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THICKNESS MAPPING OF BODY ARMOUR: A COMPARATIVE STUDY OF EIGHT BREASTPLATES FROM THE NATIONAL MUSEUM OF SLOVENIA

Abstract: There is relatively little information available on the weight and thickness of historical plate armour. The purpose of the present study is to present a detailed analysis of eight torso defences from the National Museum of Slovenia dating from the early 16th to the mid-19th century. Each artefact has been measured in detail and its thickness mapping is presented in graphical diagrams. Furthermore, 3D modelling has been used experimentally to estimate the height of individuals expected to wear the armour. The results illustrate important ideas of armour design during the Middle Ages and the early Modern Period, especially with regard to the increasing effectiveness of firearms.

Keywords: armour, breastplate, Middle Ages, early Modern Period, thickness mapping, 3D modelling, National Museum of Slovenia

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Publications of historical armour often provide surprisingly little in the way of relevant technical or statistical data. For instance, the weight of armour, a vital and truly basic piece of information, has been ignored by a great many authors, or at best treated in a rather cursory manner.[1] Sir James Mann's catalogue of the Wallace Collection armoury is one of the few early exceptions, listing the weight of every single item on display.[2] Such is not necessarily the case even today, in specialist literature otherwise of the highest standard.

The thickness of plate defences is perhaps an even greater mystery, as well as a matter of considerable speculation and misunderstanding. Only a handful of recent publications have addressed this subject to any major degree.[3] Moreover, even in those few instances when clear reference is made to the thickness of plate armour, the reported values are generally restricted to the maximal values measured on the specimen.

This is quite problematic, for the maximal thickness of medieval or early modern body defences is rarely representative of the entire piece, let alone the complete harness. A closer inspection of historical plate armour generally reveals that the elements covering the vital areas, particularly the central section of the breastplate, were deliberately made much thicker than those covering the extremities or less vulnerable parts of the body.

Such design principles allowed the armour makers to achieve an optimal distribution of mass and protection, obtaining the highest degree of security at the lightest possible weight. These considerations were extremely important to the overall functionality of armour. Modern soldiers face similar challenges in the quest toward developing effective body protection without sacrificing the wearer's mobility – a problem to which no single definite, entirely satisfactory solution has been found so far, and perhaps will never be. However, the fighting men of the medieval and early modern period must have felt these constraints even more

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[1] Ffoulkes 1912, 119; Blair 1958, 191-192.

[2] Mann 1962.

[3] Williams 2003, 913-917; Williams et al. 2006.

vividly than their counterparts of the 21st century due to the preponderance of close-quarter combat and the correspondingly smaller reliance on missile weapons in preindustrial warfare. The heavily armoured combatant of the earlier historical periods was primarily expected to engage the enemy with cut-and-thrust or blunt weapons, essentially in a melée where his ability to move and fight unimpeded by his equipment was even more critical than in modern infantry warfare.

The late medieval or early modern suit of armour represented a complex whole intended to protect the wearer from head to toe. It was made up of a considerable number of elements, the most crucial one – and physically the largest – being the breastplate. A gradual development of an independent breastplate is usually seen as the defining point in the evolution of late medieval body defences, starting the era of the *harnois blanc* or true plate armour.[4] It also symbolized an important technological milestone, for the manufacture of such armour required a high degree of metallurgical knowledge and well-developed production centres capable of supplying large quantities of wrought iron and steel.[5]

Apart from head defences, ensuring a solid protection of the combatant's torso has always been the highest priority in the design of any effective armour. As a result, the breastplate was usually the heaviest and thickest part of the harness. From the early 17th century onwards it was often worn as the only piece of metal body armour, either alone or combined with a backplate into a two-piece cuirass.

As the armour makers strove to produce torso defences strong enough to withstand the impact of enemy cut-and-thrust weapons, arrows, crossbow bolts, and ultimately arquebus or musket fire, it soon became clear that there were two possible solutions to the problem. Using superior raw materials, such as carbon steel properly heat-treated to an optimal combination of hardness, toughness and tensile strength, ensured much better protection at the same weight than low-quality wrought iron.[6]

Another possibility was to make armour thicker, though this invariably increased its weight. The introduction of increasingly powerful field artillery and hand-held firearms from the early 15th century onwards provided a clear stimulus toward stronger and thicker armour. Gunpowder weapons represented an acute threat due to their kinetic energy, vastly surpassing earlier missile weapons such as bows and crossbows.[7]

In practice, medieval and early modern armour makers were keenly aware of these issues. It was understood full well that no practical form of plate harness could protect its owner from the entire range of threats on the battlefield. On the other hand, it was quite possible to produce reasonably light armour strong enough in the critical areas – mainly the head, neck and frontal torso region – to provide good protection against most types of attack, possibly even small arms fire,[8] but with a much lighter degree of protection elsewhere across the wearer's body, e.g. the back and extremities to keep the overall weight of the armour within bounds.

To maximize the effectiveness of torso defences, armour makers tended to manufacture breastplates from quite thick iron or steel sheet, leaving the central section as strong as possible but thinning down the stock material quite drastically toward the outside, where the owner's body was less exposed to direct attack. These design principles appear simple enough but their full extent and implications are not necessarily understood very well today even among reenactors and historical martial arts practicioners, by and large the only group in the contemporary society having in-depth practical experience with metal body armour.

The reason for that is quite simple – most modern replicas available on the market are made of rolled steel sheet, which is highly uniform in thickness. Most replica makers nowadays use steel sheet that is fairly thin to begin with in order to reduce the amount of work needed to complete the final product. Depending on the intended application, much of the commercially available armour is made from 1.2 mm (18 gauge) to 1.6 mm (approximately 16 gauge) steel sheet. This appears to be an acceptable compromise for most purposes as it allows quite rapid and simple production of reasonably authentic-looking replicas that provide satisfactory protection at a comparable weight as the historical originals.

However, by the same token the inherent variations in thickness found in such a replica are likely going to be much smaller than those found in authentic medieval or early modern armour. This is particularly apparent in the case of torso protection, which is now generally made from much thinner stock. On the other hand, limb defences tend to be made thicker than was the norm in the past, and are hence heavier and more burdensome than the originals.

In other words, historical plate armour was usually designed in a much more refined, thought-out manner to maximize the protection of vital areas. This trend is observable even in the case of low-quality 'munitions-grade'

[4] Blair 1958, 59-62.

[5] Williams 2003, 53-59.

[6] Williams 2003, 3-25, 893-902.

[7] Williams 2003, 918-944.

[8] Krenn 1989.

armour made by the lowest bidder – yet still up to craftsmanship standards surpassing most modern replica manufacturers. To be fair, it is worth pointing out that the latter are catering to the reenactment and martial arts market rather than the demands of an actual battlefield.

Comparative study of torso armour from the National Museum of Slovenia

The observations listed above underline the need for a much more methodic study of historical armour. One particularly valuable, yet hitherto underused tool to this end is thickness mapping – a graphic presentation of the gradation between the thinner and thicker areas of armour. It is a simple method that requires only basic measuring tools, such as calipers of suitable length and reach. However, it tends to be time-consuming, especially if a large number of measurements is to be taken to allow a meaningful interpretation.

