Scaling universality and quantitative analysis of historical edged weapons based on allometric equation.

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Allometric scaling has been demonstrated for many biological organisms, but similar analysis was only recently extended to material objects [3]. In this work we demonstrate that a vast majority of historical edged weapons exhibit exponential scaling of mass with length, and the scaling exponent is directly related to the weapon's type, typically assuming values between 1.5 and 2.5. We also show that measured scaling exponent and characteristic mass of a given set of weapons can serve as unique quantitative identifiers, allowing for a more precise attribution and dating of artifacts.

In biology, it has been well established that for most animals the mass *m* grows exponentially with a characteristic size parameter *x*, such as height (Eq. 1) [1, 2]:

$$m = Cx^b \qquad (1),$$

where *C* is a constant. A typical value of the exponent *b* is below 3, but above 2 [8], and remains reasonably consistent for the given species. Related observations have been established recently for material objects, such as airplanes [3].

In light of this, it would be of interest to see how the mass of historical edged weapons varies with length, whether it adheres to the dependency provided by (Eq.1), and what are the key factors affecting the values of parameters involved. It has to be immediately noted, that the suitability of fitting any such dataset to (Eq.1) relies on properly identifying existing “phenotypes”, since each of them is expected to have its own value of *b* parameter. For biological organisms different genus and species can be objectively separated based on DNA analysis, and further distinction, if required, can be made on the basis of population’s location and ecosystem. In case of weapons the analysis is intrinsically more subjective, as classification and dating of weapons heavily relies on visual observations. Indeed, typically for these purposes one first identifies a set of weapons, for which the dating and attribution are possible based on associated provenance, signatures, or archaeological methods, and then other artefacts are studied on the basis of comparison with this set. It can be theorized that visible similarity of signatures and overall shape might not be enough in some cases to determine that one deals with the same type of weapon, thus corresponding to specific values of parameters in (Eq.1). Alternatively, it is theoretically possible that weapons belonging to the same type (as determined on the basis of similar shape, design and functionality) would still have different values of *b* parameter, depending on historical period in which they were produced.

On the other hand, it is difficult, if not impossible, to supplement visual observations with any quantitative experimental technique. Carbon dating is largely inapplicable, due to the common use of mined coal in steel production. Metallography [4] and isotope analysis [5] play important, but limited roles, as both are destructive, and results are often inconclusive - drastically different sword types, produced in different regions, can still exhibit substantially similar isotope content and microstructure [6]. Numerous attempts have been made to classify and date weapons based on geometric measurements alone [7], but since even swords belonging to the same type, produced in the same year and in the same workshop can still have substantially different lengths and even curvatures, the methodology required to yield definitive results is bound to be too complex for practical use.

This lack of either objective criteria or methods that would allow one to identify the distinctive "phenotypes" prompts us to propose that the allometric scaling analysis itself can be used to verify the validity of the existing classification. If we are to assume that a specific type of weapon indeed corresponds to a specific relationship between its mass and length, most types identified on the basis of conventional visual analysis should reasonably well satisfy (Eq. 1). There would however be cases, for which fitting to (Eq.1) or other allometric formula results in poor match with the data; one can then attempt to reexamine the classification, and see if studying certain subsets of this type individually might could lead to a substantial improvement in the accuracy of the fitting results – suggesting that these subsets are more than just regional, decorative variations of the same design.

We intend to demonstrate throughout this article that such approach does exhibit substantial level of self-consistency and thus not only provides a mathematical description of scaling for the types previously identified, but allows for further refinement of the existing classification. To give just one example, initially we considered edged weapons shorter than 55cm as daggers, and those longer as proper swords. This separation is commonly assumed in the literature [9], based on supposedly different functionality, i.e. mostly thrusting weapons below this size, and cutting – above. However, it became quickly apparent (Fig. 4) that nearly all weapons between 55 and 70 cm of total length exhibit the same mass to length dependency as daggers, and including them with swords would significantly distort the analysis of the latter. Therefore, we chose to adjust the classification to consider all weapons shorter than 70cm as daggers, which immediately allowed us to assign distinctive values of *b* parameters to most of the sword and dagger types under consideration (Table 1).

In this publication we will address only the data for swords and daggers, 224 artifacts in total, because of the profound role these weapons plaid in human history, as well as due to the fact that unlike spears or maces, they come in a substantial range of weights and sizes. We confine ourselves to the period between tenth and nineteenth centuries AD, though the present method can easily be extended to the earlier finds, including those from the Bronze Age. There is also emphasis on Asian weapons, since they have been a subject of our previous publications [10, 11], and thus we are extensively familiar with their classification. European swords are included for comparison purposes only (Fig. 5), as detailed classification of European types is beyond our current ability.

In all cases, we record the total length, from tip to pommel, as well as the mass of what would be a battle-ready, drawn out sword, i.e. accompanied by guard, pommel and other period fittings, but not including a scabbard. Unfortunately, in many cases there are complications caused by drastic differences in physical condition of the swords. Excavated examples usually lack some of the fittings, and their surface can be contaminated; among other weapons included in the analysis many were reworked at some point, and thus do not have their original, period specific, length and mass – a consideration especially important with regards to the Japanese swords, nearly all early examples of which were reworked in 16th-17th centuries, and also, supposedly, experienced substantial material loss due to repeated polishing.

