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AN X-RAY FLUORESCENCE INVESTIGATION OF ANCIENT ROMAN MUSICAL INSTRUMENTS AND REPLICA PRODUCTION UNDER THE AEGIS OF THE EUROPEAN MUSIC ARCHAEOLOGICAL PROJECT

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Abstract

This paper reports on the investigation of a number of metal musical instruments, from the Roman period, by combining non-invasive portable X-ray fluorescence spectroscopy and technical analysis. The study is part of the European project EMAP (European Music Archaeology Project, 2013-2018) which aims to highlight Europe's ancient cultural roots from variety of perspectives, including: musical, scientific and "sensorial". In particular, the analysis and technical details of some Roman cornua stored in the Naples museum will be presented. The cornua under investigation came originally from excavations carried out in Pompeii. The characterization of the metal alloy and of the various soldering materials was performed utilising X-ray fluorescence spectroscopy in a totally non-invasive mode by means of portable no-contact equipment. This choice of technique resulted from the impossibility of transporting the instruments out of the museum for further investigation and also of taking samples for laboratory analysis. The alloys utilised in the cornua from Pompeii are made up of copper and tin, with a tin content of around 1%. Solders are made from copper, lead and zinc (about 4-5%). Mouthpiece, receivers when present, exhibited high counts of zinc. The use of a brass alloy for solders identifies a sophisticated technological ability which was employed when creating the musical instruments.

Keywords: *Roman cornua; Metal alloy; Music archaeology, X-ray fluorescence spectroscopy*

Introduction

This paper reports on the investigation of five ancient Roman *cornua* within the European project EMAP (European Music Archaeology Project, 2013-2018) which aims to highlight Europe's ancient cultural roots from a variety of perspectives, including: musical, scientific and "sensorial" [1-3]. The starting point is music, because music has always been perceived as a primary need of any civilization [4-5]. The project's starting point was an analysis of the available iconographic evidence and archaeological findings, some of this being

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fragmentary. It continued with the analysis of the constituent materials of the physical evidence and the reconstruction of high quality instrument reproductions, capable of recreating the possible original voice of the instruments, in order for the wider public to be able to appreciate the sophisticated knowledge and skills needed to produce and play such instruments. The project will find its natural conclusion in performances, when the music will finally come to life once more.

In the present paper, we chose to report analysis and technical details of five Roman *cornua* stored in the Naples museum which came originally from Pompeii, in order to illustrate the methodological approach followed in the EMAP project.

The *cornua* from the Naples museum are incomplete instruments, the current displayed items being made from fragments assembled and attached to panels for safe-keeping in the Museum's store [6]. Ancient Roman *cornua* were bronze/brass instruments shaped in an arc covering somewhat more than half a circle (shaped like an upper-case letter 'G') with or without a cross-bar/handle across the diameter (see Fig. 1). They had a very-slightly conical bore and, probably, a shallow cup-shaped mouthpiece, although no mouthpiece has been found with a *cornu*.

Cornua were generally used in the army, but also in amphitheatres, during circus games and all kinds of ceremonies, such as funerals and processions [7-8]. A lost mural painting in Pompeii, known only thanks to a 19th century watercolour, would suggest that, in this particular case, the gladiator himself played the *cornu*. In its military role, the *cornu* was used to signal orders, add pomp and ceremony to the presentation of the colours, and to enhance the warlords' prestige [9-10]. Some rare examples from Roman times were brought to light during archaeological excavations [6, 8].

The characterization of the metal alloy and of the various soldering materials was performed utilising X-ray fluorescence spectroscopy in a totally non-invasive mode by means of portable non-contact equipment [11-13]. This course of action resulted from the impossibility of transporting the instruments out of the museum for further investigation and also of taking samples for laboratory analysis, as specified in the access agreement from the National Archaeological Museum of Naples (MANN). The XRF analysis was performed in collaboration with the instrument makers in order to gather both compositional and technological information on the *cornua*. Technical details were investigated during the on-site analysis of the instruments. Finally, a *cornu* replica was produced and played on the occasion of the conference *Brass Instruments from Ancient Europe*, November 11th -14th, 2015, Viterbo (Italy), organized within EMAP activities.

Experimental

The five *cornua* which were examined are shown in Fig. 1. As can be seen from the illustration, the *cornua* had been re-assembled and then mounted permanently on a support panel, making it impossible to remove them for analysis. The on-site investigation was fundamental for obtaining the technical information on the instruments and was performed with the support of a magnifying lens and a portable video-microscope.