Thickness mapping of extant body armour is not an entirely new approach. It may be observed for instance in A. Williams' recent publication of multi-role breastplates.[9] A similar approach has also been used by the authors of the present paper during a detailed examination of a 16th century suit of armour made by Valentin Siebenbürger.[10] A decision was made to expand upon this work with a comparative study of torso armour from the National Museum of Slovenia.

The analysis involved eight breastplates of various types and provenance dating from the early 16th to the mid-19th century. Thickness measurements provide highly illustrative insight into the "anatomy" of historical armour. It is hoped that our study will help shed light on the design principles employed by armour makers in different historical periods, as well as provide reference material for future work. By taking into account the typical metalworking techniques employed by medieval and early modern artisans, and contrasting them with methods commonly used nowadays, this data may also be used to differentiate between genuine antiques and modern reproductions.

The measurements were performed with a digital outside caliper marketed by iGaging. The extra-long jaws of this measuring tool are specifically designed to allow easy access even on curved, irregular surfaces impossible to reach with ordinary vernier calipers. As a result, we were able to measure the thickness of steel sheet in virtually every section of the analyzed artefacts. Only in several cases were the measuring jaws found to be slightly too short to reach the very centre of the breastplate, most commonly due to their extremely pronounced curvature.

It is imperative that thickness mapping is carried out systematically and documented with care, otherwise sensible interpretation of the results becomes very difficult, nor is it possible to establish a precise gradation in thickness across the armour. Some of the analyzed breastplates are strongly reinforced along the upper or bottom rim. In most cases, such reinforcements are largely decorative, or intended to ensure a better fit with the other elements of the harness. However, since the thickness of reinforced rims is usually much larger than the rest of the armour, it has been decided to treat them as a separate category in graphical representation of the mapping diagrams.

Armour thickness is closely related to weight. All the items included in the present study were weighed with an X-Spot portable digital scale. Obviously enough, torso armour made from thinner wrought iron or steel sheet weighs less than a thicker one, which has important implications concerning the ergonomic qualities and practicality of body defences.

In themselves, size and thickness measurements of historical armour may not seem particularly informative. However, such metrical data may be used for a variety of purposes, such as anthropological studies of the medieval and early modern population. Due to the rigid construction of plate armour, estimating the size of its original wearer is quite straightforward. Such an approach can be used with good effect to determine the average body height in the past, but has only been exploited so far in a very limited number of anthropological studies.[11]

It is generally recognized that our medieval and early modern predecessors were smaller in stature compared to the contemporary population. In fact, a major increase in average height has been observed during the last century, and particularly during the post-World War II period.[12] In order to estimate the body size of individuals expected to wear the torso defences analyzed in this paper, extensive use was made of experimental 3D modelling. Due to unsatisfactory results obtained with 3D scanning in the past,[13] the armour was measured carefully with a flexible tape ruler and calipers; rigid tape rulers and measuring devices are much less practical due to the prevalence of curved, irregular shapes found in plate body defences.

[9] Williams 2017.

[10] Kraner 2016; Lazar 2018; Kraner et al. 2019.

[11] Koepke and Baten 2006, 135-138.

[12] Cardoso 2008; Štefančič 2008; Leben-Seljak 2011; Bele 2012.

[13] Despite multiple attempts involving different types of equipment, obtaining truly accurate 3D scans of plate armour from the collections of the National Museum of Slovenia has proved to be an elusive task. The results of laser scanning and 3D photography have been quite underwhelming in our experience due to the reflectivity of large, highly polished metal surfaces. In an industrial setting, the problem might be solved by applying non-reflective paint, but this is not permissible in the case of valuable museum artefacts.

Inv. no.	Mass (kg)	No. of measurements	Rim max (mm)	Rim min (mm)	Rest of the armour max (mm)	Rest of the armour min (mm)
N 35361	3.75	153	12.8	7.7	3.5	0.9
N 5043	2.73	126	9.3	2.9	2.2	0.8
N 4534	1.88	97	11.2	7.4	3.9	0.6
N 5045	1.81	122	9.8	3.9	2.1	0.6
N 5044	2.54	125	-	-	3.2	0.4
N 17776	5.68	54	-	-	7.8	1.5
N 37977	4.90	104	-	-	5.9	1.1
N 37978	4.57	104	-	-	5.7	1.1

Table 1. Measurements of selected breastplates.

A simplified but fundamentally exact and realistic 3D model was created of each analyzed artefact, superimposed over an idealized model of a male figure. The latter was adjusted in size until it fit the armour model as ergonomically as possible. While this method may never be entirely accurate due to the inherent variations in human body shape and proportions, it is fairly simple, non-destructive and has been found to produce reasonably reliable results in comparison to testing performed with the assistance of live models.

Measurements and typological study of selected breastplates

1. Breastplate

NMS, Inv. no. N 35361
1530s, Valentin Siebenbürger, Nuremberg

The breastplate consists of a thick, fluted central section with a smaller curved lame riveted along each armpit cutout. The narrow waist is formed of a separate lame, to which a three-piece fauld is attached. The bottom lame of the fauld is fitted with straps and buckles to fasten the tassets; the latter are made of four lames. The upper edge of the breastplate, armpit cutouts and bottom edges of the tassets are finished with heavy roped edges. A folding hook-shaped lance rest is riveted just below the right armpit cutout.

The breastplate belongs to the only complete, original suit of armour from the National Museum of Slovenia (NMS), a war harness for a mounted man-at-arms made in the 'Maximilian' style by the Nuremberg master Valentin Siebenbürger.[14] The harness, which is currently missing only the codpiece, weighs 23.75 kg in total.

The weight of the breastplate alone is 3.5 kg. It measures up to 590 mm in height and 500 mm in width, reaching the maximum across the fauld, or hip area. All in all, 157 thickness measurements were taken. The highest three values, from 12.8 to 7.7 mm, were obtained on the roped edge along the upper rim. These figures are in stark contrast with the material thickness elsewhere, ranging from 0.9 to 3.5 mm. The thickest areas are found covering the chest, whereas the lower section is notably thinner. For comparison, the backplate belonging to the harness is made of much lighter material, only 1.5 to 0.7 mm thick and weighing 1.91 kg. Computer simulation involving a 3D model suggests that the armour would fit a person with a height of 1.73 m.

2. Infantry armour

NMS, Inv. no. N 5043
Mid-16th century, Central Europe

The frontal section of the armour is largely complete, consisting of a breastplate with a curved lame attached at each armpit and a fauld with two lames. The bottom lame is fitted with a pair of tassets. However, only the upper lames of the latter have been preserved. The breastplate is plain, with roped edges along the armpit, neck and groin cutouts. The overall shape of the breastplate is predominantly globular. The central section of the waist is defined quite sharply, though the peak is not as pronounced as in the case of a proper '*Tapulbrust*'.

The overall design features of the breastplate suggest Central European production dating from the mid-16th century. It was originally worn in conjunction with a backplate, now missing, as indicated by the buckles riveted to the upper corners of the armpit lames. Infantry half-armours of identical type were commonly used by the *Landsknechte*, particularly the rank and file of massed formations armed with pikes or halberds.[15]

The infantry armour weighs 2.73 kg and measures approximately 470 × 500 mm in height and width. 126 thickness measurements were taken overall. Several values stand out, ranging from 9.3 to 2.9 mm; all were observed along the reinforced upper and bottom rim. Across the rest of the armour, maximum and minimum values detected are between 2.2 to 0.8 mm, corresponding to a deviation range of 1.4 mm. Computer modelling suggests that the armour was worn by a person 1.54 m tall.

