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The Effect of Hammer Mass and Velocity on Flake Mass

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This paper presents the results of controlled fracture experiments designed to investigate the effects on flake mass of varying the mass and velocity of the hammer. It was found that the contribution of these two independent variables are almost negligible for a given combination of exterior platform angle and platform thickness, though they must be sufficient to initiate production of a flake of a given potential mass.

Keywords: LITHICS, CONTROLLED EXPERIMENTS, FLINTKNAPPING.

Introduction

The focus of this paper is on the relationship between flake mass and two fundamental aspects of the striking of a core: the mass and velocity of the hammer. For years flintknappers have reported that these two aspects, in conjunction with angle of blow and other properties of the hammer itself, have a significant effect on flake size and flake production (e.g. Bordes & Crabtree, 1968; Neuman & Johnson, 1979; Crabtree, 1972*a*,*b*; Patten, 1980; Patterson, 1981; Toth, 1982) and similar conclusions have been drawn on the basis of controlled experiments (Speth, 1974, 1981; Dibble & Whittaker, 1981). Indeed, the direct relationship between ''force'' and flake size has reached almost axiomatic status. However, new experimental evidence presented here suggests that the direct effects of hammer mass and velocity on flake size are minimal. Rather, flake size appears to be governed largely on the basis of particular platform characteristics, principally the exterior platform angle and platform surface area. Likewise, when these aspects are held constant, then flake size remains the same in spite of significant variation in mass or velocity of the hammer.

There are important implications of these findings for the analysis of prehistoric lithic artefacts. If it were true that the force with which flakes were struck is one of the primary determinants of flake mass, then archaeologists would be missing a key independent variable giving rise to variability in flake morphology. But if force is not a significant factor, and flake mass were primarily a function of platform characteristics, the situation is completely reversed. Platforms are preserved on flakes, and studies of how platform characteristics were controlled by the prehistoric flintknappers could potentially provide significant information on the strategies they employed to obtain particular results. Furthermore, these same platform characteristics could be used to reconstruct the original size of broken or reduced pieces.

Materials and Methods

The procedures of this experiment were similar to those of Speth (1972) and Dibble & Whittaker (1981), with flakes being produced by dropping steel ball bearings (serving the same function as a hammer, or indentor, in flintknapping) from an electromagnet onto plate glass cores. This design was chosen because it allowed us to vary both the mass of the indentor (by using ball bearings of different weights) and velocity of the blow (by varying the height from the electromagnet to the core).

The cores used in these experiments were fashioned from 7·6 × 15·2 cm or 7·6 × 30·5 cm rectangular pieces of 1·27 cm thick plate glass. At one of the small ends, a striking surface was cut by a diamond saw to prepare exterior platform angles (see Figure 1) of 55°, 65° and 75°. Thus, every drop was onto the smooth cut surface produced by the diamond saw. The cores were then secured in a padded vice, positioned in such a way that the edge to be struck was as far away from the jaws of the vice as possible. The angle formed between the platform surface and the vertical was set to a constant 50°.

The steel ball bearings were all manufactured by the same process and they possessed identical properties except size and mass. Four different ball bearings were used ranging in weight from 28 to 535 g. A total of five different drop heights were employed, ranging from 34 to 275 cm. Velocity, *V*, calculated as

$$V=\sqrt{2gh},$$

where *g* is the gravitational constant of 9·8, and *h* is the drop height, ranged from 2·58 to 7·34 m s^{-1}.

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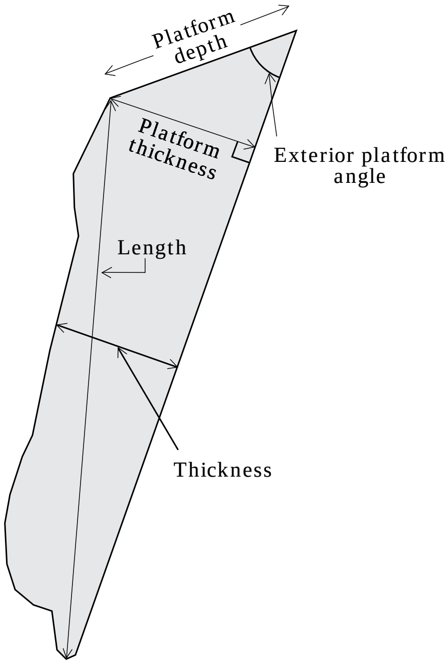

Figure 1. Longitudinal cross-sectional view of a flake showing how the various measurements were taken. Note that platform thickness was computed based on the values of exterior platform angle and platform depth.

