Rough Notes on a Preliminary Analysis of the Entire Published Corpus of Indus Weights

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August 2013

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The Data

There has been some confusing discussion recently on the Web about the accuracy of the Indus Valley weight system. One example of such a thread can be found here: http://groups.yahoo.com/neo/groups/Indo-Eurasian_research/search/messages?query=indus%20weight%20standards. Depending upon what extreme one wants to take, the Indus Valley either had no standards at all, or the standards were very accurate, and furthermore extended over both a large geographical area and over hundreds or thousands of years.

The claims from the traditional archeological literature (e.g. Hemmy, in Marshall, 1938) is that the weight values were accurate to within about 2-3% measured as the ratio of the standard deviation to the mean, and that this was much more accurate than contemporaneous civilizations (e.g. Mesopotamia, Egypt), which usually had accuracies of about 5%. Furthermore, the Harappan standard seemed to hold over the entire civilization, with the same standards being used at the various cities of Harappa, Mohenjo-Daro, Chanhu-Daro and so forth. But all of these claims were made on the basis of a subset of the data that we *now* have at our disposal.

Furthermore, recent work on the weight system of the Indus Valley (Vahia & Yadav, 2007; Fournet, 2011), has been based solely on one list, which comes from Table X of Mackay 1938 (see below).

The purpose of the present work is threefold:

1. To perform a public service by providing an open-source distribution of the *entire* published corpus of Indus weights
2. To assess the accuracy of the system based on that corpus
3. Hopefully to acquire similar data from other contemporaneous civilizations so that we can see how the systems compare.

Another reason for being interested in this relates to the so-called Indus "script". In one version of his paper (http://www.scribd.com/doc/156175428/WSR-Fournet-Entropy-Indus-Signs), Fournet makes the bizarre claim that “it is hard to believe that a well organized society with precise weights could not have some kind of writing system at the same time.” And then again: “In other words if we dismiss the corpus of Indus Signs as being a writing system we are then faced with the paradox of a well organized society with planned urbanization and precise weights but no writing system at the same time. Is that really possible?”[1] The problem with these kinds of “I can’t imagine” argument is that they usually have more to say about the impoverishment of imagination of the proponent, than about the phenomenon under consideration. In any case, it is unclear why precise weights would necessitate writing as opposed to, for example, mere skill at handiwork. But in any case whatever one may believe about the connection, it is useful to see what the facts really are.

To that end, I have collected all of the published archaeological material that gives tables of individual weights. The sources were as follows:

- Marshall, J. 1931. *The Indus Civilization*. Volume II, Chapter XXIX, "System of Weights at Mohenjo-Daro", Appendices I, II. London: Arthur Probsthain. Appendix I contains 121 weights from Mohenjo-Daro; Appendix II contains 39 weights from Harappa.

- Mackay, E.J.H. 1938. *Further Excavations at Mohenjo-Daro*. Volume I, Chapter XVII, "System of Weights", by A.S. Hemmy, Appendix I, Table X. New Delhi: Government of India Press. 577 weights from Mohenjo-Daro.

- Vats, M.S. 1940. *Excavations at Harappā*. Volume I, pp 360-365. (Republished 1974) Bhartiya Publishing House. 199 weights from Harappa.

- Mackay, E.J.H. 1938. Chanhu-Daro Excavations. Chapter XV, "Objects of Scientific Interest: Weights at Chanhu-daro", by A.S. Hemmy, Table I; “The Cube Weights in Boston", by A.R. Hall. New Haven: American Oriental Society. 123 weights from Chanhu-Daro.

- Rao, S.R. 1985. *Lothal: A Harappan Port Town*, 1955-1962. pp 560-564, Table XIX. New Delhi: Archaeological Survey of India. 27 weights from Lothal.

- *Harappa Archaeological Research Project*, 1986-2001, Courtesy Richard H Meadow. 68 weights from Harappa.

In the few cases where it was feasible to do so based on catalog numbers --- e.g. in some cases in Hall’s tabulation of the weights from Chanhu-Daro --- I eliminated duplicates.

Note therefore that there may well still be duplicate specimens represented, which would tend to

[1] Note that Fournet has, on the other hand, disavowed in email any connection between the precision of the weights and the issue of literacy.

spuriously raise the precision.

The raw data for all of these weights can be found here:

http://rws.xoba.com/indus_weights/weights.xml

Analysis of the Precision of the System

For a preliminary analysis of the data, I considered how precise the weights are, where we define precise (as have previous authors such as Hemmy and Hall) as the ratio of the standard deviation of the weight values to the mean of the values. Claims in the literature have been that this precision is as low as 0.02, much lower than the 0.05 more typical for 3rd millenium BCE civilizations.

A priori we do not know what the weight standard(s) was (were). And more importantly, we do not know which weight specimens were intended by the maker to be instances of which weight standard. For example, if we assume that the basic unit weight is around 13.7[2] grams, what are we to do with a specimen that weighs in at 12.3 grams?

