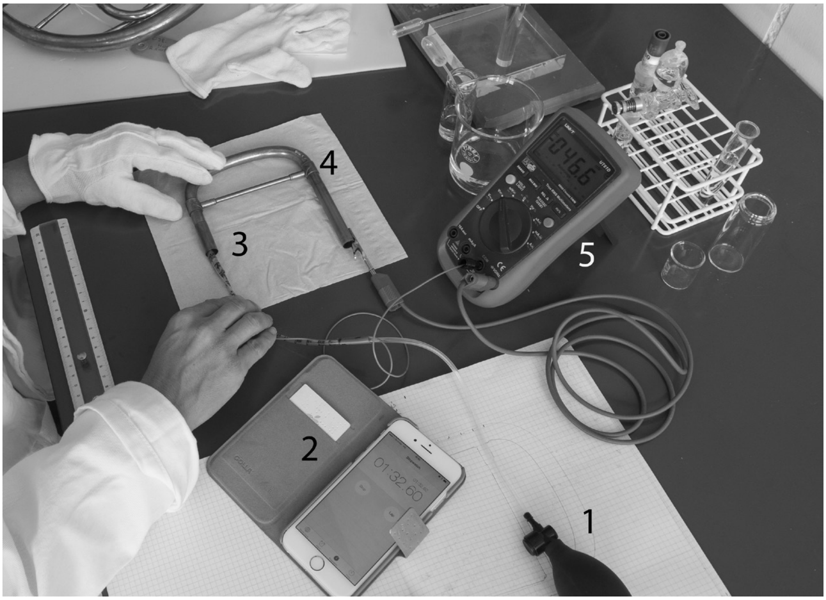

Figure 3: Experimental arrangement for the in-situ measurements of corrosion potential. 1: hand pump; 2: chronometer to record values at precise times; 3: PVC tube in which the sensor and a reference electrode were mounted; 4: tuning slide used as a working electrode; 5: voltmeter to measure potential values.

larization resistance allowed us to determine the instantaneous corrosion rate at the point of measurement. However, it is not possible to ascertain any precise indication of the corrosion state (i.e., reasons why the Rp might be higher or lower). To assess this, we also conducted controlled laboratory experiments using X-ray photoelectron spectroscopy (XPS) surface analysis in parallel with the Rp measurements.[17] Samples from old instruments with a thick oxide film showed the highest Rp values (the lowest corrosion rates); by contrast, freshly polished samples showed low Rp values (high corrosion rates). In combination with the results obtained from inside the instruments, we can conclude that the corrosion rate correlates to a high degree with the surface condition of the brass alloys. A mechanistic interpretation based on the effect of surface composition on the rate of oxygen reduction reaction has been proposed.[18]

After these preparatory investigations, measurements were taken inside the tuning slides of all sixteen instruments (at a total of 102 spots). As already mentioned above, these measurements were taken at the start of the study, at seven months, and then at fourteen months when the study concluded. The results of the Rp are presented here as a cumulative probability graph, which is a statistical analysis appropriate for any distributed values.

1. Instruments without preventive conservation (Figure 4a): It can be noted that the average of the polarization resistance is lower after fourteen months of playing (it shifts to the left) as compared to the average Rp beforehand. This indicates that the average corrosion rate measured was approximately a factor of two higher after fourteen months of playing, due to the high humidity remaining inside the instruments. The lines at the three measuring times (0, 7, 14 months) are nearly parallel, indicating that the standard deviation remained the same.

2. Instruments with preventive conservation (Figure 4b): The Rp values remained approximately constant (the curve at fourteen months is identical to the curve before the test). This indicates that the average corrosion rate measured in the tuning slides remained approximately constant over the test period; drying with the fan was thus a preventive conservation measure that worked effectively against the onset of the more rapid corrosion observed in the tubes without preventive conservation (Figure 4a).

In conclusion, after fourteen months of playing, the two groups of instruments (those using the fan, and those not) could clearly be distinguished from each other. Inside the tubes of instruments to which the drying procedure had been applied, the corrosion rate was the same as before the test or had increased only slightly. However, in the tubes of instruments without this preventative procedure, the corrosion rate increased over time by a factor of two on average.