Each analysis point was careful documented and allocated its own unique location reference number.

The analysis of the metal parts of the *cornua* was performed utilising the XRF Surface Monitor II spectrometer, supplied by Assing. The instrument was equipped with Au anode tube operating at 50kV at a distance of 94mm from the analysed surface with a spot of 2mm. The current beam was 300μA and the time of acquisition was set to 60s for each measured point.

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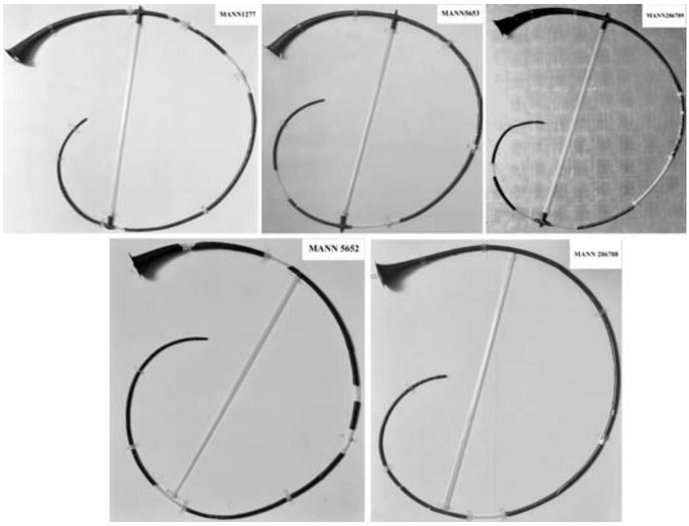

Fig. 1. Photographs of the five *cornua* which were investigated.

Results and Discussion

Technical investigation

The careful on-site investigation of the five *cornua* yielded much useful technical information about the instruments. These were fragmentary when found, lacking some parts of the tube. The original transverse rod was also lacking.

The five instruments investigated are currently fixed to panels by round Perspex bars inserted into the tubes in such a way to re-assembly the fragments of each *cornu* (see Fig. 1). This method of assembly made it difficult to measure the diameters and thicknesses of some instrument parts, due to the lack of access to the tube fragments which were in contact with the mounting board.

However, the ability to compare five *cornua* from the same archaeological context was invaluable in the evaluation of the instruments as a whole, both with respect to their morphology and the level of production technology employed. Comparative analysis revealed that, apart from minor differences, the five *cornua* were designed and made fundamentally in the same manner. In effect, the instruments have a spiral form with their maximum diameter being spanned by a transverse rod which forms a support bar. The strong similarities between the instruments suggest that they were planned to a precise, set pattern with clear geometrical rules being utilised define exactly the dimensions of the artifacts.

Each *cornu* is made of curved tubular elements connected by decorative rings. Each sector follows the curvature of the corresponding semi-circumference that constitutes the overall spiral. The two ends of the *cornua* were connected by a transverse rod, presumably of turned wood, but no evidence of these is present. Similar features are documented in the iconographic sources and the remnants of wooden support rods, retained in place by iron nails are seen in similar circumstances on Etruscan *cornua* [14-15]. The presence of this rod is confirmed by two connectors, still present, with the housing for the *cornu* tubing, the rod ends and holes provided for the nails which secured the support bar to the *cornu* tuning nails (Fig. 2).

Each part of the tube is made of 0.5mm thick sheet, probably in bronze, shaped in such a way as to have the two strips on the longest sides overlapped each other and fixed by soldering, using a probable Sn-Pb alloy (Fig. 3). The excess of soldering alloy was removed using sharp tools or stones as testified by the working traces visible on the *cornua*. The junction rings are apparently made of brass and probably soldered onto the tube.

Fig. 2. Details of the connectors used for housing the wooden support bars. *Cornu* 286788.

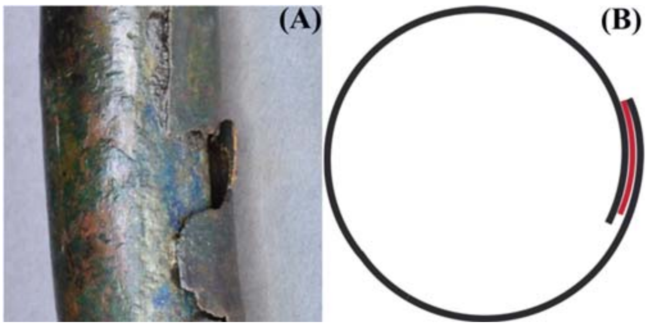

Fig. 3. Detail of the soldering of the tube (A) and its graphical representation (B).