So in order to make the fewest assumptions, I performed the following analysis, focusing for now on specimens that weigh in 20g or less: these are in any case the most common weights in the collection. I considered **center values** ranging from 1.0 to 20.0 in 0.1g intervals. Then I considered the collection of weights that was within a **window** ⅔ and 1 ⅓ of that value. Thus for example for a center value of 10.0, the window would include any weights that are within about 6.7g and 13.3g. The window of plus or minus ⅓ is of course arbitrary, but since the weights at the lower end of the scale have been argued to be in values of multiples of 2 of each other, a window of ⅓ on either side would not, in a truly perfect weight system, include specimens that should properly belong to the next higher or lower weight. Finally, I then shrunk the window in **increment widths** of 0.1g. Thus one gets fewer and fewer weights in the **set** falling in the window, and concomitantly higher precision. Then for each set we compute the standard deviation divided by the mean (σ/μ).

If one plots all these values of σ/μ, one would expect to see the following behavior. First of all, the values of σ/μ should become minimal as the **center value** approaches the target standard weights of roughly 13.7, 13.7/2 and 13.7/4. Second, obviously, as the **increment width** of the window decreases, the ratio σ/μ should decrease.

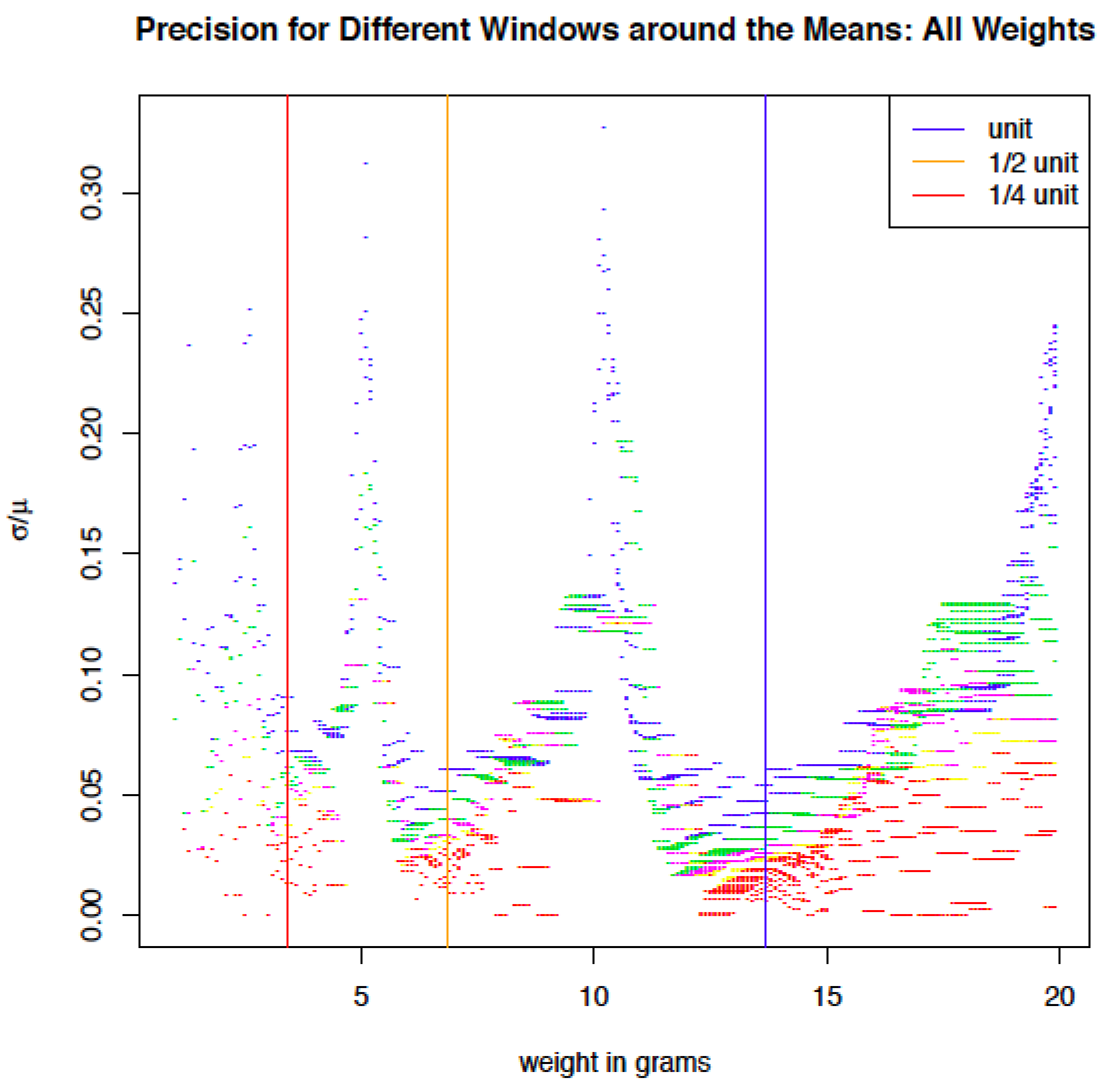
I computed these statistics for the following subsets of the weights. First of all, I removed from consideration any specimen that was listed as “doubtfully a weight” (only thus listed in Mackay’s data from Chanhu Daro). Then I considered the following:

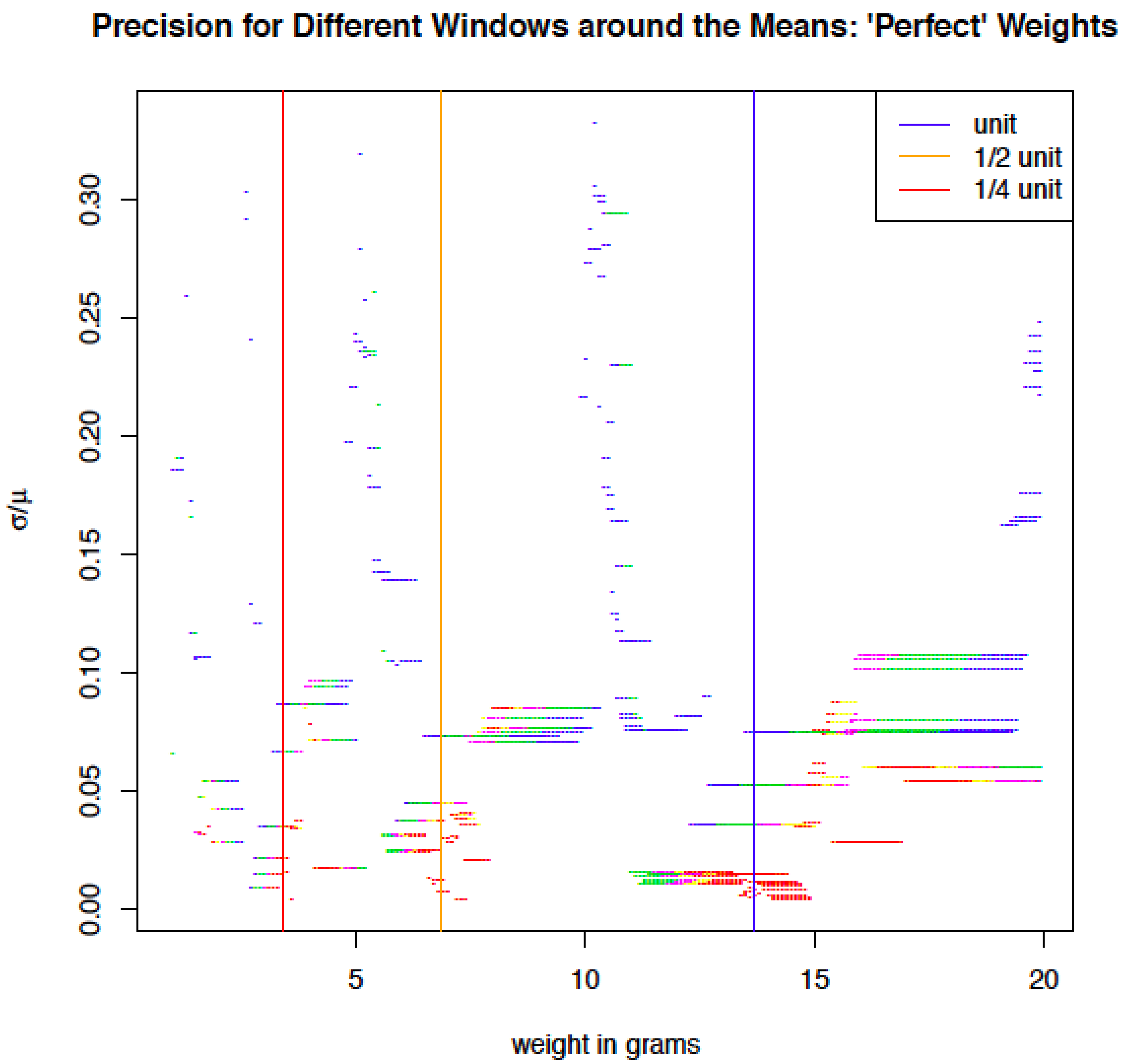
[2] Or 13.6 grams, see below. In any event somewhere around these values.