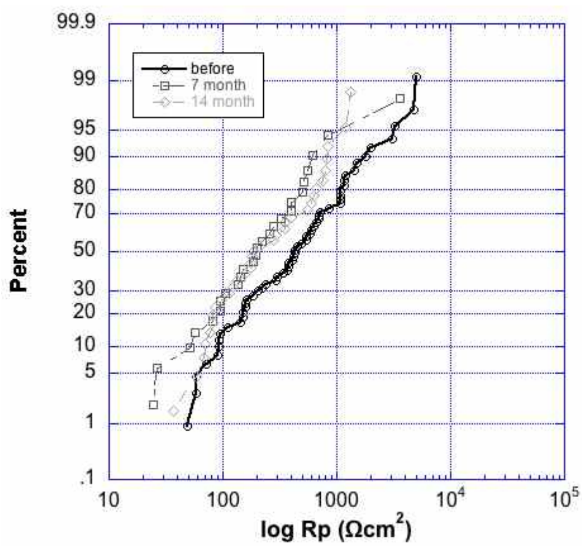

Figure 4a: Statistical analysis (cumulative probability plot) of the polarization resistance Rp, measured in the different tubes of the brass instruments before, after seven months and after fourteen months of playing; without preventive conservation.

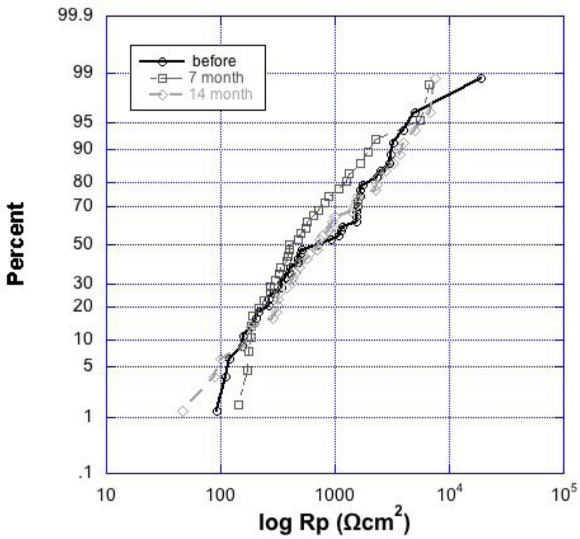

Figure 4b: Statistical analysis (cumulative probability plot) of the polarization resistance Rp, measured in the different tubes of the brass instruments before, after seven months, and after fourteen months.

Neutron tomography

Neutron tomography is a non-destructive testing method that uses principles similar to those of X-ray tomography, providing information on the depth of a 3D object, but with different, partially complementary contrasts.[19] Due to the higher transparency of metals and neutron tomography's high sensitivity for hydrogenous materials, this has proved to be a promising method for investigating brass instruments.[20] We used it to monitor fifteen of the tuning or valve slides at the beginning and the end of the long-term study; the same slides were also examined using endoscopy and electrochemical methods.[21]

We had two different strategies for assessing the changes that occurred during the project. First, the surfaces of the tuning slides were compared for changes or displacements. This type of analysis turned out to be problematic because the surfaces of the tuning slides changed, not only as the result of corrosion, but also as a consequence of normal manipulation by the players. Several slides showed deformation that arose simply from moving them in and out of the instrument. Even though these plastic deformations were in the range of only a few tenths of a millimeter, it was almost impossible to use this approach to detect any changes that were due to corrosion. Another problem is that the items are relatively large, hence the detection size was accordingly rather large, which entailed a rather coarse spatial resolution for such investigations.

This made it difficult to ascertain the growth of a corrosion layer whose thickness could be below the resolution.

Secondly, we examined the gray values—i.e., a numeric value for every point in the 3D-data set, corresponding to the attenuation coefficient and hence the elemental composition. This approach is based on the assumption that corrosion also induces changes in material composition (i.e., including oxygen and hydrogen atoms in the corrosion products and modifications in density). As a consequence, there are changes in the gray values in the reconstructed tomography data. Depending on the change in contrast, it should be possible to observe any changes that occur. The tuning slide cylinders were virtually unrolled so that we could examine any changes in the gray values and thus the attenuation coefficients of the object. This approach proved to be effective in most cases, as can be seen in Figure 5.[22] Hence, neutron imaging allowed us to inspect otherwise inaccessible regions in brass instruments, such as the bends.