The bells appear to be made of a similar bronze alloy to that of the tube, but they appear to have been brazed/welded utilising brass as the brazing/welding medium (Fig. 4).

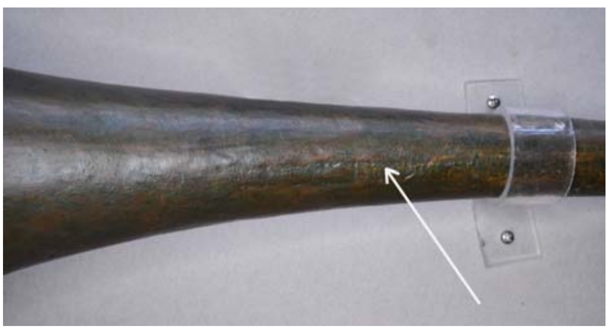

Fig. 4. Detail of the bell in *cornu* 286788. The arrow indicates the braze welding presumably made by brass.

The refined geometrical profile of the bells follows that of a Bessel Horn, flaring towards the bell exit diameter. The bell were created from a flat sheet of metal, folded along the main axis and shaped in such a way as to overlap the two strips of the longest sides which were then fixed by brazing/welding.

This method of working allowed for several hammering stages (which traces are clearly visible in the bore of the bells) and annealing steps to be carried out, these being necessary to obtain the final desired form of the bell, starting from a single sheet and a single soldering much like the processes employed in the manufacture of modern trumpets.

At least one bell appeared to have been tin plated in the inner bore. This detail suggests a high degree of finishing and aesthetic refinement in the production of *cornua*. Moreover, the construction technique, highlighted during the careful on-site investigation of the instruments, serves to emphasise the high planning skills of Roman instrument makers. In fact, the physical development of the *cornua's* forms during manufacture tells how the necessary preliminary design layout stages were carried out utilising a compass and a well-developed construction process in order to obtain the final desired geometry of the finished objects. This construction process itself required a high awareness of each working step, suggesting that the instrument makers were certainly refined connoisseurs of the geometry and at the same time skillful craftsmen.

XRF analysis of the metal alloy

The results of XRF analysis are reported in Tables 1-4 in terms of counts per second of each detected element.

Table 1. Results of XRF analysis on the upper and lower connectors, expressed as counts per second (cps) of each detected element.

Cornu	Point of measurement	Ca	Fe	Cu	Zn	Pb	Sn
1277	X1 – ring	53	404	13451	1741	113	14
	X4 -ring	65	165	9566	860	99	31
	X3 - knob	68	196	10135	2217	134	16
	X2 – central zone	68	246	15483	2578	175	25
1277	X6 – central zone	60	179	15594		280	251
	X7 knob	46	229	11998		106	102
	X8 ring	71	169	11592		154	184
	X9 – knob	98	161	7643		222	154
	X10 ring	67	121	8828		297	210
286789	X1 ring	55	83	7674		1764	
	X2 – knob			7374		1115	
	X3 - knob		73	6301		1104	
286789	X4 ring	58	179	12434	2003	259	
	X5 grey zone	46	140	5502	975	200	
	X6 – dark zone	32	278	15522	1947	181	
5653	X11 knob	159	89	8731		338	229
	X12 knob	95	62	7851		363	170
	X13 – ring	110	83	8474		182	163
	X14 central zone	138	111	14003		325	262
	X15 - ring	19	26	2012		46	64
5653	X1 – ring	53	159	13785		296	156
	X2 knob	44	105	10822		205	93
	X3 – knob	70	107	10844		296	132
	X4 central zone	60	115	15836		200	182
	X5 - ring	68	101	8048		206	107

The XRF analysis on the connectors, assembled in *cornua* 1277, 286789 and 5653, revealed the presence of copper as main elements and differing amounts of tin, lead and zinc. The calcium and iron found is pretty-well always present in the examined points and this is probably due to a depositional phenomenon (Table 1).

Zinc was detected only in two cases, *cornua* 1277 (upper connector) and 266789 (lower connector), with percentage ranging from 8 to 17%. It is suggested that the connectors were wrongly assembled during the instruments reconstruction because it seems anomalous that two connectors on the same *cornu* have different compositions in terms of metal alloy.

