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Throwing Behaviour and the Mass Distribution of Geological Hand Samples, Hand Grenades and Olduvian Manuports

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This research examines the efficiency of impact energy delivered by a thrown rock and the relationship between the mechanics of throwing and how rocks are chosen. This choice tends to lead to a Poisson distribution of mass with different means for men and women. These values are reflected in the mass of hand samples selected by geologists, in the throwing stones made in the last century by the Nuie Islanders, in the sport of handball and in the design of hand grenades. When the mass distributions of manuports from Olduvai and Koobi Fora are examined two very different mass distributions can be een: one indicating a probable selection by larger creatures of almost modern human size, the other by creatures that were far smaller. Observations of Olduvian cobble tools indicate that their mass distribution is similar to the manuports hoarded by the larger hominids. A simple engineering model links the mass distribution of selected rocks to body size and it is suggested that this technique can be used to reveal sexual differences in cobble tool making and any differences in body size during the development of the Olduvian industry or at distinct geographical sites. Perhaps the most intriguing use of this technique, however, is in the examination of the mass and form of stone deposits laid down before stone tools were manufactured. A specific clustering would indicate, within a certain degree of statistical probability, the deliberate selection and hoarding by a hominid species that used the systematic hurling of rocks as a behavioural strategy. In this case, stone tools would represent an improvement on an object of the same mass and material that had been part of an earlier culture.

Keywords: THROWING, MASS DISTRIBUTION, MANUPORTS, LITHIC TECHNOLOGY, EARLY STONE AGE.

Introduction

In 1871 Darwin wrote in the *Descent of Man* that: "hands and arms could hardly have become perfect enough to have hurled stones and spears with true aim, as long as they were used for supporting the body". This statement infers that stone throwing had played an important role in human evolution, and raises the questions of what size of stones were hurled, why these were chosen and during which stage of the evolutionary process did throwing become an important behavioural strategy?

Impact Energy and the "Ideal Throwing Stone"

In order to examine the variation of impact energy in relation to mass, a simple experiment was carried out using a selection of seven rocks of Brazilian granite with a similar, roughly spherical, shape and specific density of about 2·6. These samples were painted bright yellow in order to stand out on film and covered a wide range of possible throwing material: 180, 380, 400, 480, 560, 950 and 1900 g. A target set at 10 m from a line marked on the ground and at a height of 80 cm, was set up and five young men aged 14–32 and with heights ranging from 1·74–1·88 m, were then asked to check all the samples and choose the stone that they felt would offer the greatest impact. All the subjects chose the 480 g stone for their first throw. The test was then repeated with the other stones, each throw being recorded on videotape. This tape was analysed to count the number of frames between the time the rock left the thrower's hand to the moment of impact. The trajectory of the samples was taken as linear (although the heavier rocks did describe a slight parabola), hence the velocity of the rock was considered to be constant for this range. The impact energy for each rock sample was then estimated using the average thrown speed of all five subjects.

The plot of impact energy, "y" (right scale), against thrown mass, "x", gives a near perfect growth curve of the form:

$y=k(1-e^{-ax})$, where "k" and "a" are constants.

The inverse of the differential of this equation represents the marginal mass to obtain an extra Newton-metre, equivalent to the economic concept of "Marginal Cost". Examining, for a given value of mass (x), the relation between the rate of gain in energy per

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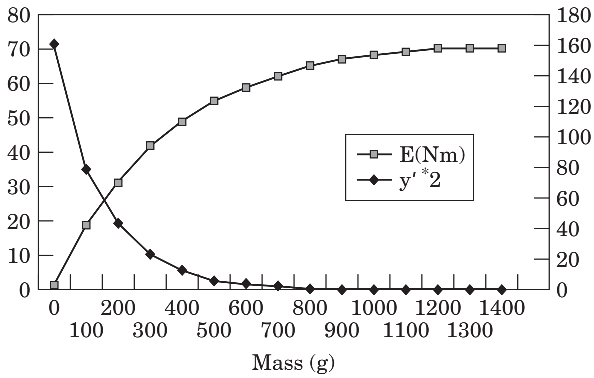

Figure 1. Impact energy and efficiency of rocks thrown at a range of 10 m by young men.