The momentum with which an indentor strikes a core is dependent upon both the velocity and mass of the indentor, expressed as

$$\text{Momentum} = MV^2,$$

where M is the weight of the hammer and V is the velocity with which it strikes the core. Thus, with the various sizes of ball bearings and different drop heights, a number of different momentums could be achieved. However, the goals of this experiment dictated certain combinations in order to best evaluate the independent effects of velocity and mass. The actual combinations of velocity and mass used, along with the calculated momentums, are shown in Table 1. These combinations allowed us to evaluate the effects of different velocities whilst holding mass constant, different masses whilst holding velocity constant, or varying both whilst holding overall momentum constant.

When a ball was dropped, five different outcomes were possible. The first was that no flake was detached, in spite of the ball bearing having hit directly on the platform surface. In all such cases an incipient cone of percussion was produced. A second possible outcome was that the ball bearing hit at or near the lateral edge of the plate glass core. Regardless of whether or not flakes were attached, these cases were discarded from the analysis. The third and fourth possible outcomes resulted from the core being too short. This produced either a flake that overshot the distal end of the core or one that exhibited a pronounced interior bulge at the distal end. Examples of these latter flakes are not found archaeologically and may be the result of the restricted core width and the wave interference caused by the proximity to the end of the core (Cotterell & Kaminga, 1987). In support of this view, we found that the introduction of a longer core (7·6 × 30·5 cm) halted production of these unusual flakes as well as the overshot varieties. Since these two forms, the overshot flakes and those with the pronounced distal bulges, probably introduce a significant degree of irregularity to the experiment, any such flakes were also eliminated from the analysis.

The fifth possibility was the production of a normal flake with none of the above characteristics. For these a number of attributes were recorded (see Figure 1):

flake and core weight—taken to the nearest gram;

length—measured from the point of percussion to the most distal point on the flake;

thickness—measured at the midpoint of the length.

Platform depth and platform thickness—following Dibble & Whittaker (1981), platform depth is defined as the distance from the interior edge to the exterior edge along the platform surface. This measurement is taken along the centre line relative to the two lateral edges. Given the design of the experimental cores used here, it can also be considered a measure of platform surface area because all platforms were a constant 12·4 mm wide. Platform thickness is defined as the distance from the same point on the interior edge of the platform surface to the exterior surface of the flake and measured perpendicular to the exterior surface. In essence, it is the thickness of the flake at the point of percussion and in this experiment it was computed trigonometrically from the platform depth

Table 1. Basic results (number of incipient cones and flakes produced) for each combination of the independent variables

Ball weight (g)	Ball diameter (cm)	Drop height (m)	Velocity (m s^{-1})	Momentum	No. of cones	No. of flakes
28	1·6	2·75	7·34	1500	6	26
45	1·9	1·25	4·95	1100	23	60
45	1·9	1·71	5·79	1500	3	25
45	1·9	2·15	6·49	1900	5	9
224	3·6	0·34	2·59	1500	7	28
224	3·6	1·25	4·95	5500	0	27
535	5·0	1·25	4·95	13000	0	36