[14] Boeheim 1895; Blair 1958, 115-120; Lazar 2013; Kraner 2016.

[15] Mann 1962, cat. no. A 214; Düriegl et al. 1977, cat. no. 217; Leutenegger 2005, cat. no. 30.

Fig. 1. Breastplate N 35361 and the suit of armour made by Valentin Siebenbürger.
Photo T. Lazar and T. Lauko.

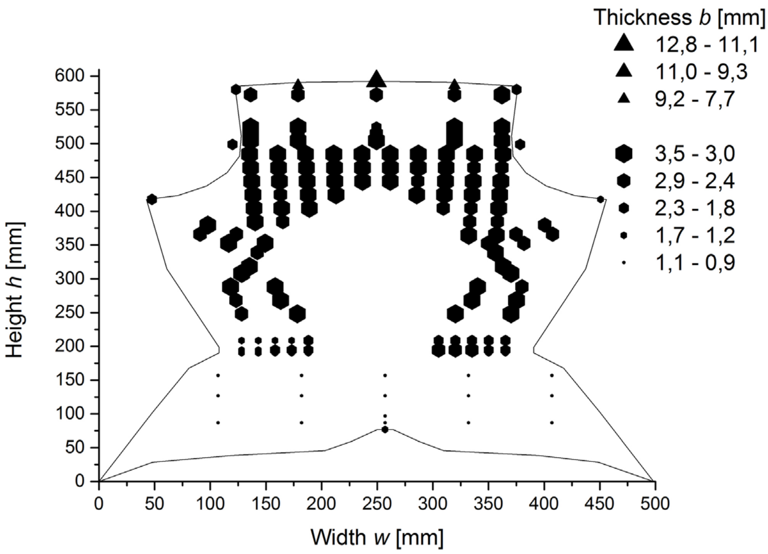

Fig. 2. Thickness mapping of the breastplate. Drawing J. Kraner.

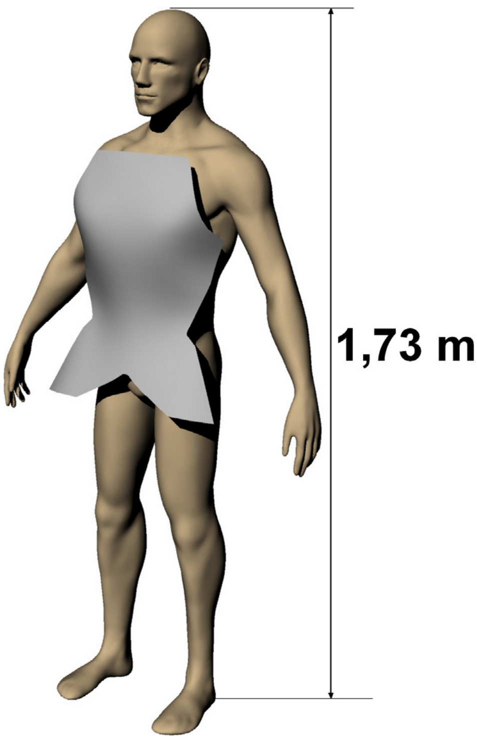

Fig. 3. 3D modelling of the armour in use.
Drawing J. Kraner.

a b

Fig. 4. Infantry armour N 5043. Photo T. Lazar.

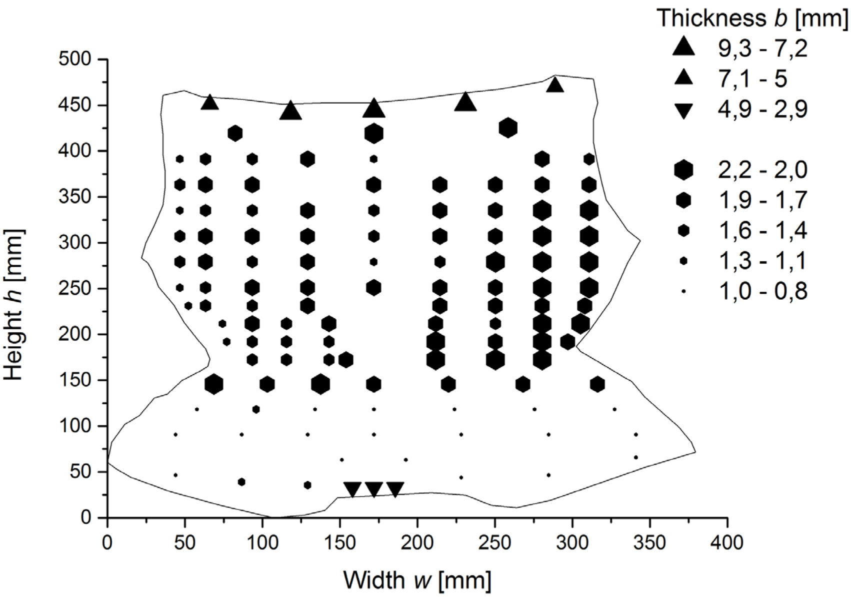

Fig. 5. Thickness mapping. Drawing J. Kraner.

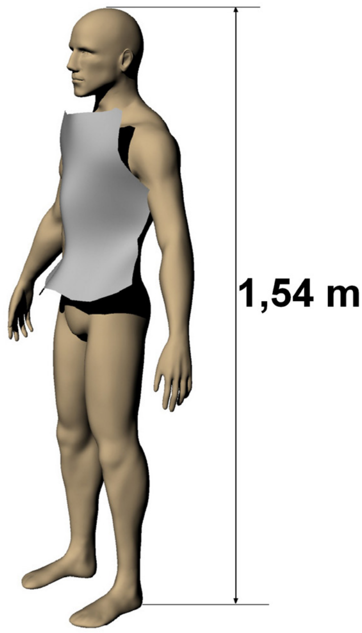

Fig. 6. 3D modelling of the armour in use. Drawing J. Kraner.

3. Breastplate

NMS, Inv. no. N 4534

3rd quarter of the 16th century, German, probably Nuremberg

Despite its somewhat fragmentary state of preservation, the breastplate is a fairly typical example of German ‘munition’ armour from the period ca. 1560-1575.[16] The upper rim of the breastplate is finished with a roped horizontal edge. Apart from a simple

[16] Blair 1958, 119-120; Leutenegger 2005, cat. no. 38.

Fig. 7. Breastplate N 4534. Photo T. Lazar.