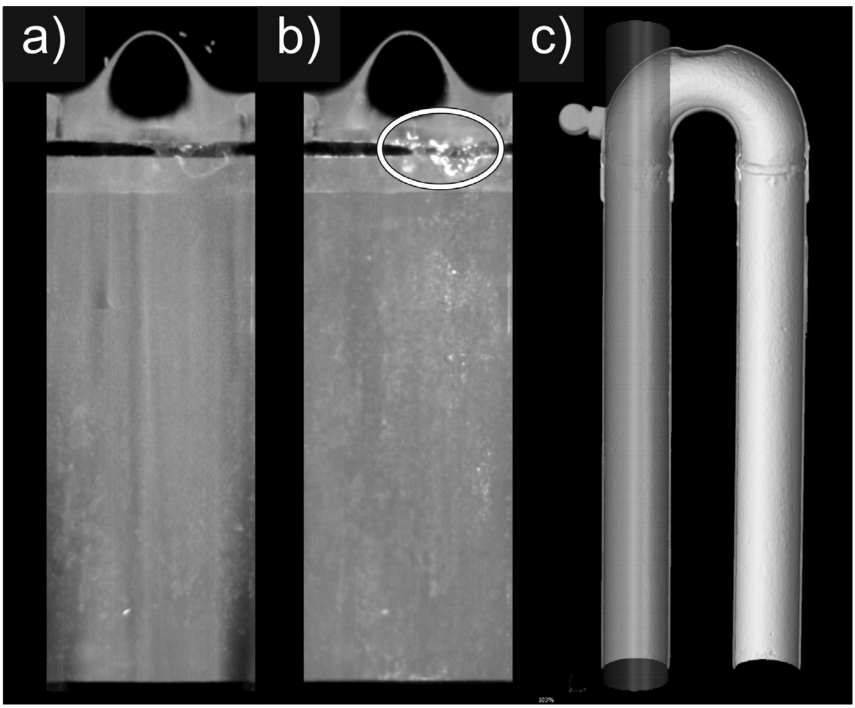

Figure 5: Neutron tomography data: virtually unrolled cylinder of HKB 5024.2 at the beginning (a) and end (b) of the playing period; the oval in b) indicates a region with increased attenuation, probably due to corrosion; c) shows the position of the virtually unrolled region seen in a) and b).
A material analysis would be needed to determine whether the increased attenuation is a product of corrosion or the result of its position on a solder seam.

Endoscopy

Endoscopy is a non-destructive, straightforward optical testing method that permits us to examine inside the instruments. The sixteen brass instruments were inspected using a rigid borescope with a viewing angle of 30° and a depth-of-field of 10–15 mm.[23] To document findings and observations, the borescope was connected to a digital camera. Images were captured in manual mode in order to maintain identical camera settings and to ensure image comparability. During the project it was possible to conduct visual inspections of both openings in thirty tuning and valve slides; sixty areas were thus inspected in all. Images were taken every 5 mm, with the lens always directed towards the outside wall. On average, the length of each inspected section was 83 mm, depending on the length of the straight section accessible to the endoscope.

In order to establish whether changes occurred in the instruments and, if so, to what extent, all sixty areas were inspected before the long-term study, at midterm after seven months, and at its end after fourteen months of playing. This procedure permitted a comparison of identical areas in their initial, intermediate, and final states. At the evaluation stage, some 3,300 images of 1,100 spots were compared visually. Depending on the changes observed, they were classified in three categories: (1) no visible changes in surface texture or appearance; (2) slight visible changes: existing deposits had increased and/or expanded slightly, and random new and localized deposits were visible; (3) significant visible changes: the surface area of existing deposits had increased greatly or a significant change was apparent in them; new deposits were present across wide areas (Figures 6–8 show examples of these three categories).

Endoscopy further confirmed that the initial state inside the tubes varies greatly, depending on the history of each instrument. This result was also detected with the electrochemical sensor. Instruments that had recently been cleaned, for example, showed almost blank inner surfaces with only a thin, homogeneous layer of copper oxide. However, even in their initial states, other instruments presented signs of strong and irregular corrosion. A large variety of deposits and surface textures was observed inside the tubes, even in different sections inside the same tube. This might explain the great variation of the polarization resistance values that we found. As an example, green and white deposits have formed over time across almost the entire surface of some tubes (Figure 7). Green deposits are a clear sign of copper corrosion. A part of the brass, albeit a small amount, has thus been converted from metal into corrosion products during the period of use, leading to a loss of the original substance.