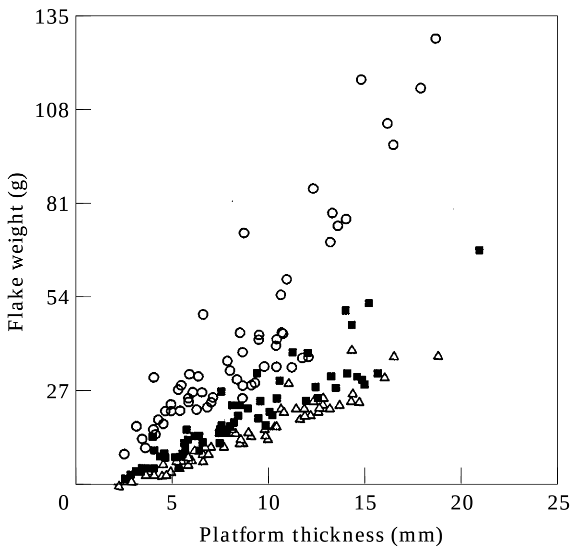

Figure 2. Graph of platform thickness versus flake weight for all flakes, including all combinations of indentor mass and velocity. Exterior platform angles: ○, 75°; ■, 65°, △, 55°.

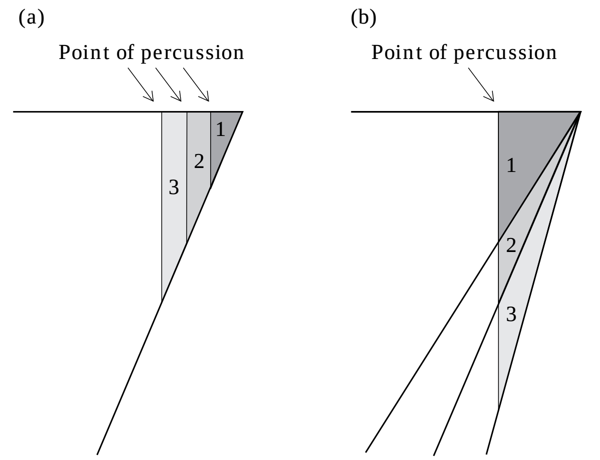

Figure 3. Comparison of the changes in volume of material removed with increases in (a) exterior platform angle or (b) platform depth.

measurement and the value of the exterior platform angle, as

$$\text{Platform thickness} = \text{platform depth} \times \sin(\text{exterior platform angle}).$$

By using this value of platform thickness, it is possible to eliminate any effect of the exterior platform angle on our measure of how far in from the exterior edge the core was struck.

Results

Previous controlled experiments published by Speth (1972, 1981) and Dibble & Whittaker (1981) have shown that some aspects of flake morphology are a direct function of two characteristics of the platform, namely the exterior platform angle and platform thickness. For the present experimental data this is shown in Figure 2, which superimposes three different exterior platforms on axes of weight and platform thickness. It is quite clear that for any given exterior platform angle, mass is expressed as a positive linear function of platform thickness. Moreover, the slope of this relationship increases with exterior platform angle; that is, for a given value of platform thickness, larger exterior platform angles will result in larger flakes and, furthermore, as exterior platform angle increases, an identical change in platform thickness results in *increasingly* heavier flakes.

At a totally heuristic level, this relationship can be thought of in geometric terms. Figure 3(a) shows a cross-sectional view of a core with three potential flakes removed (1, 2 and 3), each with the same exterior platform angle but with increasingly larger platform thicknesses. Figure 3(b) shows a similar view, but this time holding platform thickness constant while changing the exterior platform angle. In either case, increasing exterior platform angle or platform thickness results in more area enclosed by the triangle that represents the flake. Trigonometrically, if we were to assume that interior platform angle was always equal to 90°, then the area of any one of the enclosed triangles is expressed as

$$\text{Area} = 0{\cdot}5 \times \text{platform thickness}^2 \times \tan(\text{exterior platform angle}),$$

and thus is a direct function of only these two platform characteristics. However, this formula is not sufficient to model accurately flake mass and so it is of heuristic value only.

One of the factors not entered into such a geometric model is the velocity with which the core was struck or the mass of the indentor itself, which are commonly believed to be among the most important variables underlying variation in flake size and shape. As described above, these two aspects of the indentor may be combined and expressed as momentum. The experimental results obtained here confirm that mass, velocity and momentum of the indentor play a crucial role in flake production (whether or not a flake is actually produced versus the development of an incipient cone only), but they also show that, contrary to popular belief, if a flake is produced, neither momentum nor its individual components of mass and velocity has a major effect in determining flake mass.