Tin has been detected in different amounts in the examined points, ranging from 0.1-0.2% in *cornu* 1277 (upper connector) to 3% in *cornu* 5653 (upper connector), being completely lacking in the connectors of *cornu* 286789.

Finally, lead was revealed in each examined point with percentage values ranging from 1% to 18%, this latter high value being found in the upper connector of *cornu* 286789. Once again, the heterogeneity in composition suggests the possible wrong assembly of the connectors.

The XRF analysis performed on the different points of the tubes, selected by the instrument makers after close observation, revealed the presence of high counts of copper and low counts of tin, around 1% or lower, apart from the point X8 in *cornu* 286788 (Table 2).

Table 2. Results of XRF analysis on the tubes, expressed as counts per second (cps) of each detected element.

Cornu	Point of measurement	Ca	V	Mn	Fe	Cu	Zn	Pb	Sn
1277	X5 – tube	71			110	16077			215
	X16 – overlapped strip	85			159	16236		72	123
5652	X1 – end part of the tube	94			101	13005		83	108
	X2 – solder	152			200	10377		1297	289
	X3 – close to the solder	95			126	14707		442	209
	X8 - tube	172			132	17271		115	185
5653	X6 - un-oxidized zone close to the seam				97	14631			171
	X7 - un-oxidized zone opposite to X6		42	48	87	13581	180	48	30
	X16 – uncorroded zone	77			144	18845			87
286788	X1 – uncorroded zone	105			157	17001		133	208
	X2 – end part of the tube	117			105	11017		76	80
	X3 – point close to X2	86			119	15359		151	122
	X8 – light grey area of the tube	230			59	3118		1694	577
286789	X9 – ring between tube and mouthpiece	37			117	13158	2062	29	
	X10 – uncorroded zone close to X9	48			145	15818	791	47	
	X11 – point close to X10				137	14906	524	61	31
	X12 – uncorroded zone	49			183	18731	634	64	
	X13 – point close to X12	51			149	18665	488	107	
	X16 – solder	98			33	5418	322	199	
	X17 – solder	105			80	11320	383		
	X18 – solder	155			60	8522	415	438	
	X19 - uncorroded zone close to the upper fitting	33			98	15807		46	
	X20 – point close to X19	33			106	17264		41	

In this case, the percentage of tin reaches 10%, a value that, along with a reading of 30% lead suggests a possible soldering point. The percentage of Pb must be 1% or less for sheet metal components, in order to avoid cracks when hammering or forging [16-17].

Zinc was detected in some points of *cornua* 5653 and 286789 with percentages ranging from 1% to 13%, this last value being found in point X9 of *cornu* 286789 corresponding to the junction between the tube and mouthpiece receiver. The presence of zinc confirms, especially in high percentages detected on the joints, the use of braze/welding utilising brass.

The use of a bronze alloy with about 1% of tin is particularly interesting from a technological point of view and it is absolutely functional to the braze/welding carried out with a brass filler [16, 18-20]. In fact, this kind of bronze alloy is a good compromise between the mechanical resistance of the sheet and the possibility of working and annealing, even after the preliminary braze/welding.

The results of elemental analysis on the bells are reported in Table 3.

Bells are made of copper, as main element, and tin (1-2%). In the point X7 on *cornu* 286788, high counts of zinc were detected, seen as a confirmation of brass use in the braze/welding process. Bronzes/brasses utilising this percentage of tin were widely used for the production of sheet and wire objects [16, 21].

Table 3. Results of XRF analysis on the bells, expressed as counts per second (cps) of each detected element.

Cornu	Point of measurement	Ca	Fe	Cu	Zn	Pb	Sn
1277	X11 – grey area of the bell	60	61	11537			96
	X12 – flat zone	125	115	6916			188
5652	X6 – uncorroded zone	55	173	16907			86
	X7 – uncorroded zone	31	79	7215			44
5653	X8 – grey uncorroded zone		34	4256			37
	X9 – grey zone on the edge	377	120	11799			358
	X10 – point close to X9	381	149	13055			301
286788	X7 – uncorroded zone, end part of the bell	150	10308	5773	85	20	150
286789	X7 – uncorroded zone	130	213	15238		35	
	X8 – uncorroded zone	126	224	17653		40	

Table 4. Results of XRF analysis on the mouthpiece receivers, expressed as counts per second (cps) of each detected element.