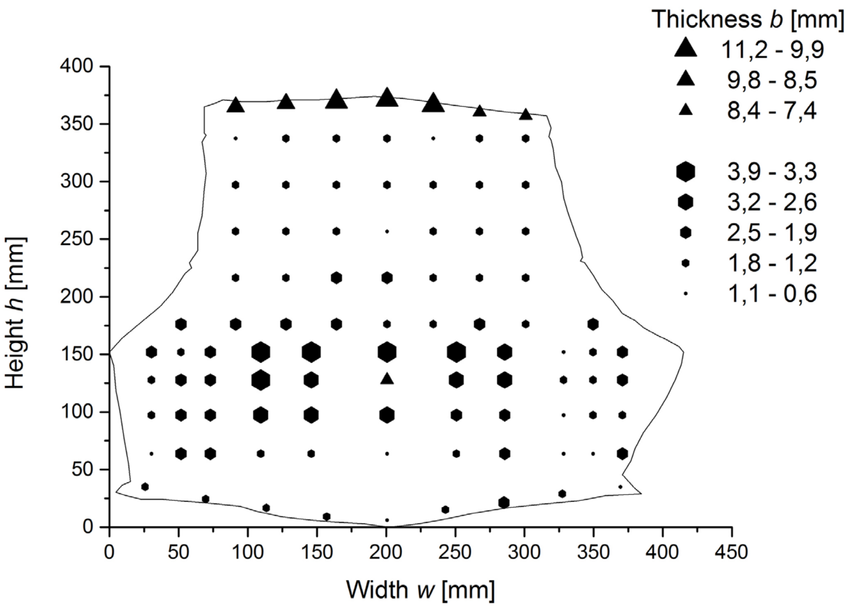

Fig. 8. Thickness mapping. Drawing J. Kraner.

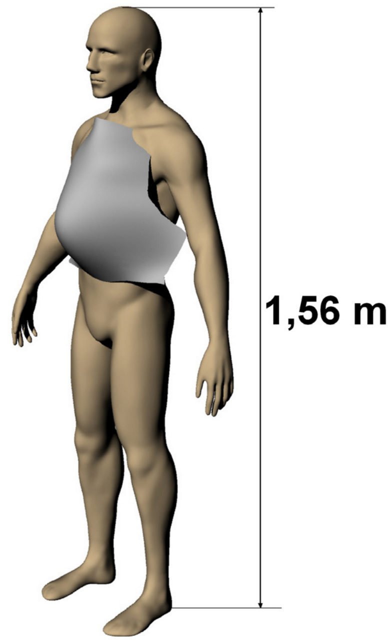

Fig. 9. 3D modelling of the armour in use. Drawing J. Kraner.

decorative pattern incised into the upper chest section the surface is quite plain. At the waist, the central vertical ridge rises sharply into a prominent peak (‘*Tapulbrust*’).

The breastplate was originally fitted with an additional lame along each armpit and at least a narrow fauld attached to the bottom rim, all of which are now missing. In all likelihood, the breastplate was worn with a corresponding backplate. Cuirasses of such form, imported predominantly from Nuremberg, were very common in Central Europe during the third quarter of the 16th century. Depending on the configuration of the armour, they could be worn as part of a half- or three-quarter harness, suitable either for infantry or cavalry. Several cuirasses of this type, intended for use by mounted arquebusiers, survive in the Styrian provincial armoury in Graz.[17]

[17] Krenn 1987, 16-17; Habsburg-Lothringen 2015, 30.

Fig. 10. Infantry armour N 5045. Photo T. Lazar.

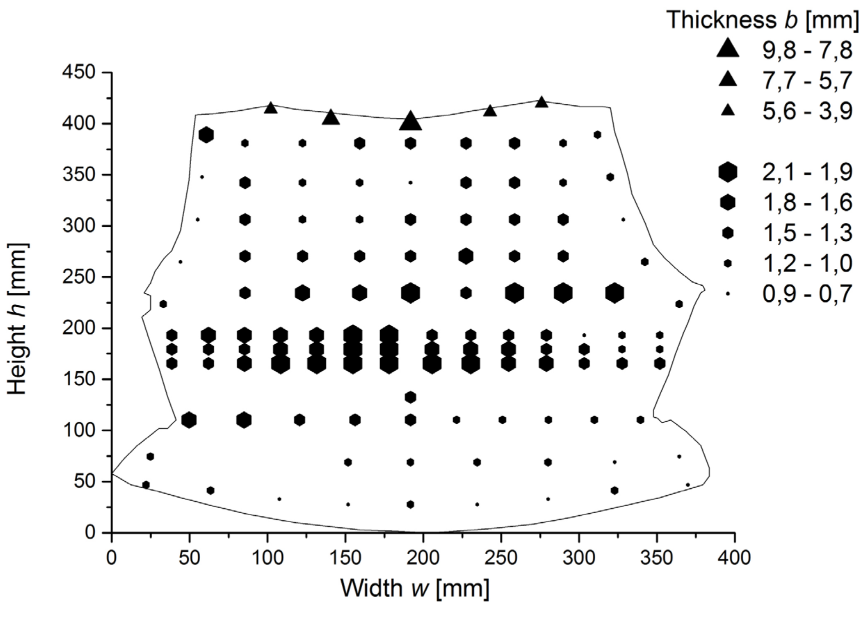

Fig. 11. Thickness mapping. Drawing J. Kraner.

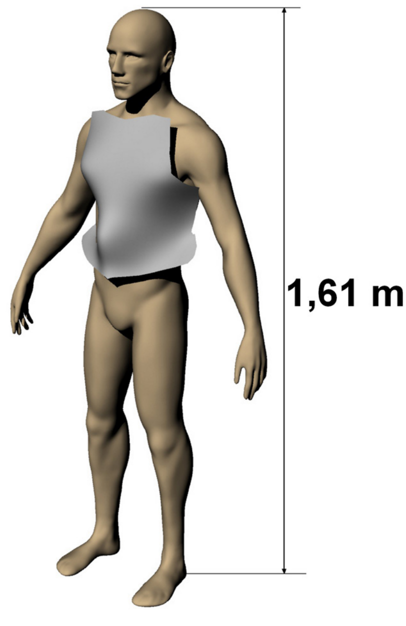

Fig. 12. 3D modelling of the armour in use. Drawing J. Kraner.

The breastplate weighs 1.88 kg. It measures 350 mm in height, the same as the width of the breastplate across the lower abdominal section. The maximum width of the armour, just beneath the armpits, reaches up to 520 mm. 97 thickness measurements were taken all in all. Same as in the previous case, the reinforced upper rim is much thicker than the rest of the armour, with five measured values between 11.2 and 7.4 mm, and another one within that range observed on the extreme central curvature of the breastplate.

Across all the other areas of the breastplate the material is between 3.9 to 0.6 mm thick. The strongest areas are found on the upper torso or chest, while the sides and the upper section just beneath the reinforced rim are notably thinner. By using 3D modelling, the height of the armour wearer has been calculated at 1.56 m.

Fig. 13. Cuirass N 5044. Photo T. Lazar.

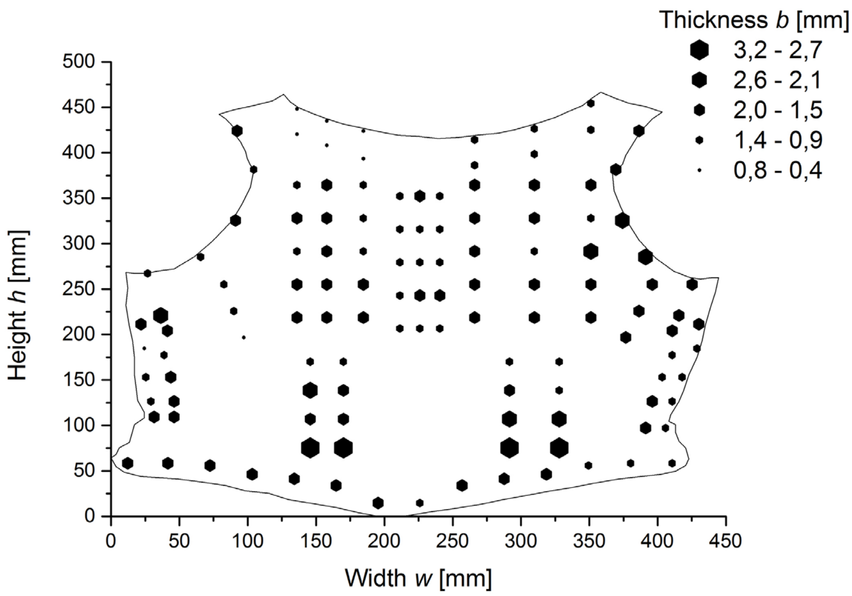

Fig. 14. Thickness mapping of the breastplate. Drawing J. Kraner.