In the present study we thus chose to consider only the best preserved blades, and did not adjust the measured parameters in order to account for condition differences, aside from common missing parts, for which we increased the measured weight by what we believe to be a representative average. For a full length Japanese sword (for all dagger-size Japanese weapons, only those with all of the fittings intact were considered), we added 140 g to account for a missing Japanese *tsuba* guard, 35 g for *habaki*, and 140 g for *tsuka* hilt. As Japanese fittings were usually not made for a specific sword, this approach is likely to result in only slight errors, mostly affecting the shortest and the longest of the swords under consideration. Similarly, for the dugout Steppe swords we assumed 110 g for a missing guard, 35 g for a missing pommel and 120 g for a missing hilt, not including the guard and pommel.

With Japanese swords, there was a further complication that majority of the data was taken from a publicly available external database, created by a sword dealership *Token Hataya*. Per Japanese tradition, the overall length is not measured, instead the length of the "active part" of the blade, between the tip and the hilt portion, so called *nagasa,* is provided. The measurements (Fig. 1) conducted by us and our collaborator, Dmitry Pechalov, demonstrate that there is a strictly linear relationship between this value and the total length. Such being the case, the analysis specific to Japanese swords (Fig. 7) in this publication involves *nagasa* rather than a total length, but for comparisons with other weapons, the value of total length is extrapolated on the basis of the linear fit, produced from the data shown in (Fig. 1). This concerns only the proper long swords, as all items shorter than 70cm of total length were analyzed using the total length only.

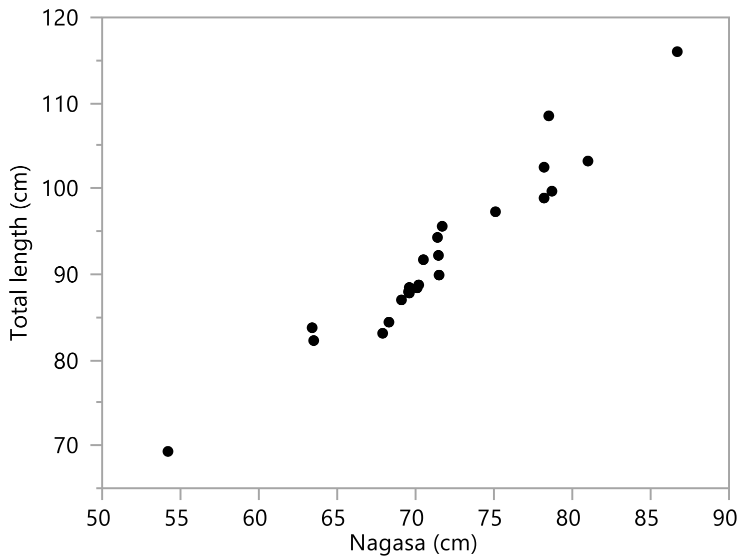

Figure 1. Nagasa (length of the portion above the hilt) versus the total length for a selection of Japanese long swords.

For most European longswords, Polish-Hungarian sabers, military swords, two shashkas, one Western Georgian palash, as well as some of Caucasian kindjals, the measurements were provided by Livrustkammaren Museum, Stockholm, Sweden. For Japanese swords, the measurements were mostly provided by Dmitry Pechalov, private collector, or taken personally by the article’s author.

In order to measure the exponent parameter *b*, one would typically plot both mass and length on a logarithmic scale [8], and then fit the data with a linear function. However, there are some intrinsic difficulties in applying (Eq. 1) to the case of edged weapons. First, there are always a few unusual, custom made examples, with extreme length and weight, which can substantially skew the fitting procedure. At the same time, as of now the number of measured data points available is relatively few, especially for such cases as excavated Steppe swords, so discarding all of the examples with extreme values of mass or length is ill advised. Second, and more importantly, the mass of a weapon is generally expected to follow a more complex dependency than the one defined by (Eq.1), for example:

$$m = C_1 x^b + C_2 x^a \qquad (2).$$

The first part with the exponent b is due to the edged portion of the blade. The second, with the exponent a, includes tang, guard, hilt and possibly other fittings. One could imagine that at least for some of the latter elements the mass exhibits only slight correlation with the weapon's length, and thus the value of a is expected to be considerably smaller than that of b.

But while (Eq.2) might appear a more correct form in principle, it is substantially more difficult to use. A practical approach then can be to simply estimate the errors, incurred by using the (Eq.1) instead. It appears that only for select few cases such forced simplification presents an issue. First and foremost these are Japanese long swords, where the weight of fittings (guard+hilt+habaki) is considerable, yet almost length-independent. The impact of using (Eq. 1) can then be negated by performing the fitting for bare blades instead (Fig. 7), accounting for the weight of fittings only when comparing Japanese swords to other weapons. In almost all other cases, the fittings are more or less an integral part of a weapon, or there is a functional requirement for them to scale similarly to the rest of the blade, for example, to counterbalance the increase in the weight of the edged portion, i.e. they do change significantly in weight between very short and very long blades. Therefore, it will be shown that allometric scaling for the bare blades (Fig. 7) exhibits more or less the same behavior (Eq.1, Fig. 6) as that of the complete weapons.

As it will be shown in the present article, a more important consideration is that using only b parameter in (Eq.1) is insufficient to describe the distinguishing features of a given sword geometry. Its value is determined by how the weapon's cross-section changes when its length is being increased, in order to maintain a torsial rigidity without too much increase in weight. Yet different types of weapons are expected to also have substantially different cross-sections and curvatures; it is not uncommon for blades to have a similar value of a *b* parameter, but substantially different mass for the same overall length. One thus has to provide a way to also describe vertical offsets between the mass versus lengths dependencies exhibited by different weapons (as seen, for example, in Fig. 7). It could be done by recording the fitted value of *C* from (Eq.1), however we choose instead to use a characteristic mass, the one that would correspond to a weapon of average total length for the given class – 45cm for daggers, 95cm for long swords (Table 1). The advantage of using this parameter is that it allows to immediately pinpoint the difference with minimal fitting errors, especially when different types of weapons form separate clusters of data, which we will demonstrate to be an important practical consideration.