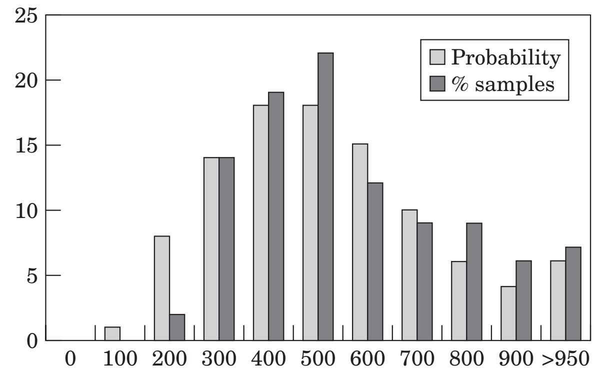

Figure 2. Mass distribution of geologist's hand samples.

rate of change in marginal "cost", this gives a measure of efficiency, or "what you get out for what you put in" expressing:

$$\left|\frac{dy}{dx}\right|^2$$

It is clear from the graph (left hand scale) that up to about 400 g of mass, there is a positive gain of impact energy for every additional gram thrown. After 600 g, the gain is almost negligible and the extra impact energy obtained is simply not worth the effort. The value between these limits, on the knee of the curve, is around 500 g, the ideal mass for a throwing stone.

How Rocks are Selected by Men and Women

Thrown stones are dangerous. A 500 g rock, thrown at the range of velocities commonly reached by professional baseball players (Gowan *et al.*, 1987), carries an impact energy of more than 200 Nm, or about the same as a 32-revolver bullet. Faced with the need to throw a rock at a potential predator we would thus expect the first choice to be a stone with a mass of around 500 g. However, a second choice would be stones that offered, say, a ± 5 Nm difference in energy, a third choice would be stones that gave ± 10 Nm of energy and so on. Small stones would be ignored as these would have, literally, little impact and large rocks that would be awkward to throw would be avoided. This leads to a probability distribution of the choice of stones of the Poisson type, rather than a Normal or Gauss distribution and suggests that, if throwing were instinctive behaviour, this pattern would be reflected in the mass distribution of rocks chosen by modern man.

An analysis of the mass of geological hand specimens belonging to the Geological Museum of the University of Paraná, the University of Rio Grande do Sul and the Geological Museum of Zimbabwe, showed that hand specimens start around the 300 g mark and tail off gradually into larger specimens with both mode and mean values lying between 500 and 500 g. Although the geologists that collected the samples were aware that smaller samples would be easier to carry, these, mainly male, geologists remarked that the 400–600 g samples just "felt right". A comparison of these hand samples with a Poisson curve, adjusted to fit the same scale (y=P*100, x=mass*10, $\lambda=5$), shows a very close similarity between the two curves. The hand specimens represent good throwing rocks and were chosen by instinct.

A study on the throwing stones from the Niue Islands (Isaac, 1987) indicates the mass distribution of rocks deliberately made for throwing by modern humans. Unfortunately, the number of samples is as yet too small to verify the type of distribution, which ranges from 280–950 g, with a mean of 597 g. Although stones are no longer used as weapons, their direct descendent is the hand grenade, devices designed and perfected over decades to be thrown (principally) by young adult males.

The models of fragmentation grenades currently used by U.S. and NATO forces (U.S. Army Field Manual 23–30, 1988) are shown in the table below. The mass of the 19 models ranges from 230–670 g, however, nine have a mass of between 470–485 g. Thus it would appear that the research done by the arms industry in the U.S. and Western Europe on the subject of 'ideal showing mass" has also arrived at a similar figure and this mass is just under 500 g.