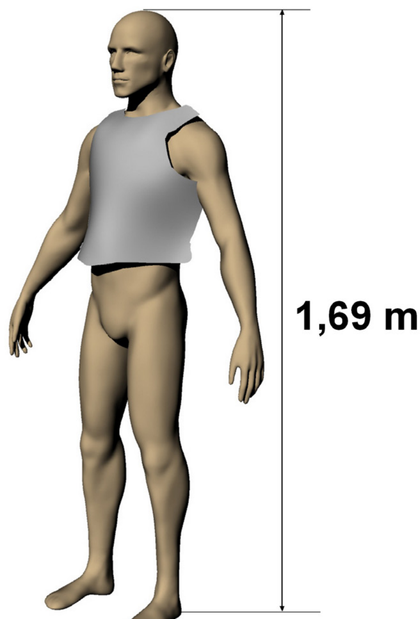

Fig. 15. 3D modelling of the armour in use. Drawing J. Kraner.

4. Infantry armour

NMS, Inv. no. N 5045
Ca. 1580, Nuremberg

Another example of munition armour, in all respects quite similar to the N 5043 except for a slightly later date of manufacture and the shape of the waist. Originally part of an infantry half-armour, all that remains now is the breastplate. Its vertical ridge terminates into a well-defined point almost at the bottom of the waist section. Each armpit cutout is fitted with a narrow lame, pierced at the upper corner for a strap buckle. The one attached on the right shoulder is still intact, but the left buckle is now missing. A single horizontal lame is riveted to the bottom edge of the breastplate. The rivets attached to the bottom section indicate that the fauld must have consisted of at least two lames, and probably a pair of tassets as well.

A faint Nuremberg inspection mark is stamped onto the upper section of the breastplate. Stylistically, the armour can be dated into the late 16th century, probably ca. 1580, based on its ‘peascod’ form still somewhat reminiscent of the earlier ‘*Tapulbrust*’.[18]

[18] Blair 1958, 120; Leutenegger 2005, cat. no. 64.

Fig. 16. Breastplate N 17776. Photo T. Lazar.

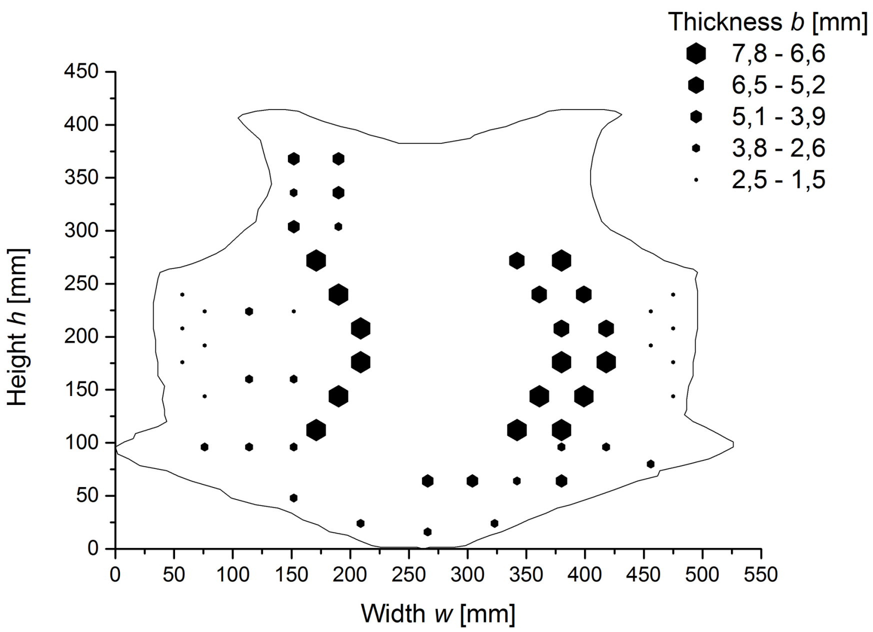

Fig. 17. Thickness mapping. Drawning J. Kraner.

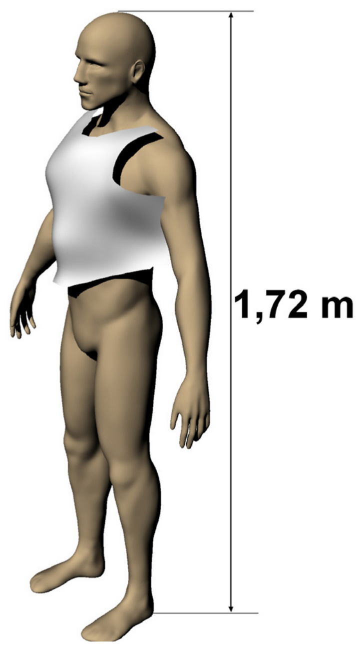

Fig. 18. 3D modelling of the armour in use. Drawing J. Kraner.

This torso defence is quite light, weighing only 1.81 kg. It is up to 400 mm tall, widening to a maximum width of 520 mm beneath the armpits. 122 thickness measurements were carried out. Five of them, from 9.8 to 3.9 mm, stand out. All were observed along the reinforced upper rim. The other 117 measurements vary between the maximum value of 2.1 mm, detected across the lower chest and abdomen, and the thinnest sections measuring just 0.6 mm. Computer simulation suggests that the armour was made to fit a person 1.61 m tall.

5. 'Hussar' cuirass

NMS, Inv. no. N 5044
Ca. 1580-1590, Central Europe

The cuirass consists of a breast- and backplate, each fitted at the top with a rounded neck guard that reaches over the shoulders, effectively forming a gorget. Each of the two major sections is made up of one large plate covering the upper chest or back, respectively, and four additional lames attached with

Fig. 19. Cuirass N 37977. Photo T. Lazar.

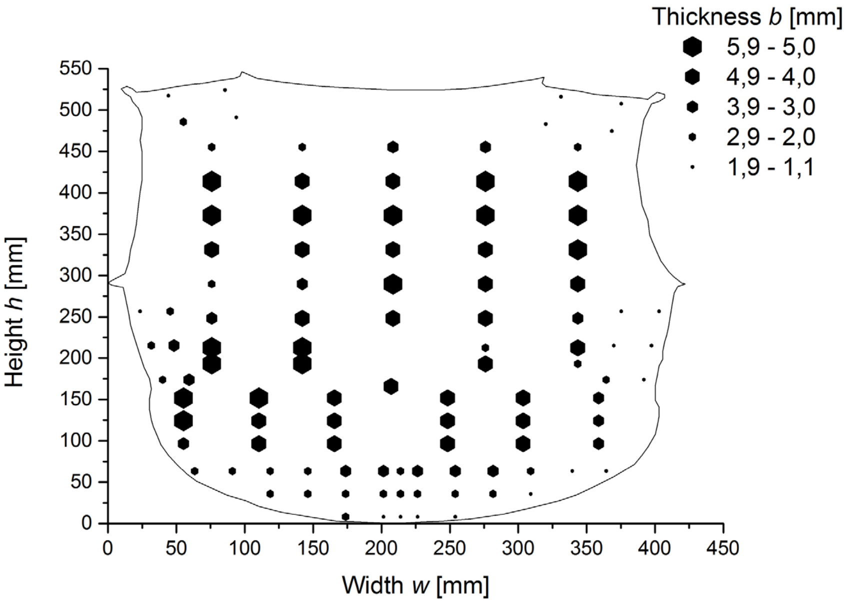

Fig. 20. Thickness mapping. Drawing J. Kraner.