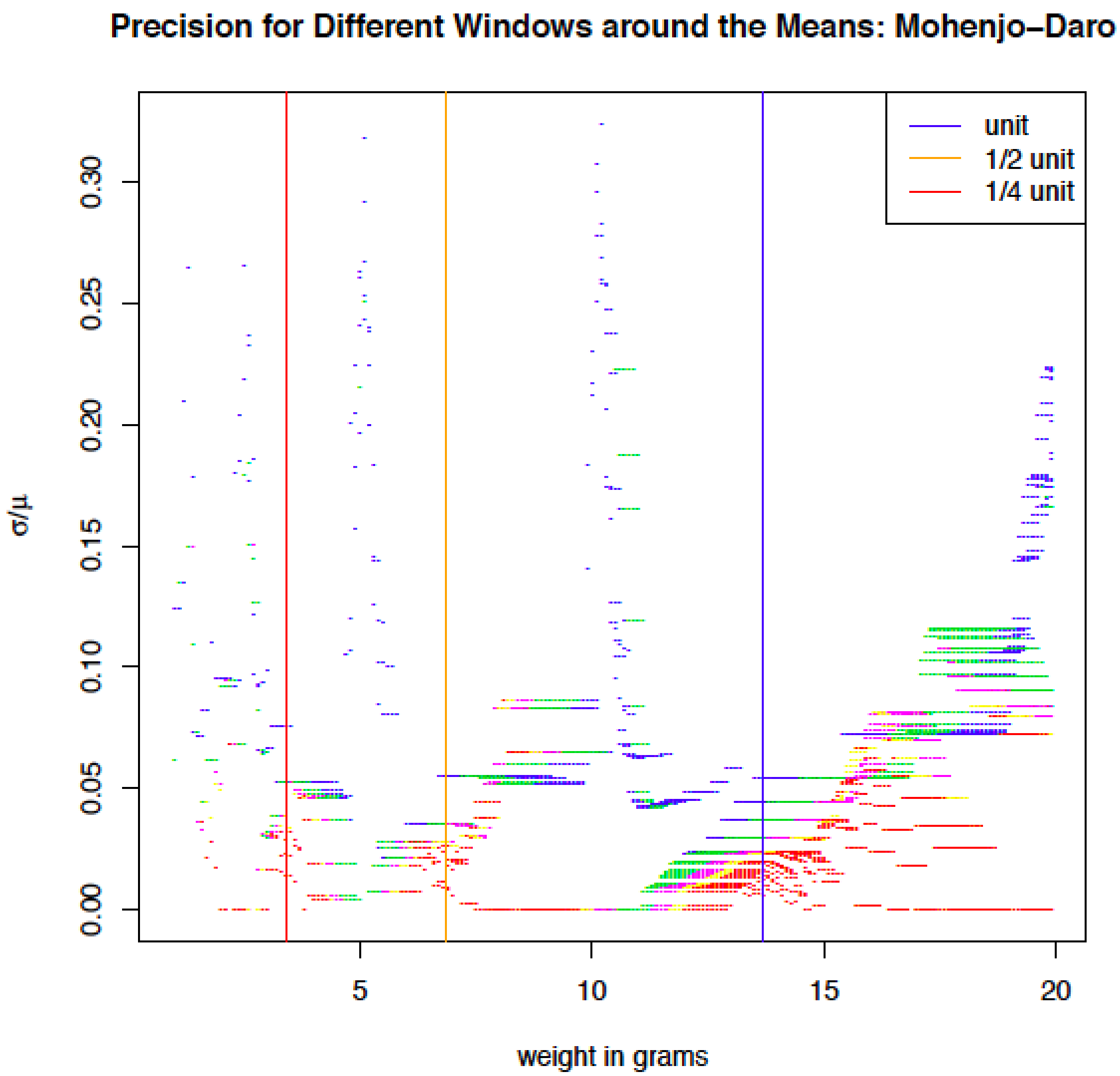
- **All** remaining weights (n = 1119)
- Only weights listed as **"perfect"** i.e. not damaged. (Only available for Mackay for Mohenjo-Daro and Chanhu-Daro; and Rao for Lothal.) (n = 108)
- All weights from **Mohenjo-Daro** (n = 698)
- All weights from **Harappa** (n = 306)
- All weights from **Chanhu-Daro** (n = 88)