In order to determine the unit of mass preferred by women, a group of three young, fit women (17–20) were asked to throw rocks at a target set at about 10 m, again considering this target to be a "threat" to their young. After a few test throws, they were then asked to choose three "ideal" rocks from a large supply of rounded, sea eroded cobbles of dense sandstone (specific density 2·5). All the chosen samples were very closely grouped around 320 g. To check on this result, another test was made using as subjects 10 girls of a high school handball team (aged 14–16). These were presented with 10 rounded, river eroded granite cobbles of similar shape and colour ranging from 140–740 g. Without actually throwing any of the samples, they were asked to select their "ideal" rock

Table 1. Mass of hand grenades used by U.S. and NATO forces by model, mass and country

Country	Model	Mass (g)
U.S.	M61	485
	M67	425
	M30	485
	M26	630
Netherlands	F1NR17	475
	NR13	475
	F3MM2	630
	NR 1CI	670
	NR 20CI	380
Germany	F11 MDN11	470
Belgium	F12 35	230
U.K.	F14 80WP	485
	F16 12 AL	395
Austria	F19 HG77	480
	F20 HG78	520
	HG79	360
	HG84	480
	F23	485
	F24	355

that could be thrown at a predator at a range of 10 m. The average mass of their first choice was 332 g, the 310 g stone being chosen five times.

The difference between the male and female choice can be explained by sexual dimorphism.

A very simple engineering model for scaling down size and mass would imply that the mass of a three-dimensional held object would be related to cube root of the length of the right arm and shoulder, thus, if the male choice is some 500 g, the expected female version would be: (0·87) cubed*480=329 g: a value consistent with the "feminine pound" of some 320–330 g. The sport of handball reflects these differences; the official men's ball has an average mass of 455 g (a pound), the official women's ball being smaller, with an average mass of 365 g.

Evidence of Throwing Behaviour in Prehistory

In 1997 three spears made of European spruce were discovered in Schöningen, Germany and dated at 400,000 years old (Dennell, 1997). They range from 6 to 7·5 feet in length, with a diameter similar to a modern javelin (24–36 mm mid section) and were balanced for throwing. Estimates by Prof. Reider of the Heidelberg Institute of Sport and Sports Sciences put the mass of the spears at between 500–600 g. Although these people (*Homo heidelbergensis*) were far more thickset and muscular than modern humans, their arm length was similar to modern values; hence the simple engineering model would predict that the male choice of throwing mass wold also be similar. The model also suggests that these spears were made and used by males.

The throwing motion of a right-handed person shows that three pivoting movements are involved: trunk, shoulder and elbow, a final push being given by the right leg, transferring body weight from the right to the left foot. In order to obtain the maximum impact energy a human—or hominid—has to use **only one** of the upper limbs, the other being used to balance the rotation of the shoulders. Powerful throwing requires the trained use of a preferred arm and the support of the same side of the body in order to achieve maximum effect and evolution has indeed led man to be either left or right sided, although the great majority (90%) favour the right. The distribution of left or right handedness is also not affected by sex, suggesting that the reason the majority favour the right side could be related to the behaviour of primate females, that hold their young with the left arm—closest to the heart—leaving the right arm free. A study has shown, in fact, that more than 80% of human mothers hold their babies in their left arms—where the left breast offers extra milk (Sieratzski & Woll, 1996).

If the systematic throwing of stones was an important advantage to survival then this activity would, over time, be built into the structure of the brain and the body. The Nariokotome *Homo erectus* boy of 1·6 million years ago was shown to have had a longer right ulna and clavicle indicating right-sidedness (Walker & Shipman, 1997). This suggests that throwing may have been incorporated into *rectus* behaviour at an earlier date. If this were so, then the mass distribution of the rocks chosen by hominids should reflect this behaviour and also their physical build.

The Mass Distribution of Olduvai and Koobi Fora Manuports

Some 20 years ago, 167 "manuports" were discovered and described by Richard Potts in Beds I and II in the Olduvai Gorge. All the rocks were of lava, except for 10 quartz examples. The stones were found in "caches" which represent small samples of stopping points in a highly dynamic system of flow/transport of rocks across the landscape—in and out of the sites excavated. In the oldest layer, FLK NN3, are 22 unbroken rocks that were collected by hominids some 1·8 mya. Although the range of mass chosen is from 158–695 g, when grouped around units of 100 g, there can be seen a marked preference for rocks around 400 g—the mean is 408 g and the mode 416 g. This mass distribution again shows there is a great similarity to a Poisson type distribution (y=P*100, x=mass (g)*10, $\lambda=4$).