Figure 4 reproduces the same points as shown in Figure 2, but in separate graphs for each value of exterior platform angle and with different symbols indicating flakes produced by different ball bearings dropped from the same height. Thus, mass is being varied (by more than a factor of 10) but velocity is held constant. It is clear from these graphs that while differently sized ball bearings do seem to have some effect on flake mass, this effect is neither very strong

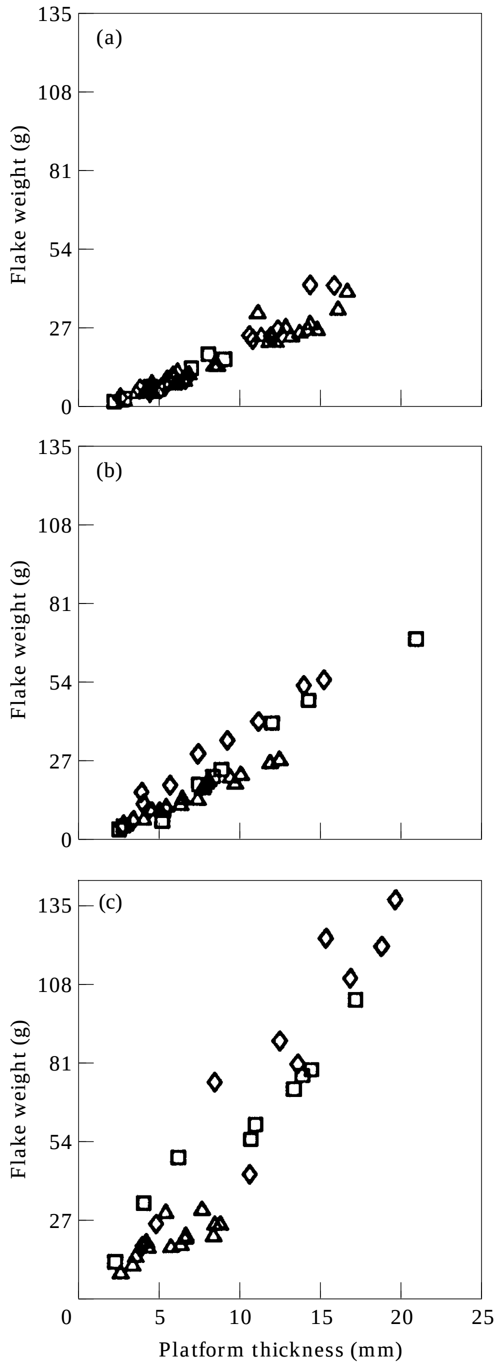

Figure 4. Graph of platform thickness versus weight for all flakes produced from a drop height of 1·25 m. Exterior platform angle: (a) 55°; (b) 65°; (c) 75°. Ball bearing weight: △, 45 g; □, 224 g; ◇, 535 g.

nor even apparent for every value of exterior platform angle. For flakes with exterior platform angles of 55° there is, for example, a complete overlap between the different ball bearing sizes, showing that in this case ball size does not have any effect on flake size. However, for flakes with exterior platform angles of 65° and 75° there is some degree of separation among flakes produced by different ball bearings; for both of these exterior platform angles, the heavier ball bearings produce heavier flakes for any given platform thickness. It should be noted that the three graphs together suggest that the effect of ball bearing size on flake size increases with exterior platform angle, i.e. the same change in mass of the indentor produces larger differences in flake weights as exterior platform angle increases. This suggests that higher values of exterior platform angle tend to amplify the effects of ball bearing size, just as it amplifies the effects of increasing platform thickness.

Figure 5 shows the effect obtained by different velocities, in each case holding overall momentum constant. Here it is quite clear that varying velocity alone makes absolutely no difference in flake mass. The same is true when ball size is held constant, but velocity (and therefore momentum) is changed (Figures 6 & 7). This is especially interesting because in this case there is a change in the momentum of the indentor, but the effect is insignificant even at the higher values of exterior platform angle. This may suggest the differences seen in Figure 4 that were attributed to differences in mass may actually reflect more the difference in ball size which may effect the size of the initial ring crack.