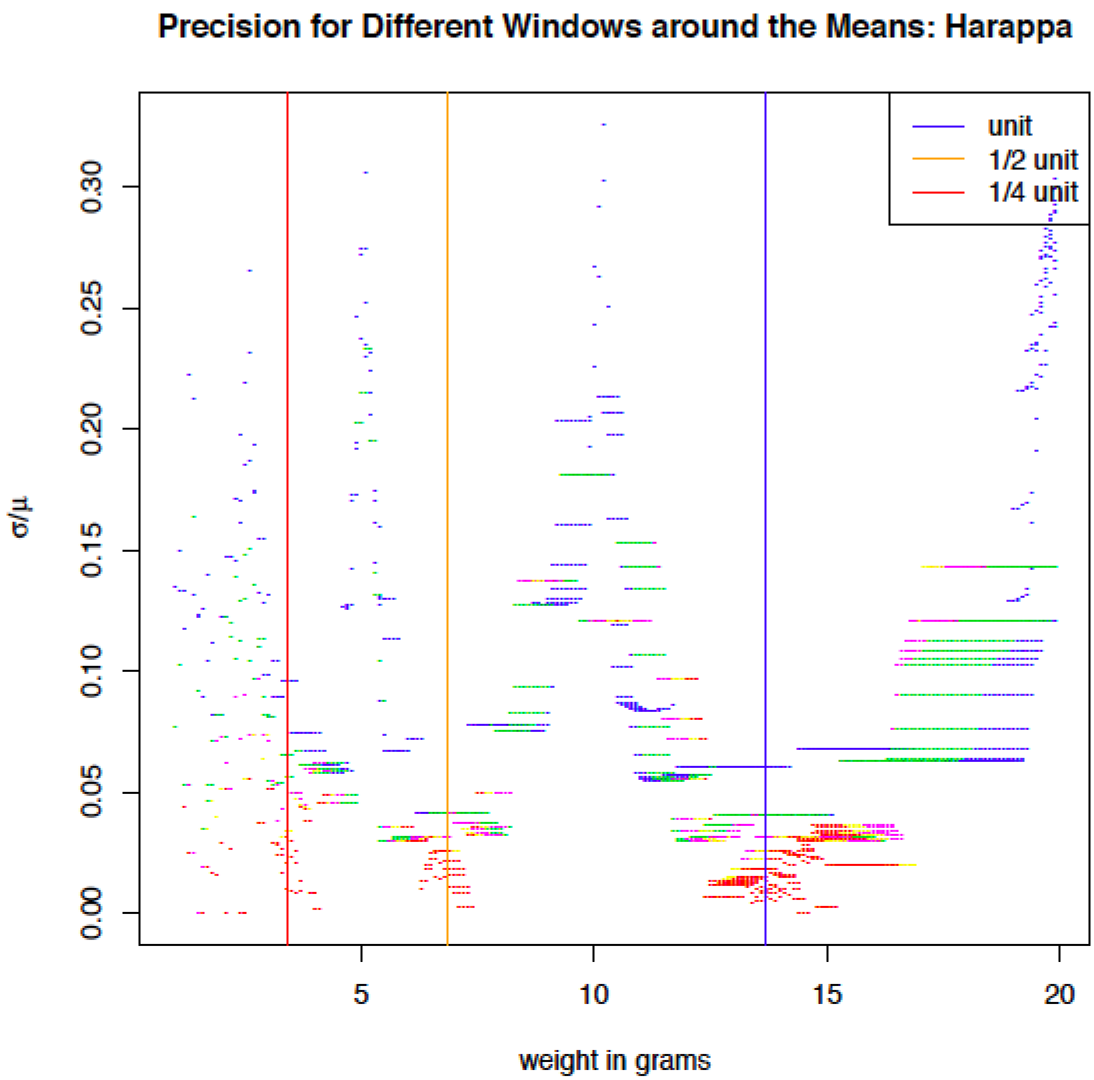
(There are too few weights in the Lothal data to be worth considering by itself.)

The plots can be found below, and also here: http://rws.xoba.com/indus_weights/plot.pdf