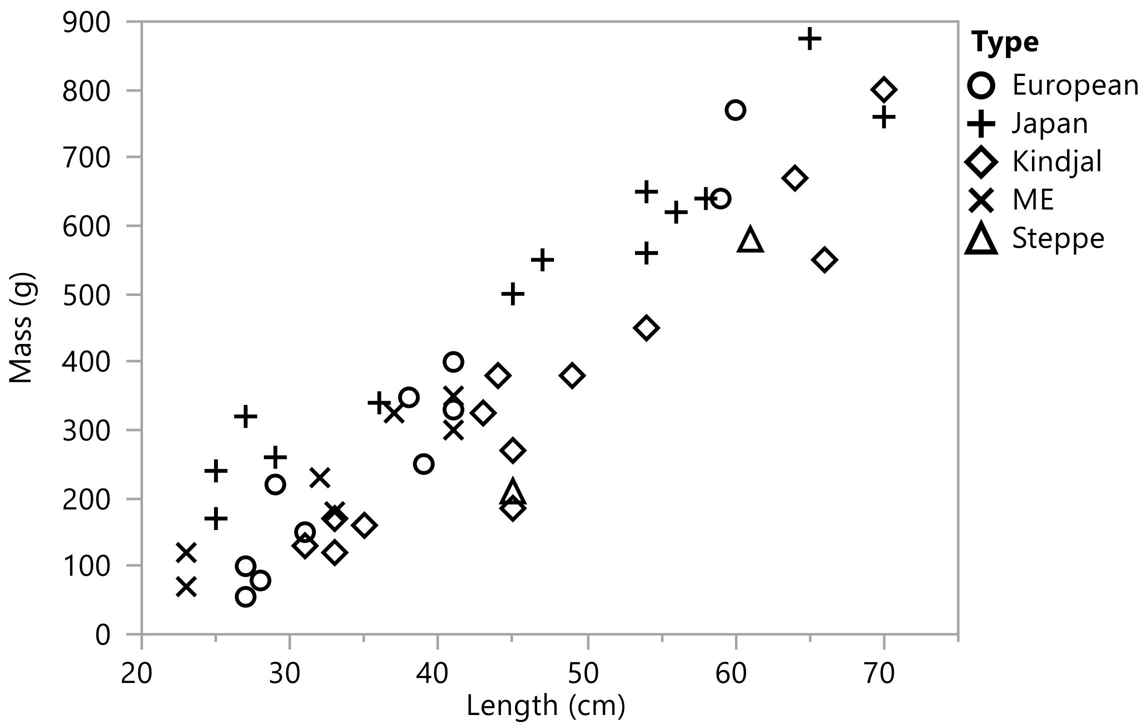

Figure 2. Mass as a function of length for daggers. Identified here are: European, various 15th – 17th century Western European types; Japan – 13th – 18th century tanto and wakizashi; Kindjal

– 19th century Caucasian, Turkish and Persian kindjal daggers; ME (Middle Eastern) – 16th – 18th century Persian and Ottoman daggers; Steppe – 14th century Mongol period daggers from the Pontic-Caspian Steppe.

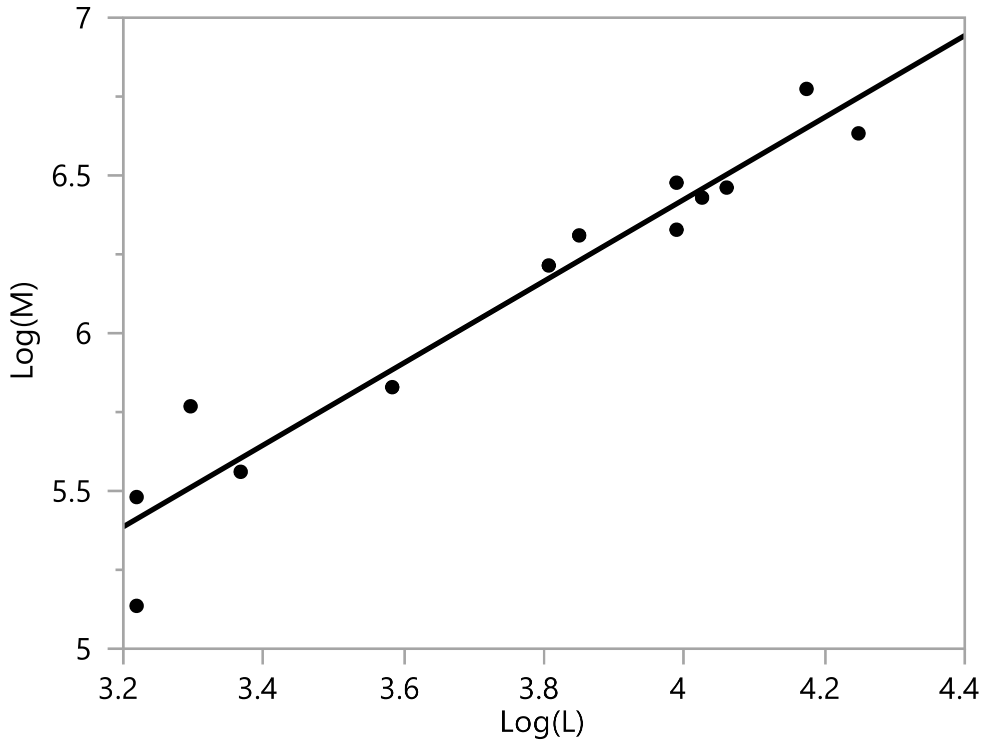

Figure 3. Logarithmic plot of mass versus length for Japanese daggers (tanto and wakizashi) with a linear fit of the data, corresponding to b=1.3.