Control of the preventive measures—endoscopy and electrochemistry

Changes inside the tubes due to corrosion during the long-term study were monitored both with the electrochemical technique and with endoscopy. The results are shown in Figure 9; we have separated the instruments that were dried with the fan from those without it. In the group of instruments that were actively dried after use in accordance

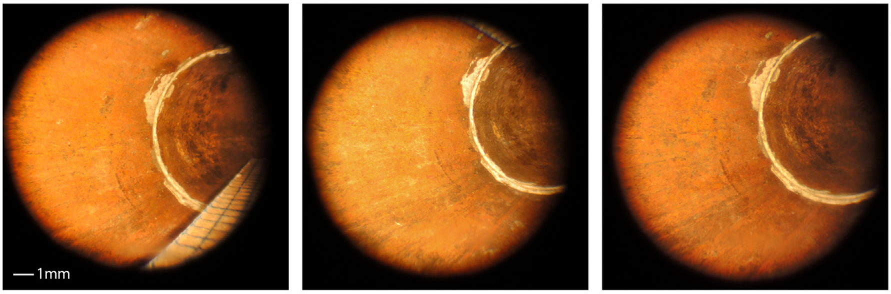

Figure 6: Endoscopic image of the tuning slide of a horn showing no change (from left: initial state; intermediate state after 991 minutes of use; final state after 1,978 minutes of use).

Figure 7: Endoscopic image of the tuning slide of a trumpet in which slight changes have occurred during use (from left to right: initial state; intermediate state after 961 minutes of use; final state after 1,893 minutes of use). Whitish spots have appeared.

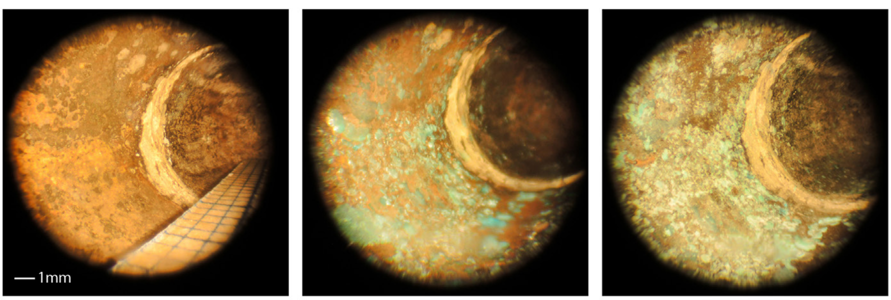

Figure 8: Endoscopic image of the tuning slide of a trumpet with significant changes (from left to right: initial state; intermediate state after 1,054 minutes of use; final state after 2,014 minutes of use). In this example, large-scale deposits attributed to copper corrosion have formed over time.

with the preventive conservation protocol, there was only one instance of significant change in the endoscope test, and only two in the electrochemical tests. Thus 90% of the tuning slides tested showed an endoscope image that had similar or identical Rp values. In the group of instruments that was maintained in accordance with common practice (i.e., not using the fan), endoscopy revealed eleven instances of obvious changes, and the Rp values of eight instances were much lower than before the test.

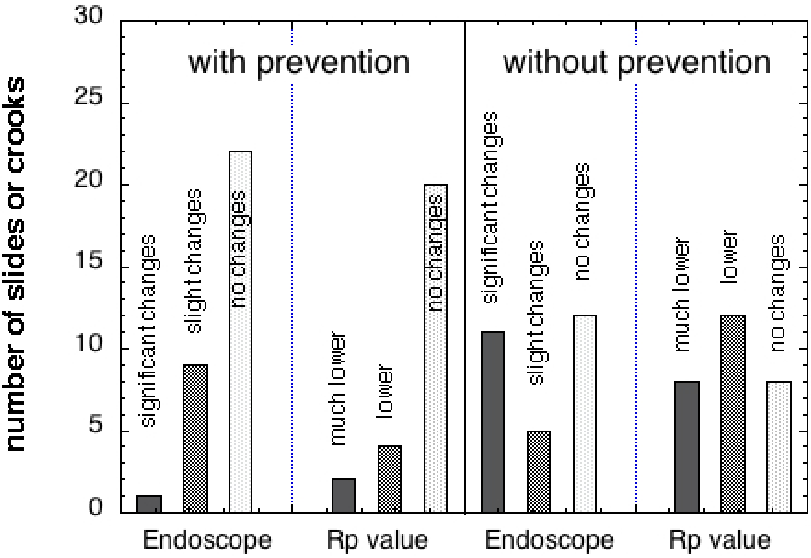

Figure 9: Diagram illustrating the frequency and extent of changes inside the inspected tuning slides as a result of long-term use, as determined by endoscopy (visual examination) and electrochemistry (polarization resistance).