The FLK NN3 samples, with an average mass value of around 400 g, thus appear to reflect the choice of males. In this case, an estimate of the size of the right arms of the male(s) that gathered the NN3 samples can be given by:

scale factor=cube root (408/480)*100=95%.

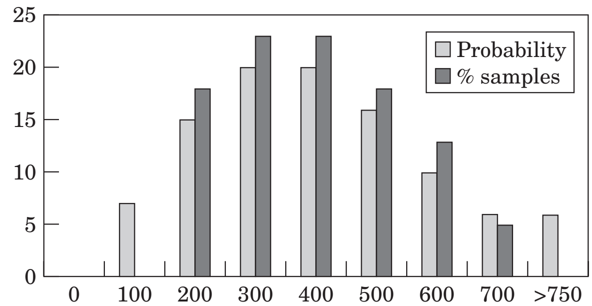

Figure 3. Mass distribution of manuports at Site NN3, Olduvai Gorge.

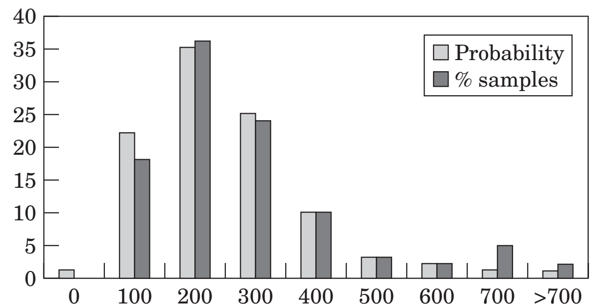

Figure 4. Mass distribution of manuports at Site ZINJ, Olduvai Gorge.

This suggests that the arms and shoulders of the males were equivalent to those of a modern man of 180*0·95=171 cm.

On the other hand, the manuports found in the FLK ZINJ deposits, although of similar age to the NN3 rocks, show a completely different mass pattern. Most of the 41 unbroken samples are grouped around the 200 g mark, the average mass for all samples being 289 g with a mode of about 225 g. A Poisson curve still offers a good fit to this data with a mean of 225 g.

These samples show a much larger range of mass distribution—from 87–965 g, but there is a definite "peak" of choice clustered around 200 g. In this case an estimate of the size of the arms and shoulders of the hominids that did most of the collecting can be obtained by:

100*cube root (225/480)=78% (male value) or 100*cube root (225/320)=89% (female value).

Both values suggest a being of some 1·4 m, in terms of equivalent arm and shoulder size of modern humans.

Similar data can be found in the Koobi Fora manuports (Isaac, G. 1997), which presents the mass of tools, and manuports in terms of a standard distribution. The more recent samples, associated with typical Ergaster tools (sites 33 & 37), show a clear tendency for mean values to group around 430 g, consistent with a selection by males of almost modern human size. The manuports from sites 18 & 20, on the other hand, have a group means of around 220 g—similar to the ZINJ samples. The sites marked in bold were associated with channels and ready supplies of raw stone; hence the samples tend to be larger and heavier. Even so, the masses of the stones from site 18NS are clearly grouped around the 220+g mark.

Table 2. Mass data of unmodified cobbles at Koobi Fora

Site	Number of samples	Mean (g)	Standard deviation	Group mean (g)
20AB	6	174	101	
20E	27	240	148	
20M	36	178	163	
20S	1	55		
23	2	231	16	
				201
16	130	469	650	469
18GU	13	362	173	
18NS	18	268	186	
18IH	3	109	91	
				290
33	13	412	364	
37	27	429	619	
				423

The distribution of cobbles from site 16 is marred by the presence of one (or more) very large stones that would not have been carried by one hand and, without the mass distribution data of the individual samples, no clear conclusion can be drawn.