Weapon	Characteristic mass, g	*b* parameter
European dagger	412	2.5
Kindjal	392	2.2
Japanese tanto and wakizashi	446	1.2
Middle Eastern dagger	371	2.2
Steppe sword	837	1.5

Japanese sword	997 (Koto) and 1105 (New)	1.6
Polish-Hungarian saber	842	1.6
Shashka	678	N/A
Zweihander	N/A	3

Table 1. Characteristic mass and b parameter for various types of weapons.

We start by using a selection of daggers, produced between the 13th and 19th centuries, between Japan in the East, and Germany and Italy in the West (Figs. 2-3). What is immediately apparent is that there is a significant spread of measured masses for very short daggers, i.e. those below 30cm of length. Most of variation is due to the mounts' weight; for example, one of Japanese daggers included in the study came with a gold guard, whose weight by itself if 122 g, despite its diminutive size. However, since quite a few *kindjals* and European daggers are of integral design and cannot be in principle disassembled, we have to accept these limitations. Still, in terms of characteristic mass most daggers are quite close to one another (Table 1), with an exception of Japanese daggers. The latter's additional weight is due to thicker tang portion, as well as complex and heavy fittings.

When using a logarithmic scale we see a similar picture in a sense that all types of daggers considered (European, Middle Eastern, Caucasian kindjals) have the fitted values of exponent *b* that lie between 2 and 2.5 (Table 1), with the sole exception of Japanese daggers (Fig. 3). The latter is affected by two factors: first, heavier fittings disproportionally impact the weight of its short length version, and second, the longer version, *wakizashi* (between 50 and 75cm of total length), is more a shortened sword, rather than a very long dagger by design, and as we will see in the next paragraph swords tend to have much smaller *b* parameters than daggers. As a result, Japanese *tanto* are somewhat heavier than expected for a weapon of their length, but *wakizashi* are somewhat lighter, and overall dependence of Japanese short edged weapons' mass on length is uncharacteristically shallow.

It is apparent from (Fig. 4) that the mass does not become a limiting factor until its value reaches about 1000 g, so the scaling exponents of short weapons all tend to be relatively large (Table 1). This is also consistent with an observation that even the longest weapons in this class [9], save for some Japanese *wakizashi*, indeed evolved from daggers and thus retained the same characteristic proportions. Upon reaching 1000-1100 grams, roughly corresponding to the length of 70cm, the transition to sword forms is accompanied by a discontinuity, which can be observed in both the linear slope of mass versus length, and in the first derivative of *b* parameter (Fig. 4). From there and until 140cm or so of total length, more or less all sword designs exhibit *b* parameters between 1.5 and 2.2 (Fig. 4), with values around 1.5-1.6 being especially common (Table 1). However, above 140-150cm, especially with two handed German swords (*zweihanders*, Fig. 4 and Table 1), we see the return to "heavy" designs, as *b* parameter jumps to 3. *Zweihander* appears to be the only sword type among those considered by us, which scales equivalently in all three directions, possibly since at such extreme length, this weapon requires progressively thicker cross-section to strengthen the blade, thus apparently a much larger increase of mass per cm of length. It is interesting to note that the largest zweihanders, in 190-200cm range, are often considered to be presentation rather than combat-ready weapons due to their mass, however their *b* parameters are well within the range expected for the type, meaning that they belong to the same, "combat" design as somewhat shorter examples, i.e. it is quite possible that these were still intended to be combat-ready, though placing extreme requirements on their users.

But at the same time almost all practical evolution of long swords is confined to the overall lengths between 70-75 and 140cm. Apparently, in this case the weight can be a substantial detrimental factor, so even the longest specimen do not exceed the value of 1400 grams, and much effort was expanded to keep the weight of most swords under 1100 grams.

Let us now discard daggers and zweihanders and confine our interest only to proper longswords with the total length between 70 and 140 cm (Figs. 5-7).

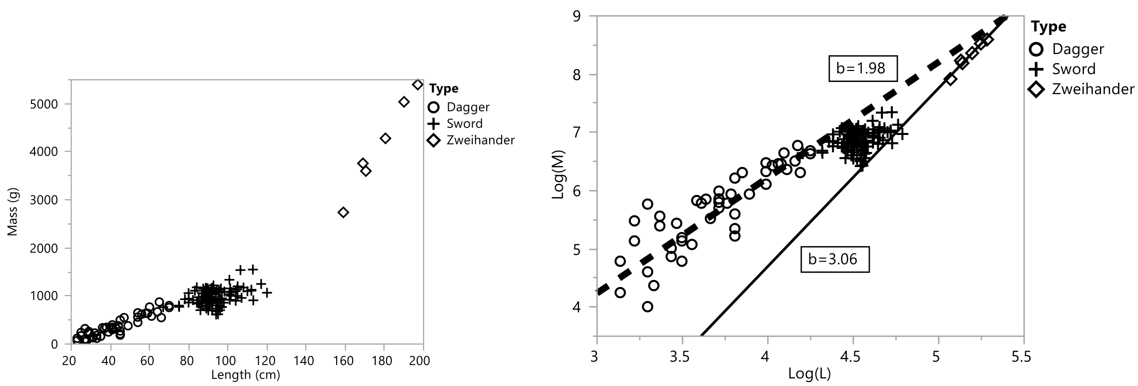

Figure 4. Mass versus length for pre 19th century swords (excluding European long swords due to a substantial spread of values exhibited by this class of weapons) and daggers combined – logarithmic (left) and linear (right) scales. On the logarithmic plot, two particular fitting curves are shown, corresponding to b=3.06 (zweihanders) and 1.98 (all daggers combined together) respectively.