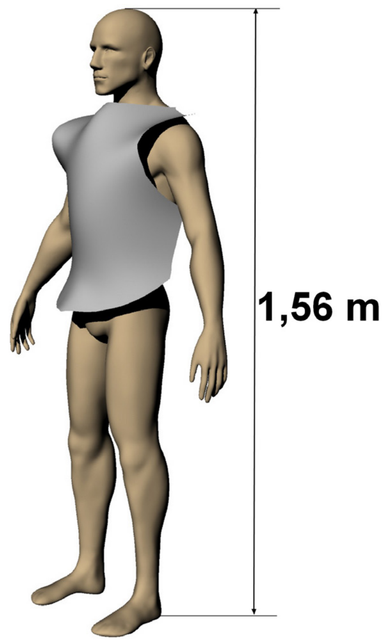

Fig. 21. 3D modelling of the armour in use. Drawing J. Kraner.

movable rivets and a centrally positioned strap. The armour iszdecorated with blue and gilt borders and gilt rivets. A bullet dent may be observed on the upper right section of the breastplate. Unfortunately, an attempt was made in more recent times to "repair" it, which caused a rupture of the steel sheet.

Body armour of this type was worn almost exclusively by officers of the hussar light cavalry in service of the Habsburg Empire during the final decades of the 16th century. Its semi-rigid manner of construction permitted a greater freedom of movement at the waist than a conventional solid breastplate,[19] no doubt making it more attractive to the elite light cavalrymen serving in the defense of the Turkish border. Hussar cuirasses of this particular pattern are relatively rare.[20] The N 5044 is noteworthy for its high quality of manufacture and unusually fine decoration.

[19] Blair 1958, 124.

[20] Krenn 1987, 40-43; Habsburg-Lothringen 2015, 30.

a b
Fig. 22. Cuirass N 37978. Photo T. Lazar.

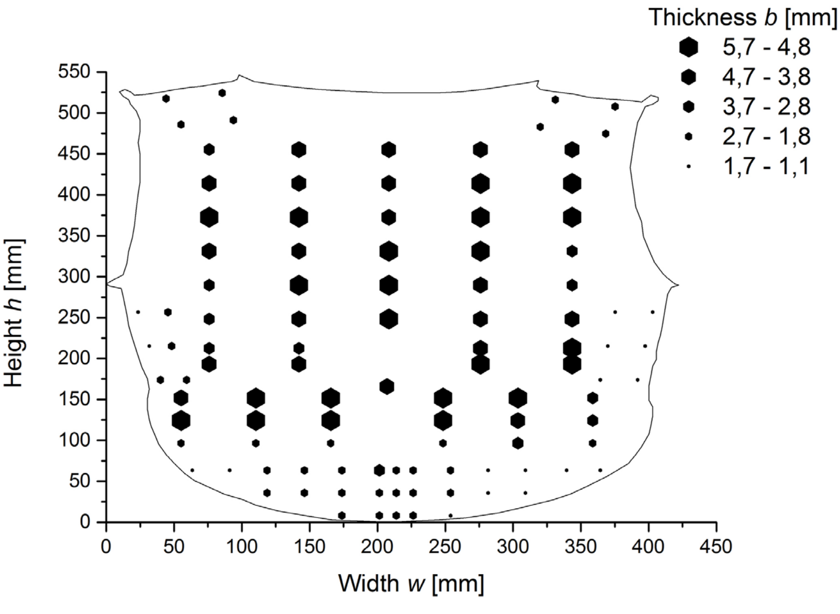

Fig. 23. Thickness mapping. Drawing J. Kraner.

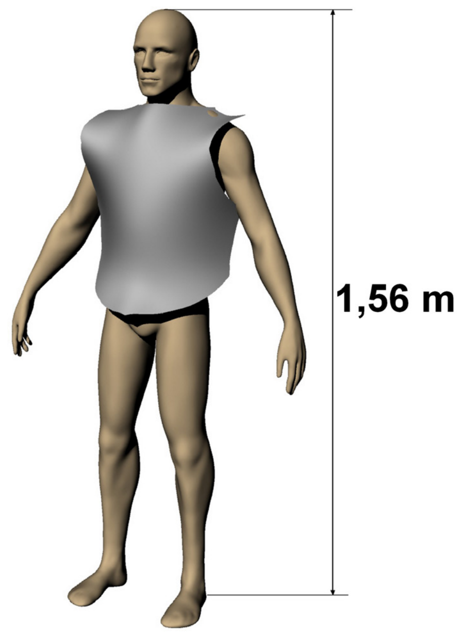

Fig. 24. 3D modelling of the armour in use. Drawing J. Kraner.

The breast section of the cuirass weighs 2.54 kg. It is 425 mm tall and up to 510 mm wide under the armpits. 125 thickness measurements were taken. The thickest areas were found across the abdomen, up to 3.2 mm. On the other hand, the lightest sections, covering the right shoulder area, are just 0.4 mm thick, resulting in a total deviation of 2.8 mm. As may be expected, the backplate belonging to the armour is lighter, though not by much. It weighs 2.17 kg. However, its thickness, ranging from 1.8 to 0.6 mm, is much more uniform. According to computer simulation, the armour would fit a person 1.69 m tall.

6. Breastplate

NMS, Inv. no. N 17776

Ca. 1600

The single-piece breastplate is quite massive, with thick, overturned edges along the neck and armpit cutouts. The central ridge is sharply defined and rises into a peak at the bottom in a characteristic 'peascod' shape typical of the final years of the 16th or very beginning of the 17th century. The bottom rim extends into a protruding fauld or flange fitted with two eyelets on each side, on which the tassets are fastened by means of rotating hooks. The surface of the armour is heavily decorated with etched battle scenes depicting armoured horsemen and pike-and-shot formations.

The breastplate belongs to a composite suit of armour whose authenticity has long been a matter of dispute. Recent research, which still awaits full publication, has confirmed that several parts of the harness were added during later restoration. The breastplate is genuine, though only of munition quality. It was made from very thick stock, clearly in an attempt to create a bulletproof defence. Its place of origin is difficult to determine due to the generic style, later restoration and absence of unequivocal identification marks.[21]

This torso defence is very heavy, weighing 5.68 kg, up to 434 mm tall and 514 mm wide. Its massive weight is reflected in the great thickness of material, up to 7.8 mm, even though it drops to merely 1.5 mm in the lightest sections. 54 measurements were taken all in all. The breastplate would fit a man approximately 1.72 m tall as indicated by computer modelling.