In conclusion, the results of endoscopy and electrochemical tests correlate with each other. Endoscopy is a suitable method for examining the internal areas of brass instruments. As it is a visual method of inspection, findings are directly observable and accessible. Moreover, an endoscopic examination can be reliably repeated, and changes over time can be documented in photographs.[24] The electrochemical tests show that the instantaneous corrosion rate can be determined inside the tuning slides.

Inside regularly played period instruments in the long-term study, corrosion was observed using both techniques in many cases. Only in three instruments were no visual changes observed in any of the tuning slides. In all the other thirteen instruments, slight changes were observed—sometimes even significant changes.

As seen above, the development of corrosion and the intensity of the corrosion rate depend on the initial state of the instrument. Pre-existing corrosion layers seem to have a protective function. Both endoscopy and electrochemistry showed that the instruments using the fan underwent fewer and less intense changes. The investigation furthermore has shown that active drying cannot wholly prevent changes in the interior of period brass instruments that are played regularly outside a museum context. However, the extent of the changes and the increase in the corrosion rate can be significantly reduced by means of the method of preventive conservation we have presented here.

Findings and discussion

The regular use of historical brass instruments in collections and museums is hardly compatible with the aims of long-term conservation. However, the playing of historical instruments is acceptable within the scope of a collection's general policies and should be restricted to research and historically informed performance practice. In such cases, even more attention must be paid to preventive conservation measures in order to realize the aim of long-term preservation.

Climate tests in this project provided clear evidence that brass instruments remain permanently humid inside after being played if they are not actively dried. The humidity levels in the instruments remain at over 60% RH for many days, and corrosion processes are likely to set in. Active drying with the aid of fans has proved to be a highly efficient, easy method. The humidity levels in all types of instruments were reduced to values matching the ambient climate within a matter of hours, thus significantly reducing the risk of corrosion.[25]

This hypothesis was then confirmed indisputably in a long-term study that used three appropriate testing methods. Electrochemical measurements showed that in the instruments using the fan, corrosion rates did not rise (or at least did not rise significantly), while these rates increased by a factor of two for instruments not using the fan. Neutron tomography visualized the humidity behavior in the instrument as well as major spots of corrosion in the tubes. Endoscopy finally depicted a wide range of corrosion phenomena as well as their changes during the long-term study.

From scientific results to a musician's routine

Apart from the instruments in safe conditions in museums, many historical brass instruments in playing condition are today in the hands of musicians in historical performance practice. A majority of these instruments originates from the nineteenth and early twentieth centuries, and they represent a great variety of different types. In line with the principle that one should use the instrument that is most appropriate for a particular performance situation, players use a large number of original instruments, changing them constantly (for this reason, the production of replicas can hardly be profitable). This trend will become more and more widely followed as the HIP movement expands further into the repertoire of the twentieth century, drawing an ever-greater number of performers and listeners into its orbit.

For this reason, it seems a matter of urgency that our project's insights should lead to a new approach in the use of these instruments too.[26] The occasional use of an instrument, or merely a "brief try-out," as is often carried out for testing historical instruments, is the worst possible method. It gives musically unreliable results and also produces an interior surface that remains humid for many days—thus activating the corrosion process. But by drying the inside of the instrument after every use with the help of the small fan, the period of wetness and thus the corrosion can be reduced significantly. This method is therefore recommended to all musicians in situations where no further conservation treatment is possible after playing.

Notes

1 This dilemma is not discussed in the present article. For further discussion and literature, see, for example, Robert L. Barclay, *The Preservation and Use of Historic Musical Instruments* (Sterling, VA: Earthscan, 2005).

2 Much more is known about the outer surface of brass instruments (here, simple cleaning after use and/or wearing gloves in a museum context can efficiently prevent corrosion). We also know more about the inside of wooden instruments, e.g., Ilona Stein, "Blasfeuchte in Holzblasinstrumenten," in Friedemann Hellwig, ed., *Studien zur Erhaltung von Musikinstrumenten. Kölner Beiträge zur Restaurierung und Konservierung von Kunst- und Kulturgut* 16 (Munich, 2004): 9–121.