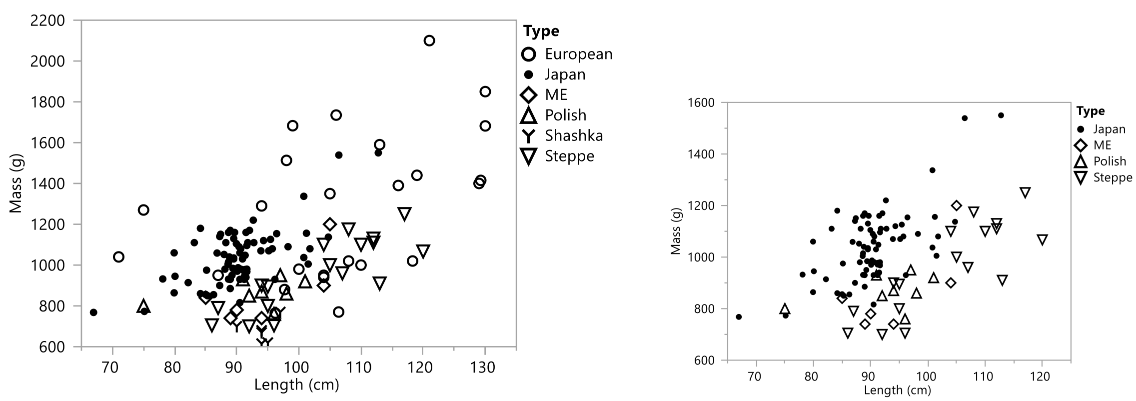

Figure 5. Mass versus length for longswords. Identified here are: European, various 11th – 17th century European (mostly Viking and German) types; Japan, 12th – 19th century long swords; ME (Middle Eastern), 17th – 18th century Persian and Ottoman swords; Polish, 16th to early 18th century Polish-Hungarian sabers; Steppe, 10th – 18th century swords from the Pontic-Caspian Steppe; Shashka, six shashka examples, dating to circa 1790-1860. The plot on the right omits the data for European and shashka swords.

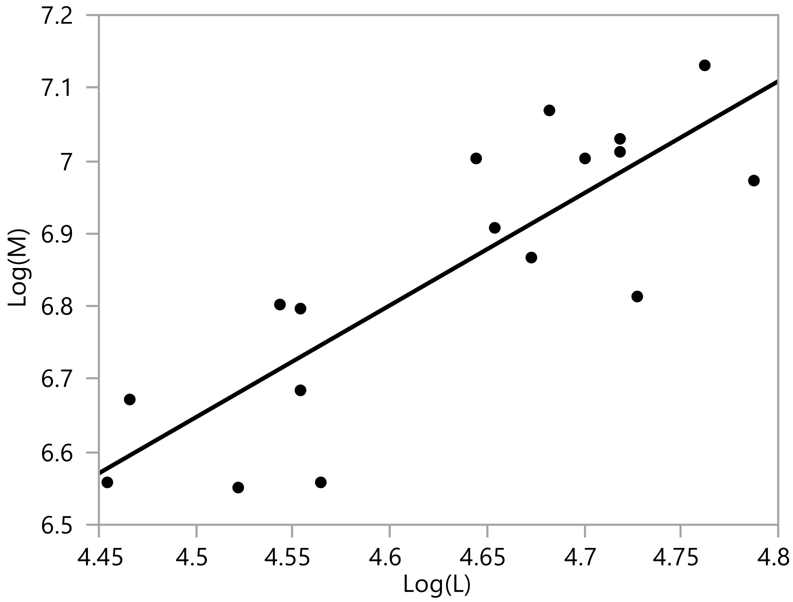

Figure 6. Mass versus length for swords from the Pontic-Caspian Steppe region (10th – 18th century), using logarithmic scale. The linear fit produces the value of b parameter of 1.53.

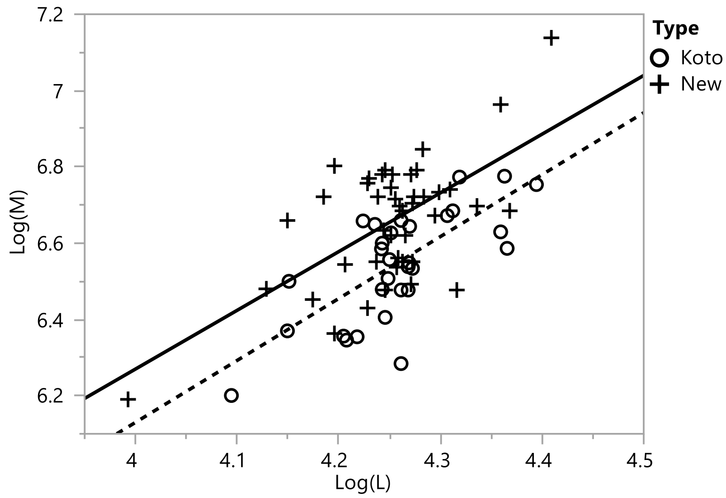

Figure 7. Mass versus length (measured from tip to hilt, i.e. nagasa) for Japanese swords from the Kamakura to Muromachi (so called Koto type, literally "old swords"), and Edo (so called New type, i.e. so called shinto and shinshinto) periods, with respective linear fits – solid line (b=1.53) for the New type, dashed (b=1.62) – for Koto.