7. Austrian cavalry cuirass

NMS, Inv. no. N 37977
Mid-19th century, A. & E. Holler, Solingen

The heavy, apparently bulletproof breastplate is made in one piece. The armpit and neck cutouts are protected by upswept rims pierced with a line of holes for the attachment of padded lining, which is now missing. In use, the cuirass was fastened on the shoulders with two plated straps and a waist belt. None of these components have survived but three knob-like and two L-shaped fittings used to fasten the mounting straps may still be seen riveted to the breastplate.

Heavily armoured cuirassiers formed the elite shock troops of Habsburg cavalry throughout the early modern period.[22] From the mid-17th century onwards their body defences grew increasingly lighter, eventually retaining only the cuirass. With the army reforms in 1765/1771 even the latter was not worn complete any longer; henceforth, the cuirassiers were issued only a blued breastplate while the backplate was to be used exclusively in the event of war against the Ottoman forces, known for their preference of cavalry and close-quarter action. This practice continued until 1860, when metal body armour was dispensed with altogether.[23]

The single-piece cuirass weighs 4.90 kg. It is up to 510 mm tall and 580 mm wide underneath the armpits. Armour thickness was measured in 104 spots covering virtually its entire surface. The smallest measured values, in the range of 1.1 mm, were found across the shoulder area, sides and bottom rim. However, the central chest or torso area, particularly the right abdominal side, is up to 4.8 mm thicker, reaching a maximum value of 5.9 mm. Virtual 3D modelling suggests that the cuirass would fit a person 1.56 m tall.

8. Austrian cavalry cuirass

NMS, Inv. no. N 37978
Mid-19th century, Braun, Austria

The cuirass is essentially identical to N 37977, differing from the latter merely in minor construction details and its manufacturer. In both cases, the lining and leather straps have been lost. The original blueing has been mostly removed as well due to the harsh cleaning methods employed in the past as part of the conservation process.

The National Museum of Slovenia owns three breastplates of this particular type (N 35669, N 37977, N 37978), the latest pattern body armour to be issued to the Austrian cuirassier cavalry. The two described in this paper were both subjected to a proof test, as shown by bullet dents in the central left section of the chest area. A closer look on the inside section of the breastplates reveals a complex method of their manufacture. While the final products were made in one piece, the central section covering the vital area was apparently reinforced by welding an additional layer of steel.

The cuirass weighs 4.57 kg. It measures 510 mm in height and up to 570 mm in width under the armpits. 104 thickness measurements were taken across virtually the entire surface of the armour. The largest values, up to 5.7 mm, were measured in the central chest and abdominal area. The lightest sections are up to 4.6 mm thinner, measuring just 1.1 mm along the outer perimeter of the breastplate and toward the bottom rim. According to computer modelling, the armour would fit a person approximately 1.56 m tall.

Discussion

Detailed examination of armour thickness shows a considerable variation in the measured values, though in every instance there is a very clear gradation in the

[21] Blair 1958, 147-148; Krenn 1987, 52-55.
[22] Seaton 1973, 38.
[23] Thürheim 1866, 47; Pavlović 1999, 10.

strength of protection, reaching the maximum in the central areas of the breastplates and growing thinner toward the outside sections of the armour. Even discounting particularly bulky design features such as turned-over or roped edges, drastic differences may be observed between the thinnest and thickest areas – a ratio of 1:4 to 1:6, and occasionally as much as 1:8.

No doubt more complex additional analyses, particularly invasive or (micro)destructive methods requiring physical removal of samples, would be able to reveal important technological information, such as the material microstructure, technological characteristics and chemical composition of the objects included in our study.[24] Nevertheless, even a basic typological examination supported by careful measurements and thickness mapping allows us to categorize the examined torso armour into four distinct groups.

The first is represented by custom-made products belonging to the upper price range: namely, the N 35361 suit of armour made in the 1530s by Valentin Siebenbürger of Nuremberg, and the slightly later N 5044 'hussar' cuirass. In both cases, the body armour was designed to provide complete protection of the torso consisting of a breast- and backplate. In each case, the breastplate is fairly thick, reaching maximum values of over 3 mm. Conversely, the backplate was made somewhat lighter and thinner, consistent with the design tendencies and military practice of the period.

The second group of analyzed material consists of three 16th century breastplates of Nuremberg (or Central European) manufacture: N 4534, N 5043, N 5045. As typical examples of inexpensive 'munitions-grade' equipment they represent the most common spectrum of body defences worn by the rank and file. Armour of this type was generally made from low-quality materials and with relatively little attention to detail. Compared to a full suit of plate armour, its design was quite simplified, achieving a "generic" fit at the expense of reduced coverage and a smaller number of protective elements. It was also comparatively light, which was particularly important for footsoldiers and light cavalry preferring mobility over maximum protection.[25] The examples included in our study display some variation in material thickness and construction; all feature reinforced rims and roped edges to some degree, too. On the whole, they are relatively light and made of thinner stock than heavy armour intended for a mounted man-at-arms. Nevertheless, they could be expected to provide serviceable protection for the common soldier, probably better than any other practically available alternative such as mail or textile armour.

The breastplate N 17776 could be classified as another separate category. It has much in common with the previous group. Clearly, it is yet another example of low-end munition armour, quite simple in design as long as one disregards the gaudy etched decoration, which was presumably added much later and has nothing to do with the armour's original purpose. Nevertheless, the N 17776 stands out due to its great mass and thickness. It is evident that in this case, an attempt was made to create a torso defence as sturdy as possible simply by shaping it from very thick stock, with little regard to ergonomy or refined design.

The final group includes the two Austrian cuirasses from the mid-19th century (N 37977, N 37978). These were made from quite thick steel sheet, though not quite as massive as the N 17776. Taking into account the bullet dents present on their chest, they were obviously expected to provide protection from small arms fire.

An additional topic of discussion involves the sizing of historical armour. That the fighting man of the early modern period was significantly smaller on average than the modern male is not in itself a new finding. However, as demonstrated in our case, 3D computer modelling offers an entirely new venue of research possibilities. It allows us to estimate the size of person intended to wear a particular item of protective equipment without the potentially risky experimentation involving physical handling and wearing of fragile historical artefacts. At the present stage, this method is still entirely experimental but already shows considerable promise. No doubt it could produce even more consistent results with further improvements in the modelling technique.

While many more comparable items would need to be measured in detail for statistically relevant conclusions, our study seems to confirm that men from the upper classes – those able to afford high-quality armour tailored to fit their person – were generally larger than the lower strata of the population, from which the common troops were recruited. All the munition armour examined here is physically quite small, in some cases downright diminutive from the perspective of modern-day adult males. This holds true for the two Austrian cavalry cuirasses as well, even though that is not particularly surprising when one considers that cavalrymen in 19th century armies were usually selected from recruits of below average height.

Anyway, it is probably not a mere coincidence that the owner of Valentin Siebenbürger's suit of armour was clearly taller than the men expected to wear munition armours N 4534, N 5043 and N 5045 from roughly the same period. It seems likely that his superior social

[24] Lazar and Nemeček 2013.