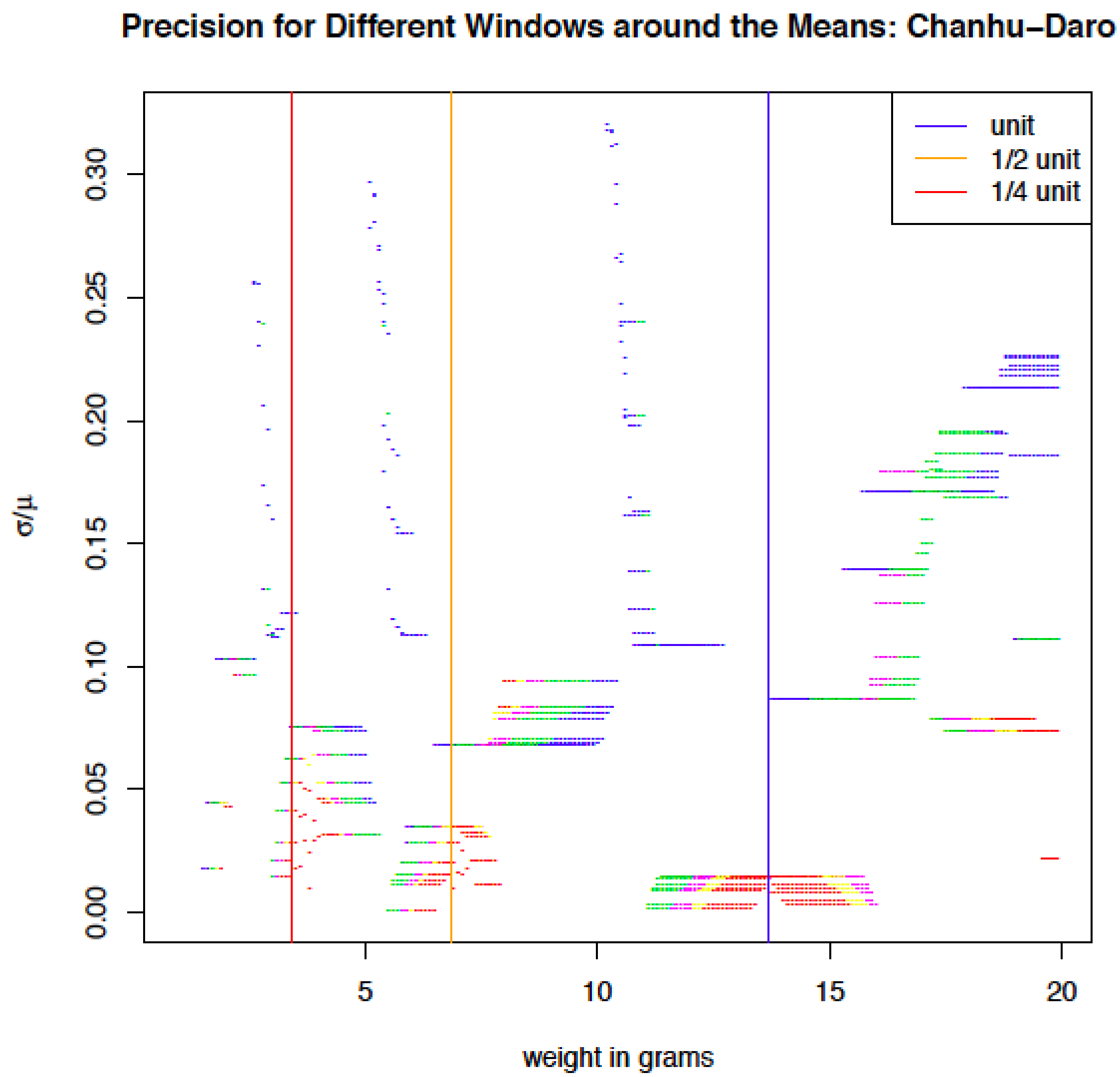



Precision for Different Windows around the Means: 'Perfect' Weights
unit
1/2 unit
1/4 unit
σ/μ
0.00
0.05
0.10
0.15
0.20
0.25
0.30
5
10
15
20
weight in grams


Precision for Different Windows around the Means: Mohenjo–Daro
unit
1/2 unit
1/4 unit
σ/μ
0.00
0.05
0.10
0.15
0.20
0.25
0.30
5
10
15
20
weight in grams



Precision for Different Windows around the Means: Harappa
unit
1/2 unit
1/4 unit
σ/μ
0.00
0.05
0.10
0.15
0.20
0.25
0.30
5
10
15
20
weight in grams



In the plots, the horizontal axis represents the weight **center value**, the vertical axis σ/μ. The color of the plotting character represents the ratio of the **center value** to the size of the **window**, as follows:

- red: ratio > 10 (i.e. the smallest relative window sizes)
- orange: ratio > 8
- purple: ratio > 6
- green: ratio > 4
- blue: otherwise

So for a 13.7g **center value**, red will represent cases where the window is between 13.7±1.37, orange cases where the value is between 13.7±1.71, purple cases where it is between 13.7±2.28, green where it is between 13.7±3.43, and blue for ranges greater than that up to