It immediately becomes apparent, that compared to both daggers and zweihanders, for longswords one observes a far greater variation in mass for any given length, even when considering only the weapons from the same culture and the same general historical period. It can relate to a more intensive customization, required to fit the needs of both tall and short fighters.

Such variation is especially apparent with European swords, to the point that there is no single value of b parameter that can be assigned to the given class (Fig. 5). This might come as a surprise, given that all these swords are double edged examples, mostly with roughly similar length and geometry, specifications retained at least from Merovingian period. However, it matches well the argument advanced among others by [14] that in fact these swords have a varied functionality – during some time periods they were more oriented towards cutting, and in other periods – towards thrusting. Without a more detailed classification of European swords it is thus impossible to provide any quantitative metric. It is clear nevertheless that in terms of characteristic mass both European and Japanese swords are substantially heavier (Fig. 5, Table 1) than other weapons considered. In both cases we deal with, to the large extent, infantry weapons, which allows, if needed, for two handed usage, and therefore the weight constrains are substantially relaxed when compared to strictly single hand, cavalry weapons, such as Steppe, Middle Eastern and Polish-Hungarian swords. Japanese blades are also of ridged construction [11], which for the same width and length of a sword should result in a heavier product. For Japanese swords, there is also a very substantial increase in mass (Fig. 7) in “new swords”, so called *shinto* and *shinshinto*, i.e. those produced during the Edo period, compared to those produced earlier, so called old swords or *koto*. It is surprising that this change occurred rather abruptly at the end of the 16th century, as when we consider swords produced during Kamakura, Nambokucho, Muromachi, early and late Edo periods separately, only the difference between Muromachi and early Edo period swords particularly stands out, the former still being basically similar in their linear density to Kamakura period swords, and the latter not that different from those of the 19th century. This excludes the possibility that the difference is solely due to additional applications of traditional Japanese polishing, which does remove a lot of material from the sword’s surface and therefore thins out the swords more or less linearly proportionally to their age. Apparently, this effect is dwarfed by the design, and possibly even related material changes, which occurred close to the beginning of the Edo period.

Overall, the significance of characteristic mass and *b* parameter respectively follows similar trends that we already observed for daggers. Characteristic mass shows a significant correlation to the weapon’s origin and date (Table 1), while *b* parameter relates to its basic type and functionality. Practically all sabers – those excavated in the Steppe, Polish-Hungarian and

Japanese ones, all retain the *b* values around 1.5-1.6 (Table 1), in all these cases these were obtained with a substantial accuracy from linear fits in the logarithmic space (Figs. 6-7). We predict that similar values would have been obtained by fitting the parameters characteristic to Middle Eastern sabers, but too few of those were considered by us in the present work, so we do not have any reliable estimate.

This relatively low value of *b* parameter, substantially below that of daggers and likely lower than that of European longswords, in particular allows for much lighter weight of long sabers (Fig. 5). It is especially evident in case of Japanese swords, which, are comparable in terms of mass to their European counterparts for smaller lengths, but are generally substantially lighter around 110cm and above, despite being a comparatively heavy saber type. The difference becomes extreme for shrine presentation swords, which maintain the proportions of regular weapons: those measuring slightly above 200cm would weight somewhat in excess of 4kg, i.e. substantially below an expected weight of a similar zweihander.

But can these observations actually improve our ability to attribute or date the existing artifacts? Let us consider two particular cases.