While there appears to be some effect of ball bearing size (reflecting either mass or diameter) on flake mass, this effect is only apparent for the higher exterior platform angles and it is easy to overemphasize its effect. In this experiment the weight of the largest ball is over 11 times the weight of the smallest ball, and over twice as much as that of the middle ball. Yet in spite of these tremendous differences in mass, the relationships between mass and the independent variables of platform thickness and exterior platform angle are still the most clear and the strongest in every case. One way to show this is to combine all of the above data and express flake mass as a function of exterior platform angle and platform thickness alone, according to the following formula (calculated with the Nonlin procedure of Systat 5·0):

$$\text{Mass} = -0{\cdot}361 \times PT - 3{\cdot}305 \times \tan(EPA) + 1{\cdot}663 \times \tan(EPA) \times PT,$$

where PT is platform thickness and EPA is exterior platform angle. This yields a correlation coefficient of 0·903, which means that over 81% of the variability in flake mass is accounted for by just these two platform characteristics, while the remaining 19% of variability is due to the effects of ball bearing size, mass, velocity and other uncontrolled factors. This relationship is graphed in Figure 8, with different symbols indicating the different momentums used to detach each flake. It should be clear from this figure that even when overall momentum is varied to such a considerable degree, flake mass is still largely determined by exterior platform angle and platform thickness alone.

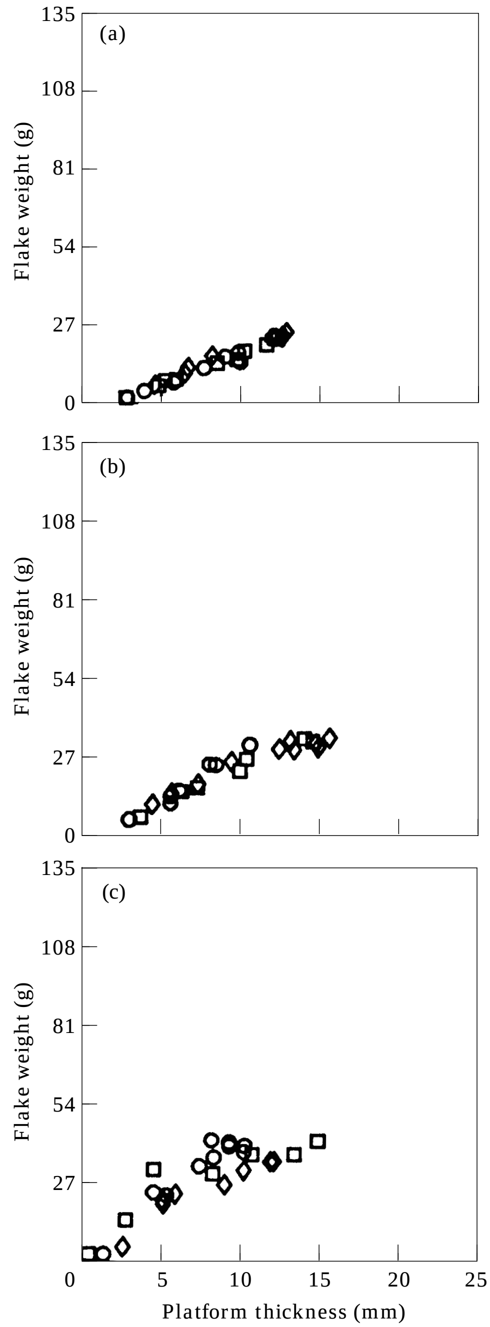

Figure 5. Graph of platform thickness versus weight for a constant momentum (1500), but varying velocity (drop height) and indentor mass. Momentum is held constant by dropping the lighter balls from increased height, thereby incresing their velocities. Exterior platform angle: (a) 55°; (b) 65°; (c) 75°. ○, 0·34 m drop height and 224 g ballbearing weight; □, 1·71 m and 45 g; ◇, 2·75 m and 28 g.