3 Adrian v. Steiger, Daniel Allenbach, and Martin Skamletz, eds., *Interior Corrosion in Brass Instruments: Proceedings of the Fourth International Romantic Brass Symposium in Bern, 2017* (Schliengen: Argus, in press).

4 See, for example, Esteban Buch, "The Scandal at Le Sacre: Games of Distinction and Dreams of Barbarism," in Hermann Danuser and Heidy Zimmermann, eds., *Avatar of Modernity: The Rite of Spring Reconsidered* (London, 2013), 59–79.

5 Paul Sacher Stiftung, Basel, Microfilm 120.1-000033. The program of *Le Sacre* (without the list of musicians) may be found online: http://gallica.bnf.fr/ark:/12148/btv1b531129484 (accessed 28 February 2018). For a program—listing the musicians—of the same season at the Théâtre des Champs-Élysées, see, for example, the program for Gabriel Fauré's *Pénélope* that same month, in the Bibliothéque de l'Opéra, Paris, shelf mark Pro B 82.

6 Truman Campbell Bullard, "The First Performance of Igor Stravinsky's Sacre du Printemps" (Ph.D. diss., University of Rochester, 1971), 96 and 237ff.

7 Albert Lavignac and Lionel de La Laurencie, *Encyclopédie de la musique et dictionnaire du Conservatoire. Deuxième partie: Technique, esthétique, pédagogie* (Paris, 1927), 1677.

8 In addition to climatic tests, instrument cases and bags were also assessed. Only cases and covers that the test results had shown to be suitable for long-term use were utilized in the project. These included all modern gig-bags, while historic cases had to be excluded. The problem of keeping instruments in cases and covers made of non-age-resistant materials is not new, as these materials often tend to be chemically unstable and emit pollutants. See Klaus Martius and Markus Raquet, "Instrumentenkästen. Schutz und Sicherheit?," *VDR Beiträge* (1/2005): 123–28.

9 The behavior of humidity inside the tubes while wetting and drying was also filmed in stop-motion technique with the help of 2D-neutron-imaging. See the project's website: http://www.hkb-interpretation.ch/projekte/korrosion

[10] In consequence, it is questionable whether it is wise to restrict playing time on historic instruments to just a few minutes, as is the custom in some museums. Few musical and technical insights are acquired in this short time (if any at all), and the problem of the subsequent wet interior is the same, regardless of whether one plays the instrument for a shorter or longer period.
[11] For the present research project, only instruments belonging to playing collections were used. For musical reasons and for reasons of availability, French instruments from around 1900 were chosen.
[12] For reference purposes, various commercial oils and greases were tested on brass plates. The oils and tuning-slide greases selected for this project were: Tromba Cork Grease, Denis Wick Advanced Formula Valve Oil with PTFE, Hetman® Synthetic Lubricant 17 Key Oil MEDIUM KEY™, and Hetman® Tuning Slide Grease 8 TSG™.
[13] E. Mattson and R. Holm, "Atmospheric Corrosion of Copper and its Alloys," W. H. Ailor, ed., *Atmospheric Corrosion* (New York: Wiley, 1982): 365–92.
[14] R. Winston Revie and Herbert H. Uhlig, *Corrosion and Corrosion Control: An Introduction to Corrosion Science and Engineering* (Hoboken, NJ: Wiley, 2008).
[15] This sensor combined an Ag/AgCl solid-state reference electrode and a small platinum grid as counter electrode, both embedded in a thin sponge. For further information, see, Bernhard Elsener, Federica Cocco, Marzia Fantauzzi, Silvia Palomba, and Antonella Rossi, "Determination of Corrosion Rate inside Historical Brass Wind Instruments: Proof of Concept," *Materials and Corrosion* 67 (2016): 1336–43; and Bernhard Elsener, Marion Alter, Tiziana Lombardo, Martin Ledergerber, Marie Wörle, Federica Cocco, Silvia Palomba, Marzia Fantauzzi, and Antonella Rossi, "A non-destructive In-situ Approach to monitor Corrosion inside Historical Brass Wind Instruments," *Microchemical Journal* 124 (2016): 757–64.
[16] Federica Cocco, Marzia Fantauzzi, Bernhard Elsener, and Antonella Rossi, "Dissolution of Brass Alloys naturally aged in Neutral Solutions: An Electrochemical and Surface Analytical Study," *RSC Advances* 6 (2016): 90654–65.
[17] An analytical procedure based on the X-ray excited Auger signals had to be designed, tested, and applied to the brass alloys in order to be able to distinguish metallic copper from Cu(I) oxide and metallic zinc from zinc(II) oxide. See Cocco et al., "Dissolution"; and Silvia Palomba, "Electrochemical Investigation of Copper, Zinc and Brass Alloys" (master's thesis, University of Cagliari, 2015).
[18] Bernhard Elsener, et al., "A non-destructive In-situ Approach," 757–64.
[19] For X-rays, the interaction probability (i.e., the contrast) indicated by the attenuation coefficient is strongly correlated to the atomic number of the elements. Hence, materials constituted of "light" elements with a low z-number, such as organic material, are easily penetrated by X-ray photons, while "heavy" elements such as metals attenuate the X-radiation strongly. Neutrons, on the other hand, show different interactive behavior with matter. Some heavy elements such as lead are almost transparent to neutrons, while some light elements such as hydrogen highly attenuate the neutron beam. Neutron imaging thus provides complementary contrasts compared to X-rays.