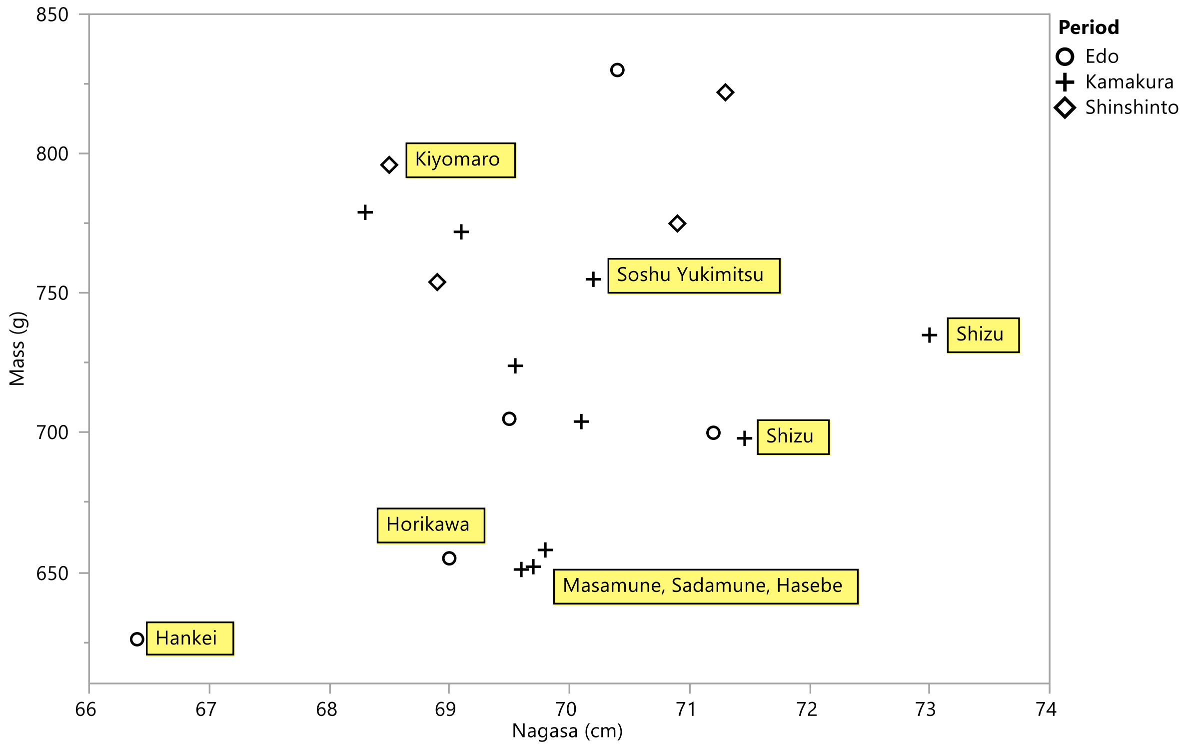

Figure 8. A selection of swords from what can be considered a "Masamune school", including the ones that were previously attributed as the works of Masamune.

The first one concerns probably the most contentious issue in the subject of Japanese swords, that of Masamune (Soshu) school and its works. Without going into too much detail, the problem can be summarized as following:

- The leading publications and collections' inventories dating prior to 1430 AD or so do not mention Masamune's school, despite that current scholarship believes it was active around the first half of the 14th century.
- In the 16th century the school somewhat suddenly attains an unsurpassable reputation of arguably the most important one in the history of Japanese sword.

- A very large number of imitations were produced in the centuries that followed, while the works of most important school's participants (Masamune, Sadamune, Go etc.) are currently considered to be either all unsigned, or very seldom signed. Because of this, attributions of specific works to Masamune are more or less contentious and most have been at least at some point reconsidered over the last centuries.

Can quantitative analysis help us distinguish a "real", 14th century Masamune from later imitations? In (Fig. 8) we show a number of works in Soshu (Masamune) style, together with their current attributions. It appears that the trend observed here is similar to that exhibited by the set shown in (Fig. 7). Shinshinto period (19th century) swords are generally the heaviest, but unlike (Fig. 7) the earlier Edo period (Shinto) example are basically indistinguishable from the Kamakura or Nambokucho period "originals". The two works by Hankei and Horikawa (Fig. 7), until recently attributed to Masamune, are especially lightweight, a very close match to the cluster of data formed by the most representative works of Masamune's school – those attributed to Masamune, Sadamune and Hasebe respectively. The fact that the latter three are so similar to one another is related to all of them being shortened at about the same time – between the very end of Muromachi until the very beginning of the Edo period, to more or less the same specified length. However, while this explains their similar lengths, such a close match potentially also hints towards a more close relationship between their makers, especially compared to their more distant contemporaries, such as those who worked in Shizu style (i.e. those traditionally attributed as works of Kaneuji from Shizu village).

From this very limited set of data (just one Masamune example, compared to at least one hundred swords in total as of now attributed to him with some certainty) we can only state that the method indeed has some potential. It shows that a number of high class Masamune school swords were shortened to about the same length and have very similar mass and likely other physical parameters, however the first class Edo makers famous for their copies and imitations of Masamune works (Hankei, Horikawa, likely also Yasutsugu) were able to reproduce those with substantial accuracy. The same cannot be said about later, in particular 19th century, imitations, which are substantially heavier on average. Whether the blades attributed to Masamune and his supposed closest associated (Sadamune) indeed exhibit together a very substantial clusterization of characteristic mass values is something that remains to be seen.

The second problem that we would like to address is regarding the origin of blades found on a Caucasian sword called *shashka* – a guardless saber, mostly produced in the 19th century. Currently there are the following leading theories regarding this type of swords:

a. It is an enlarged version of dagger-knife, judging by the name *shashka* being derived from "large knife" in Adighe language. Alternatively, it is sometimes speculated that the "knife" that was enlarged refers to a machete.
b. It uses reworked 17th century Polish-Hungarian blades, judging by the fact that in both cases the blades exhibit a few narrow fullers and are signed with stamped "sickle" marks, so called "*gurda*". It also likely to have evolved from Polish-Hungarian hussar sabers.
c. It is a variation of 18th century Western Georgian guardless single edged swords, judging by the presence of similar fullers, signatures, and similar guardless hilts [12].
d. It is a combination of a native guardless mount with an analogue of a contemporary European military blade, which for some reason was purposely given an antiquated look ("gurda" signatures, narrow fullers etc.), imitating the appearance of earlier Polish-Hungarian swords.

e. It is a variation of 18th century Middle Eastern swords or daggers.