Cornu	Point of measurement	Ca	Fe	Cu	Zn	Pb	Sn
1277	X13 – light zone	149	140	6350	639	108	44
	X14 – point close to X13	182	100	8312	882	52	46
	X15 – end part		94	12463	1873	65	
5652	X4 – central uncorroded zone			8177	775		
	X5 – solder	85	122	7358	957	336	128
286788	X4 – central part	44	221	12083	1919	32	
	X5 - uncorroded zone	22	55	3832	626	23	
	X6 – solder	84	58	2175	198	927	107
286789	X14 – central part	33	135	13835		70	
	X15 – uncorroded zone	23	41	7192		126	

Mouthpiece receivers, when present, exhibited, in general, high counts of zinc, with percentages values ranging from 9 to 14% (Table 4). The only mouthpiece receiver where zinc has not been detected is that on *cornu* 286789.

Replica production

Replica production was carried out based upon the data obtained from the in-situ physical and XRF investigations. The instrument, with museum no. MANN286788, was chosen for reconstruction because of its complete and well-preserved tube and its constant conic shape.

As a first step, a 1:1 scale drawing was produced in order to generate the necessary numerical data (Fig. 5). In this way, we acted both as instrument makers and designers. During this layout stage, it was established that the maximum diameter corresponded to 4.5 Pompeian feet (121.5cm, being 1 Pompeian foot equal to 27cm).

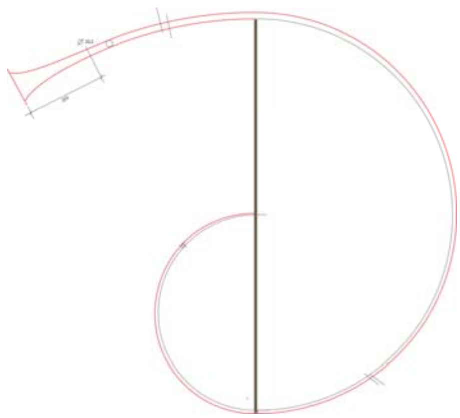

Fig. 5. Graphical representation of the *cornu* 286788, chosen for replica production, after the careful on-site investigation and measurements.

Basing further calculations upon this diameter, it was possible to construct the spiral necessary to contain the entire tube length derived from the original instrument analysis.

The choice of the most- suitable bronze sheet was made on the basis of commercial availability and of the working characteristics of the alloy. The most suitable available sheet contains 6% of tin. This alloy allows for brass soldering to be carried out, even though the melting points of the two metal alloys are only little different.

The desired overall length of the entire tube, with the mouthpiece, is 359.3cm. It was created by assembling sections of about 40.0cm length. The single straight pieces were created with the aid of wooden forms and then worked using iron curved cores to generate the appropriate curvature of each piece.

The formers utilised were not calibrated but the right conic shapes were created precisely by simply paying attention to the diameters during the hammering of the sheet. This working method demonstrated that such techniques, which rely on the skill and dexterity of the craftsman, can lead to highly precise results.

The final soldering was performed utilising a tin/lead alloy.

As far as possible, the original construction techniques were followed in the production of the replica, as these still today offer the simplest and most-natural manufacturing sequences for re-creating the *cornua*.

Only the parts which had originally been cast were reproduced by means of turned brass sections. A photo of the replica, with details of tube and bell, can be seen in Fig. 6.

Fig. 6. Photograph of the finished replica of *cornu* 286788 and details of tube, mouthpiece and bell.

Conclusions

This paper reported the results of the technological and XRF analysis performed on five ancient Roman *cornua*, preserved in the Archaeological Museum of Naples. The five *cornua* had never previously been investigated from a technological and material point of view and the working together of a team of instrument makers, chemists and conservators greatly facilitated the process of gathering useful and important information for replica production, in a way which allowed team members to address to the main aims of the EMAP project.

By combining the results of in-situ XRF analysis, performed on selected points, and the technical examination on the instruments' fragments, it was possible to determine the alloy composition, the techniques employed in soldering and, in general, the working processes employed when originally creating the *cornua*.

The production of replicas, utilising original ancient technologies provided valuable new insights into the forms of the objects and processes available in the Roman period. As a result of the multi-faceted investigation which was carried out, the musical instrument was better understood from a technological point of view, and an insight gained into the working practices which relied upon that difficult to quantify element: the professional craftsman's skill and knowledge.

Acknowledgements

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