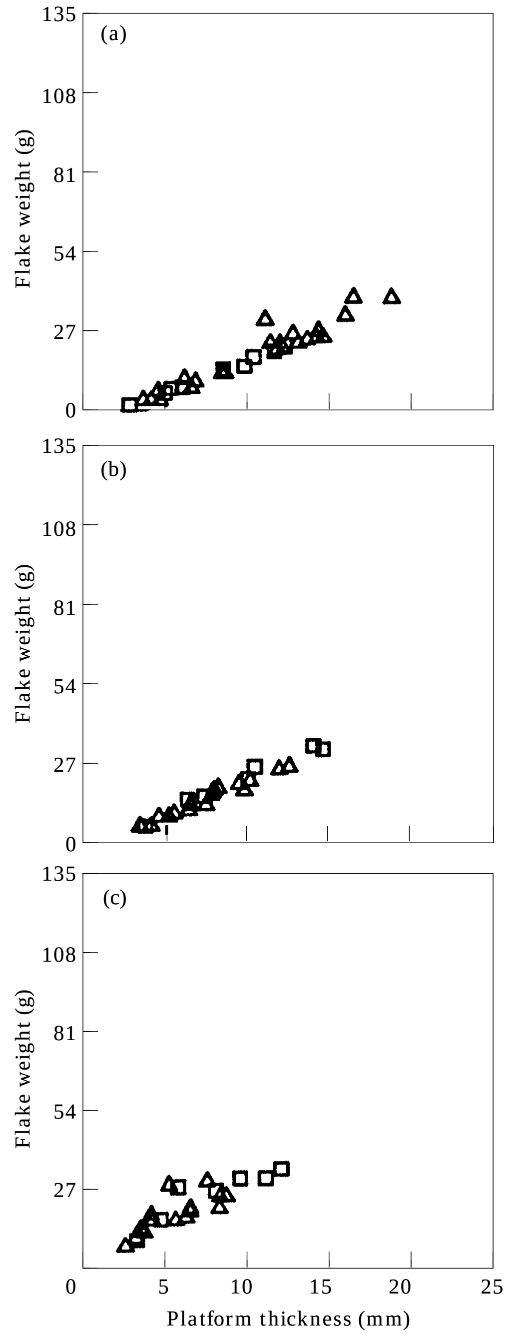

Figure 6. Graph of platform thickness versus weight for the 45 g ball bearing dropped from two different heights: △, 1·25 m; □, 1·71 m. Exterior platform angle: (a) 55°; (b) 65°; (c) 75°. Note that the corresponding changes in velocity and momentum for a constant mass do not affect the mass of the flake.

To a very large extent these same relationships can be shown to hold for the dimensional variables of flake length and thickness. Thus similar results are obtained when either flake length or flake thickness is regressed on exterior platform angle and platform thickness alone (see Figures 9 & 10). However, the nature of the cores used in this experiment are not really suitable for examining how the mass of the flake is being distributed in terms of length, width or thickness since the external morphology was always the same.

It should be clear from these figures that momentum does not play a major role in determining the mass (or