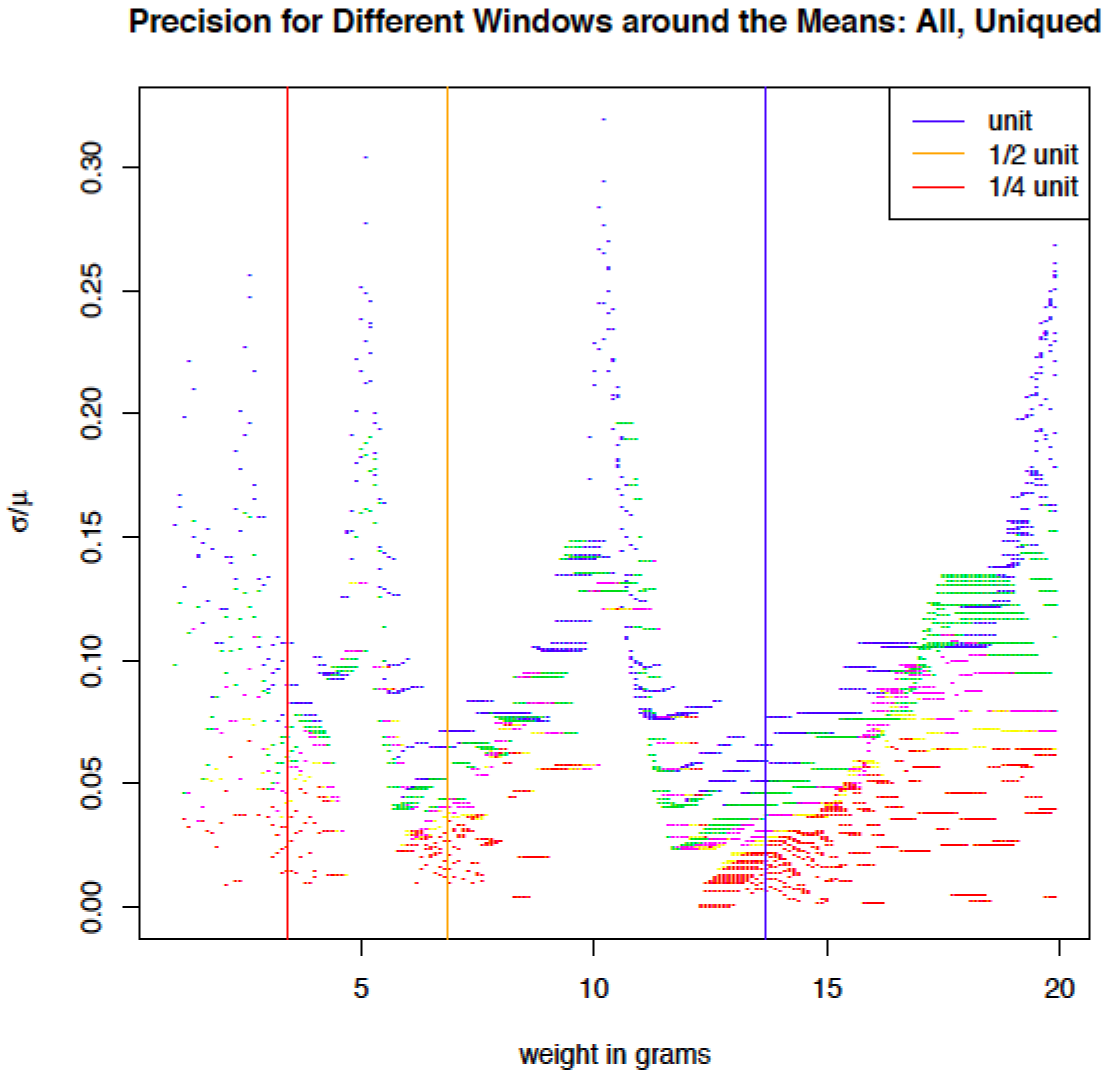
13.7±4.52.

Finally, vertical lines are plotted for the nominal standards of 13.7, 6.85 and 3.43 grams.

As can be seen, the minima for the σ/μ are indeed roughly at the nominal standard values, which is consistent with those values being the ones that the weight makers were aiming for. And, obviously, as the size of the **window** is increased, the precision decreases from somewhere around σ/μ = 0.02 to σ/μ > 0.06. If anything, the imprecision seems to become *worse* if one considers only the “perfect” weights. On the other hand the set from Chanhu-Daro seems to be rather better since there are more dots clustered close to the lower ends of the σ/μ range.

Part of the problem with these analyses is, as noted above, that we know there are duplicate weights: Table X is a good source of such duplicates but even beyond that in the various reports on Mohenjo-Daro, Harappa and Chanhu-Daro, we expect that some of the weights have been duplicated. It is hard to tell from the published material which ones they might be, and depending on how many of them there are, their presence may tend to increase the apparent accuracy of the system. To see the possible effects, we plot below the system with all duplicates removed (yielding 595 weights), which should give an idea of the worst true accuracy the system might have.

Comparing the plot below with the plot for all weights above, there is not a lot of difference, though one can see perhaps a slight increase of σ/μ for, say, the 6.85 gram weight for the smallest window sizes from about 0.03 to about 0.04.