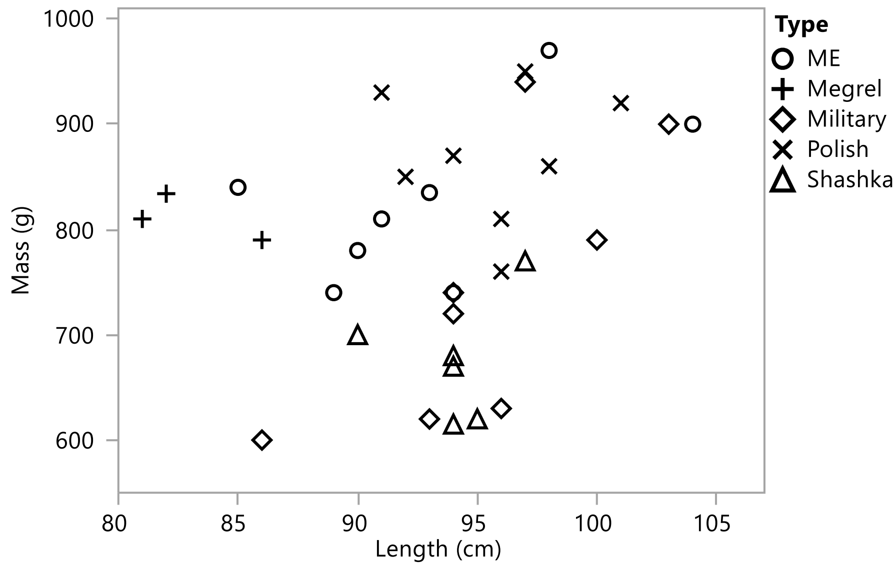

Figure 8. Mass versus length for selected single edged swords. Identified here are: ME (Middle Eastern) – 17th – 18th century Persian and Ottoman swords; Polish – 16th to early 18th century Polish-Hungarian sabers; Megrel – three Western Georgian (Imerethi-Megrelian) single edged swords, circa 1770-1800; shashka – six shashka examples, dating to circa 1790-1860; Military – various European cavalry swords, circa 1800.

Type of Blade	*Signature on the blade*	*Decorative motifs, approximate year*	*Mass, g*	*Length, cm*
Hussar	*None*	*Russian/Cossack 1790s*	*620*	*95*
Gurda	*Georgian, 1840s*	*Tbilsi, Georgia, 1840*	*615*	*94*
Gurda	*Gurda*	*Tbilisi, Georgia, 1840*	*680*	*94*
Gurda	*Gurda*	*Circassian, 1820s*	*670*	*94*

Hussar	*Running Wolf*	*1860s*	*770*	*97*
Hussar	*None*	*Mid 19th century*	*700*	*90*

Table 2. Six shashka swords chosen for comparison with other types. The classification follows the guidelines provided by us in the earlier publication [10].

Let us attempt to resolve this question by looking at the mass versus length dependency of various *shashka* swords. For this purpose we chose six *shashka* examples (Table 2), with a wide range of signatures, types of blades and decorations, and even supposedly somewhat different origin – Georgia, Circassia, Russia. It should be noted that while there are likely late 17th century depictions of shashka swords [13], the examples available to us with but a few exceptions come in the 19th century mounts, including those under consideration in this article.

The first surprise (Fig. 8) is that these six shashkas all group rather tightly together and at least four of these swords, despite the different signatures and decorations (Table 2), are so close to one another, that they were apparently produced to the same, and rather precise specifications. Comparing shashkas to other swords, we can conclude that:

a. There is no direct relationship with daggers. Even much shorter (70cm) dagger would still have to weight above 1kg (Fig. 1), so the design of the blade here is substantially different. Same goes for the comparison with another short weapon often considered to be shashka's "relative" – machete, though we did not include the relevant data on this graph.
b. Compared to Polish-Hungarians swords, the shashkas are clearly more tightly clustered together and are substantially lighter (about 620 versus 800-1000 gram), substantially

more so than can be accounted by means of guardless hilt alone. If, as believed by many, shashka blades were to carry remounted 17th century Polish-Hungarian saber blades, we would see both wider distributions, as well as substantially heavier weapons.

c. A similar observation can be made regarding a comparison between shashka and a Western Georgian single edged, guardless sword. Despite similar signatures and fullers' layout (so called *gurda* type, [10]), in both cases inspired by the early Polish-Hungarian examples, the technical specifications of these two classes of swords are very different. The Western Georgian weapon is noticeably shorter and heavier, and in terms of these two parameters it can be shown to be more closely related to the earlier (13th – 14th century) excavated examples [11], rather than to any contemporary 19th century swords.
d. There is little correlation with contemporary Middle Eastern swords.
e. The shashka data cluster directly overlaps a significant portion of the early 19th century European light cavalry swords. Despite a relatively small number of data points, the coincidence is almost perfect for four out of six shashkas.

So, based on a linear density analysis, we can conclude that:

a. Despite the existing diversity of signatures and fuller configurations, as well as varying decorative motifs used and related ethnic attributions, the shashka blades we studied, and likely a large portion of the existing examples overall, belong to essentially the same, narrowly defined, type of weapon.
b. The shashka blades are directly analogous to those mounted on contemporary European light cavalry swords. They are substantially different from all 17th century models, as well as such 18th century Caucasian weapons as Western Georgian palash [11].

Both conclusions are contradictory to what could have been established based on a cursory feature-based analysis, which would place the dominant emphasis on similarity of fullers' layout and signatures.

We can conclude by stating that as various Museums now begin to provide extensive public listings of their collections, one expects there will be a growing tendency to apply the data analysis techniques, similar to those previously used in biology and other fields, to identify trends in the evolution of material culture. Weapons are likely to be the kind of objects for which such analysis can yield especially important results. In this publication we have demonstrated that just by means of recording the total length and mass of an edged weapon, one can often reasonably well identify its place in the overall "evolutionary tree" of edged weapons, including its closest relatives and immediate ancestor types. Value of the b parameter, obtained from using a logarithmic fit in accordance to the allometric equation (Eq. 1), correlates directly to the basic type and functionality of the weapon. The mass of a typical "average specimen" is more indicative of the weapon's date and origin.

In terms of expected values of b parameter, just as one observes for a majority of complex biological organisms, the overall upper bound is 3; most long single edged weapons exhibit the values around 1.5, while for other weapons the value lies between 2 and 2.5.

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