[25] Blair 1958, 115-120.

status, combined with a diet higher in protein, contributed to his taller stature.[26]

Effectiveness of torso armour and the threat of firearms

The proliferation of gunpowder weapons proved to be a crucial factor in the development of body armour. Due to the increasing competition of firearms in the 16th century armour making experienced a gradual but steady decline.[27] Many attempts were made to improve the strength of torso armour, usually by increasing its thickness. Toward the mid-17th century, metal body defences finally lost the competition against the musket; a suit of armour simply could not be made strong enough to reliably protect the wearer while keeping its weight within acceptable limits.[28]

However, that in itself did not mark a complete demise of metal body armour. Particularly in Eastern Europe and the Balkans, mail and plate defences continued to be worn well into the late 18th century due to the relatively greater role of cavalry action and reliance on mounted shock tactics as exemplified by the steppe nomads and Ottoman armies. Even in Western and Central Europe, cuirassiers wearing heavy body armour remained a key component of Napoleonic-era cavalry.[29]

The cuirass of the Napoleonic period covered only the wearer's torso. It had no provision for additional tassets, shoulder or limb defences. Due to its limited size and coverage it could be made from quite thick steel, resulting in a torso defence that was heavy and uncomfortable but still within the absolute limits of human endurance, as well as strong enough to provide some measure of protection from bullets at least across the most important vital areas of the human torso. Still, the rapid development of firearms in the second half of the 19th century, and moreover the introduction of superior nitrocellulose-based propellants and conical bullets, dealt the ultimate blow to steel torso armour as a practical means of personal protection.[30]

Even the earliest examples of armour included in our study date from an era when the use of gunpowder was already well established in Europe. Apart from two light infantry armours (N 5043, N 5045) that were evidently made from quite thin sheet reaching no more than 2.1 or 2.2 mm, all the other examined breastplates are much stronger in critical areas. The 'hussar' cuirass (N 5044) is comparatively light, as one would expect from defensive equipment specifically intended for highly mobile cavalry. However, the central area of the breastplate is up to 3.2 mm thick and the presence of a bullet indentation implies that it was proof against small arms fire.

The breastplate belonging to the suit of armour made by Valentin Siebenbürger (N 35361) is somewhat thicker still, comparable to N 4534. An even more dramatic difference is observed in the case of breastplate N 17776, where the vital areas are protected by almost 8 mm of armour. The use of such heavy-gauge material indicates an attempt to create an absolutely solid bulletproof defence. The final two breastplates, mid-19th century Austrian cuirasses N 37977 and N 37978, follow the same trend; both were proved by firing a test shot as well, as demonstrated by the clearly visible bullet dents.

Just how well any of the armour included in our study would have protected its owner from small arms fire is a difficult question. The answer depends as much on the thickness of the material as on its quality and mechanical properties. To date, only the breastplate belonging to Valentin Siebenbürger's harness N 35361 has been investigated in detail by metallography. The analyses showed that it was made of low-carbon steel containing approximately 0.27% manganese; its microstructure contains 96% ferrite and 6% pearlite in addition to some non-metallic inclusions.[31]

In comparison to the range of materials available to the 16th century craftsmen, the low-carbon steel used by Siebenbürger in this particular case was superior to wrought iron used for the production of cheap munition armour, but could not rival the performance of properly heat-treated medium carbon steel used by the leading master armourers of the day. Based on A. Williams' calculations regarding the effectiveness of medieval and early modern armour it seems that the breastplate belonging to Siebenbürger's N 35361 would offer reasonable protection against handgun and arquebus fire, even though it probably could not stop a direct hit of a heavy musket ball at close range. Needless to say, all the other elements of the harness except for the closed helm are made of much thinner steel (1-1.5 mm) that could be easily penetrated by bullets, even though they could protect the wearer quite reliably from cut-and-thrust weapons, and also arrows and crossbow bolts to some extent.[32]

The material composition of all the other armour discussed in the study has not yet been determined with analytical methods. Considering the fine craftsmanship of the hussar cuirass N 5044 there is reason to expect that it was made of high-quality materials. If so, it is

[26] Cf. Štefančič 2008, 24-28.

[27] Williams and de Reuck 1995, 6-26.

[28] Blair 1958, 143-155.

[29] Thürheim 1866, 44-48.

[30] Dolleczek 1970; Chant 1996.

[31] Kraner 2016; Kraner et al. 2019.

[32] Williams 2003, 927-929, 945-949.

possible that its chest section was indeed bullet-resistant to some degree as implied by the proof mark.

Similar bullet indentations appear on the Austrian cavalry cuirasses N 37977 and N 37978. These belong to the last generation of steel body armour still in regular use by European armies. As such, they are already products of the industrial era. It is an interesting question whether the more advanced metallurgical techniques available at the time did in fact translate into markedly improved armour protection. The additional layer of material carefully welded on the inside central portion of the breastplates indicates a conscious attempt at creating a stronger defence, hopefully sufficient to stop an incoming bullet.

The presence of bullet dents is often interpreted as evidence that the armour so marked was in fact tested and found to be resistant to small arms fire. A recent thorough investigation of this hypothesis has largely dispelled such notions; the majority of "proof marks" analyzed by the research team were apparently produced by relatively low-energy impacts, an order of magnitude below the kinetic energy of a typical musket bullet at realistic combat ranges.[33]

This may well be the result of a flawed testing methodology, and possibly a deliberate use of much reduced powder charges during the proving process. Still, the widespread popularity of armour testing procedures shows beyond doubt that the contemporary craftsmen invested considerable efforts into the development of bullet-resistant body defences. Nor can it be merely a matter of psychology and successful marketing that "armour of proof" continued to be in high demand until the final demise of steel body protection. Even if such equipment could not withstand the direct impact of a musket bullet, it might nevertheless be able to protect the wearer from a glancing hit, or less powerful pistol or arquebus shot.[34]

In any case, it seems striking that no proof mark is to be found on the breastplate N 17776, which is decidedly the thickest of all the armour presented in this study. Most of its central front area measures from 7 to 8 mm in thickness. Even if made merely of low-quality wrought iron typical of the period it may be reasonably assumed that it could withstand a bullet from just about any kind of shoulder-fired weapon available at the time. However, such performance was attained at the cost of an uncomfortably massive, completely rigid construction. It is not difficult to understand why the wearing of such heavy defences was highly impractical in many situations, finally leading to the demise of steel armour.

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[33] Williams et al. 2006.

[34] Blair 1958, 143-147, 154.

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Streszczenie

Mapowanie grubości osłon tułowia.
Studium porównawcze ośmiu napierśników z Muzeum Narodowego Słowenii

Publikacje naukowe na temat zbroi historycznej często zawierają zaskakująco mało informacji dotyczących jej wagi czy grubości. To skutkuje błędnymi wyobrażeniami na temat zbroi płytowej z okresu średniowiecza i wczesnego okresu nowożytnego. Celem niniejszego studium jest szczegółowa analiza techniczna ośmiu przykładów płytowych osłon tułowia, pochodzących z okresu od początku XVI do połowy XIX wieku. Każda z nich została szczegółowo zmierzona, a mapowanie grubości zaprezentowano na wykresach graficznych. Na tej podstawie można było prześledzić koncepcje projektowe oraz wskazać różnice w tym względzie między odmiennymi typami zbroi. Ujawnił się wyraźny wpływ upowszechniania się broni palnej na projektowanie coraz cięższych kuloodpornych osłon tułowia. Wykorzystano ponadto eksperymentalnie wirtualne modelowanie 3D, co pozwoliło ocenić wzrost osób potencjalnie użytkujących badane zbroje.