The result of the computed tomography is a three-dimensional data set, where the values of the data points (voxels) correspond to a mapping of the attenuation coefficient in each point of the investigated object. The tomography data allows for virtual cuts in arbitrary direction and even makes it possible to "unfold" bent surfaces.
[20] See Adrian v. Steiger, Marianne Senn, Martin Tuchschmid, Hansjürg Leber, Eberhard Lehmann, and David Mannes, "Can We Look over the Shoulders of Historical Brasswind Instrument

Makers?—Aspects of the Materiality of Nineteenth-century Brass Instruments in France," *Historic Brass Society Journal* (2013): 21–38.

[21] Performed at the neutron imaging facility NEUTRA at the Paul Scherrer Institute, Villigen, Switzerland. The detector was a scintillator-digital camera system, consisting of an Andor Ikon-L CCD camera with 2048 x 2048 pixels and a 100µm thick ^{6}LiF:ZnS scintillator. Depending on the size of the slide being investigated, a field-of-view of 200 x 200 mm^2 or 240 x 240 mm^2 was used, resulting in corresponding pixel sizes of 98 µm and 118 µm respectively. The tomography was carried out over 360° in 625 equidistant angular steps. The reconstructed tomography data sets acquired at the beginning and end of the project were registered (i.e., aligned to each other) and compared using the software VG studio max.

[22] Although we found some modification of the inner surface (such as discoloration) using endoscopy in a few items, no clear result was obtained using neutron tomography. This might be attributed to different types of corrosion that might not imply changes in the elemental composition or density large enough to affect the attenuation coefficient to such an extent that it is visible in the reconstructed data.

[23] Endoscopes with non-medical applications are normally called "borescopes." In this case, we used a rigid borescope with cold light projector n°81482 (Karl Storz GmbH & Co. KG, 78503 Tuttlingen, Germany), kindly provided by the Museum of History in Basel.

[24] The use of a rigid borescope is limited to the parts of the instrument with straight access. The endoscopic examination in this project was carried out on only part of the internal surface in each instrument. The area under investigation does not necessarily represent the condition of the remaining areas within the instruments that were not accessible to the borescope.

[25] After the period of playing, and before the instrument is returned to storage, further conservation measures are required and should be carried out by a qualified conservator-restorer. See Marie-Anne Loeper-Attia, "L'impact des restaurations sur la conservation des instruments de musique de la famille des cuivres," *Actes du colloque Paris: un laboratoire d'idées facture et répertoire des cuivres entre 1840 et 1930* (Paris, 2007): 69.

[26] This is based also on insights from previous experiences made by players in the historical performance practice movement. See, for example, Martin Skamletz, Adrian v. Steiger, and Daniel Allenbach, eds., *Proceedings of the Third International Romantic Brass Symposium* (Argus: Schliengen, in press). If instruments are ever allowed to be played for research or performance purposes, they first have to be prepared so that they are in the normal state of a brass instrument. Oil must be used on valves and slides, and then the instruments must undergo preparatory playing until they are completely wet inside. Only then can reliable tests of their playing characteristics or sound be performed, otherwise their behavior is untypical. Furthermore, the players must be acquainted with historical performance practice and testing procedures and have appropriate mouthpieces. Test sessions must be documented in conservational and musical terms (e.g., on video and with comments by players and the audience). Finally, such documents must be stored with the instrument on a long-term basis. See also Arnold Myers, "Preserving Information relating to Instruments in Museums," in v. Steiger et al., *Interior Corrosion.*