The similarity of the mass distributions in the "hard" stone evidence of the smaller samples from Olduvai and Koobi Fora during similar time periods points to one of two options:

- the very strong and specific attraction shown for 200 g rocks suggests that these stones were collected by smaller beings, perhaps females and children, the 220 g mass representing their first choice of stones;
- there is the possibility that more than one species of hominid living in the same area at the same time collected and hoarded stones.

Until the *Australopithecus garhi* finds were made public (White, 1999) the presumed maker of stone tools of this era had been the pre-named *H. habilis* and several fossils have been presented as "belonging" to this species, nearly all of which fit the 4 ft something mould. We now know that a large hominid was associated with meat eating and tools over 2·5 mya. So although the first option may be the most likely, the second can no longer be ruled out.

Similar evidence to support these conclusions exists in the mass data of cobble tools. Observations of the Olduvai stone tool collection made at the Louis Leaky Foundation in the National Museum in Nairobi revealed strong evidence of a standard pattern and, although public or published mass data was not available, by using the Brazilian "olhômetro" methodology—the practised "eye-gauge"—it was possible to note that nearly all of the cobble-type tools were of the 300–600 g size with a mean value of just over 400 g. Curiously, there appeared to be no "peak" of cobble tool mass around the 200 g mark, thus inferring that cobble tool making seems to have been either a "male thing" or that only one, larger species made tools.

Using Mass Distribution as an Analytical Tool

The analytical technique is based on the concept that the mass distribution of chosen and hoarded stones leaves a recognizable pattern, something like a footprint. If a fossilized footprint indicates locomotion behaviour and the presumed size of the being that made the imprint, the analysis of mass distribution reveals throwing behaviour and the presumed size of the beings that collected the material. Although only a few hundred samples have been examined, there is the evidence of hundreds (if not thousands) of cobble tools that could either validate or refute this technique.

An analysis of the mass distribution, by geological age, of these tools would reveal:

- If there is indeed a Poisson like distribution of the mass of cobble tools around a definite mean;
- What the value of this mean is and how it compares to the manuport data;
- How this value behaves over time: the Olduvai industry covers a period from 2·6 mya to 1·8 mya, so any change in the value of the mean over these 800,000 years would give an indication of any corresponding change in arm length;
- How this distribution varies geographically, since the same stone industry was used in East Africa, Northern Spain and Georgia;
- If there are indeed two separate sets of mass distribution in the choice of cobble tools and hence, if there is any hard evidence of sexual dimorphism in tool making (or the action of more than one species);
- If tool making was fundamentally a male occupation of a single species.

Perhaps the most intriguing use of this technique would be in examining the period before flaked stone tools were made, when *afarensis* was in the wane and the Homo line just beginning. Thus, if a likely hominid site (such as a bluff close to a river or large body of water) were to be identified, together with a specific layer of deposits of some 3 million years, an analysis of the distribution of the mass of all stone deposits could be made. This raw data could then be analysed by computer to verify background "noise" or general geological mass distribution and to identify any specific clustering of a Poisson distribution of the kind indicated by the tool and manuport data. If this analysis were to show a marked statistical concentration of stones (not tools) of a similar distribution in certain locations, which could not have been formed by any natural geological process, it could then be stated, within a certain degree of statistical probability, that this bias was the result of deliberate selection and hoarding of manuports by the (right) hand of a hominid and that this species had developed the systematic hurling of rocks as a behavioural strategy. In this case, tools were not invented from scratch, but represent an improvement on an object of the same mass and material that had been part of an earlier culture, thus extending the "Stone Age" much further back in time.

It could be argued that these tools just happened to be the right size to fit the hand, however, this size of tool was "abandoned" for the heavier stone axes used for over a million years by our immediate ancestor, *H. erectus*. A discussion of the mass distribution of these is beyond the scope of this article but it is possible that there is a correlation betwene the mass of hand axes and those of modern hand-held implements.

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