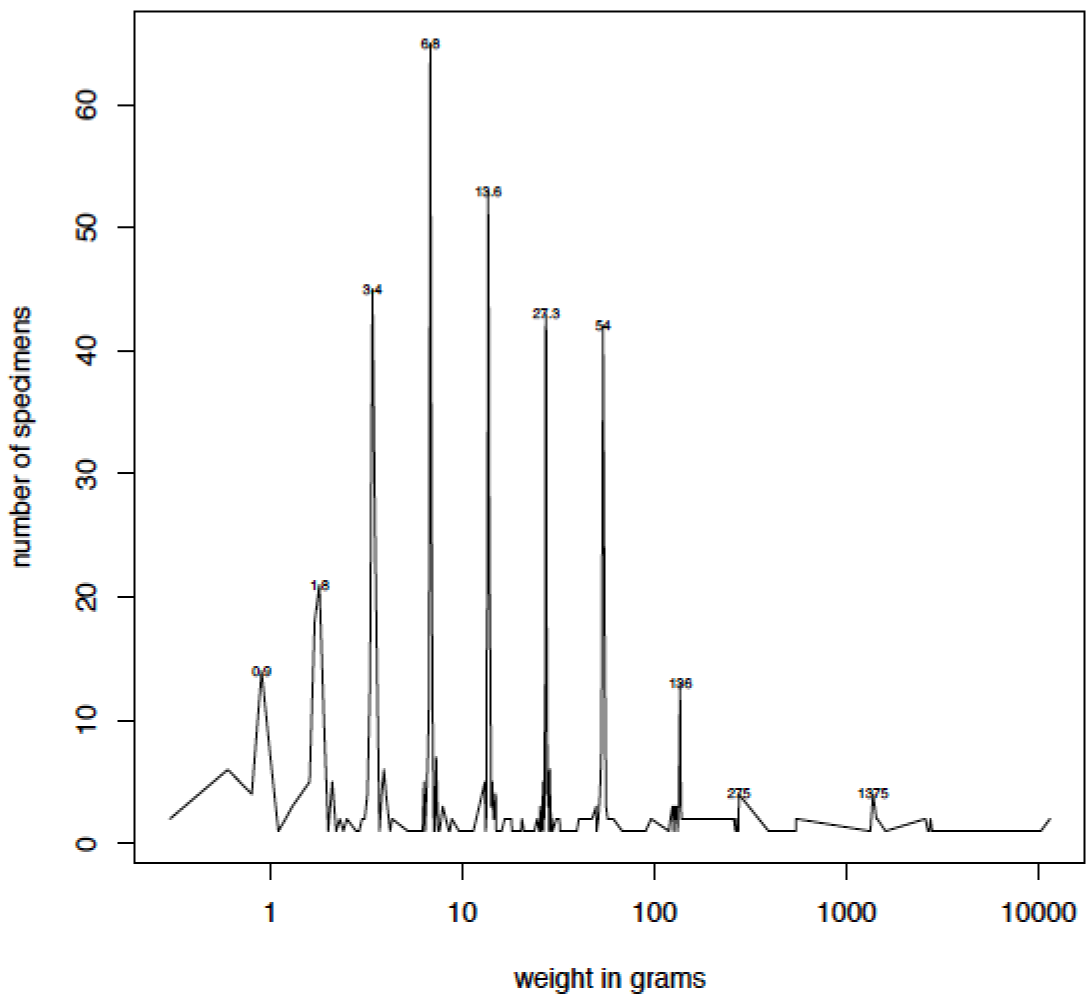


It is worth mentioning at this point that there are no differences in standards between the three main sites of Mohenjo-Daro, Harappa or Chanhu-Daro. Performing a similar variable windowing to that described above, but now just considering windows around the nominal 13.7g, 6.85g and 3.43g targets, a t-test of pairwise comparisons of the sites revealed no significant differences between the means. So at least it does seem to be true that the system is fairly consistent across different sites.

All of the above analysis may seem rather obvious, but it is worth bearing in mind that if a weight system had the accuracies that a modern system has, then all of the weight specimens for a given target would be well within the narrowest 0.1g window, and expanding the window around the target would not yield a different result. The fact that a different result is found in the case of the Indus weights is consistent with the idea that standards were crude --- hardly surprising for a 3rd millenium BCE civilization. How crude or precise they were depends of course upon how liberal you are about throwing out from consideration specimens that do not fit within a given window.

The Weight Types

The plot below shows the result of taking all reported weight values for “non-doubtful” weights, rounding the value to the nearest tenth of a gram for values less than 50 and to one gram for larger values, and counting the number of weights in each bin. The result is shown in a log-linear plot, where the horizontal axis is the weight value and the vertical axis the number of weight specimens with that value. The weight values of the peaks are indicated in the plot.



The ratios of each peak value to the previous ones are as in the table below for the first six weights; for the three highest weights for which we have much evidence, the comparison is given to a putative base value.

Previous	Current	Ratio
0.9	1.8	2.00
1.8	3.4	1.89
3.4	6.8	2.00
6.8	13.6	2.00
13.6	27.3	2.01
27.3	54	2
Base	**Current**	**Ratio**
13.6	136	10
27.3	275	10
13.6	1375	101

As with previous analyses (e.g. Hemmy's work), the basis of the system seems to be binary for the lowest valued weights --- the simplest sort of system from the point of view of weight manufacture. And consistent with previous work, the heavier weights seem to be based on a decimal system.

There is in any case no evidence here of "advanced" mathematical abilities, as some have claimed. The evidence for much beyond a binary system for lighter weights is weak: there is some evidence in the form of three peak weight values for a decimal system, two based on multiples of 10 of the base of 13.6-13.7 grams, and one possibly based on the double of that, the 27.3 gram weight. But none of this evidence, except for the 136g weight, is particularly robust.

None of these results are new. What is new is the fresh perspective that looking at *all* the available data can bring in terms of the sobering realization that with the exception of the rather simple binary system for the lightest weights, there isn't really a huge amount of evidence to support sweeping claims about the sophistication of the system.

Further Analyses

More analyses (hopefully) to follow, including:

- A similar analysis of another 3rd millenium civilization (assuming one can find the data).
- A more sophisticated way of computing the windows that might give a fairer representation of which weights might reasonably be considered outliers.

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