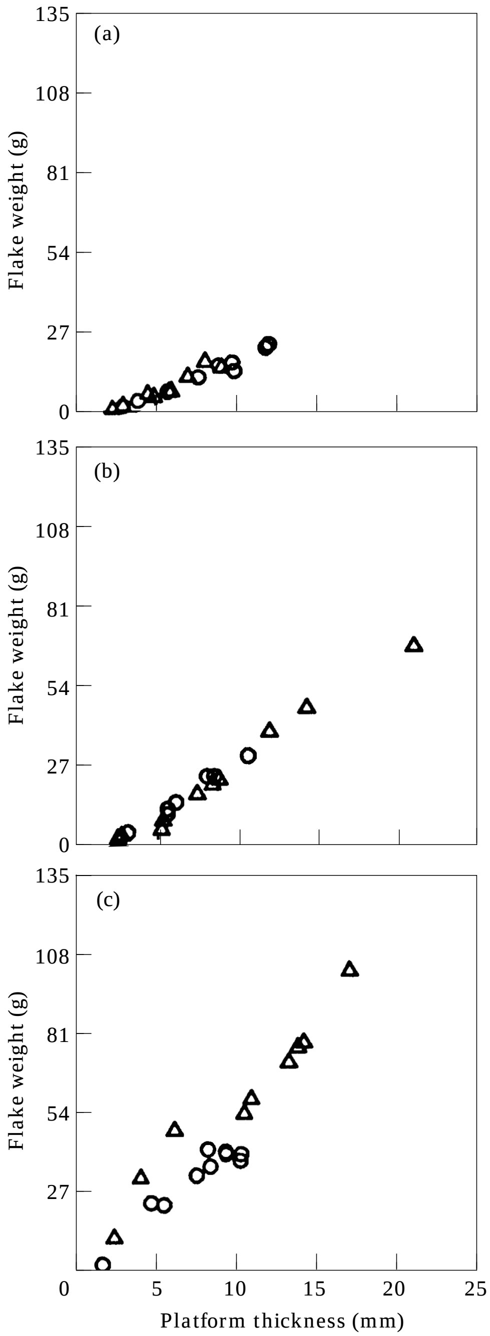

Figure 7. Graph of platform thickness versus weight for the 225 g ball dropped from the two different heights: ○, 0·34 m; △, 1·25 m. Exterior platform angle: (a) 55°; (b) 65°; (c) 75°. Note that the corresponding changes in velocity and momentum for a constant mass do not affect the mass of the flake.

dimensions) of a flake. It does, however, play a critical role in determining whether or not a flake can be produced in the first place, bearing in mind that flake mass is primarily a function of exterior platform angle and platform thickness. What the experimental data show is that for a given momentum, there is a maximum combination of these platform attributes that will produce a flake (see also Speth, 1974). The application of higher momentum, either as increased mass of the indentor (larger ball) or increased velocity (increased drop height), will produce flakes at higher exterior platform angles and larger platform thicknesses. Therefore, because the exterior platform angles and platform thicknesses can be larger with larger momentums, the resulting flakes can be larger also.

What appears to be the case is that a given momentum has the *potential* to detach a flake of a certain mass. When the exterior platform angle and platform thickness combine to determine a mass greater than the potential for that force, then no flake is produced. When they are below this threshold for a given momentum, then flakes will be produced but will exhibit a whole range of mass, varying almost solely by the exterior platform angle acting in combination with platform thickness.

This can be shown by graphing not only the successful flake detachments but also the incipient cones. Figure 11 shows that for a given momentum (holding both ball bearing size and velocity constant), as the exterior platform angle is increased there is a decrease in the maximum platform thickness that will result in a flake. Likewise, Figure 12 shows that for a constant exterior platform angle, increasing the momentum only through increased velocity (raising the drop height of the same ball bearing) allows for the successful detachment of flakes with larger platform thicknesses. Also, holding velocity constant but increasing the mass and size of the indentor also increases the maximum exterior platform angle and platform thickness, as can be seen by the fact that cones were not produced at any angle for the two larger balls over the ranges of platform thickness used in this experiment. It appears that the cluster of outliers seen below and to the right of the main group in Figure 8 represent a series of flakes that were approaching this threshold.

This threshold effect explains why it seems to a flintknapper that more momentum results in larger flakes. Even though flake size is determined mostly by exterior platform angle and platform thickness, larger values of these can be employed to produce flakes only if the core is struck with more momentum. In other words, to get a larger flake one must strike the core with more momentum because the higher values of the platform characteristics that will produce the larger flakes require it. Nonetheless, the momentum itself does not directly determine the flake mass, but rather it is the result of the platform characteristics. In fact, the application of the same high momentum on small exterior platform angles or smaller platform thicknesses will still produce smaller flakes.

This threshold effect not only can fool an experimental flintknapper, but the effect of momentum on flake size can also be mistakenly ''confirmed'' with controlled experiments. In an earlier experiment, Dibble & Whittaker (1981) reported that the size of the ball

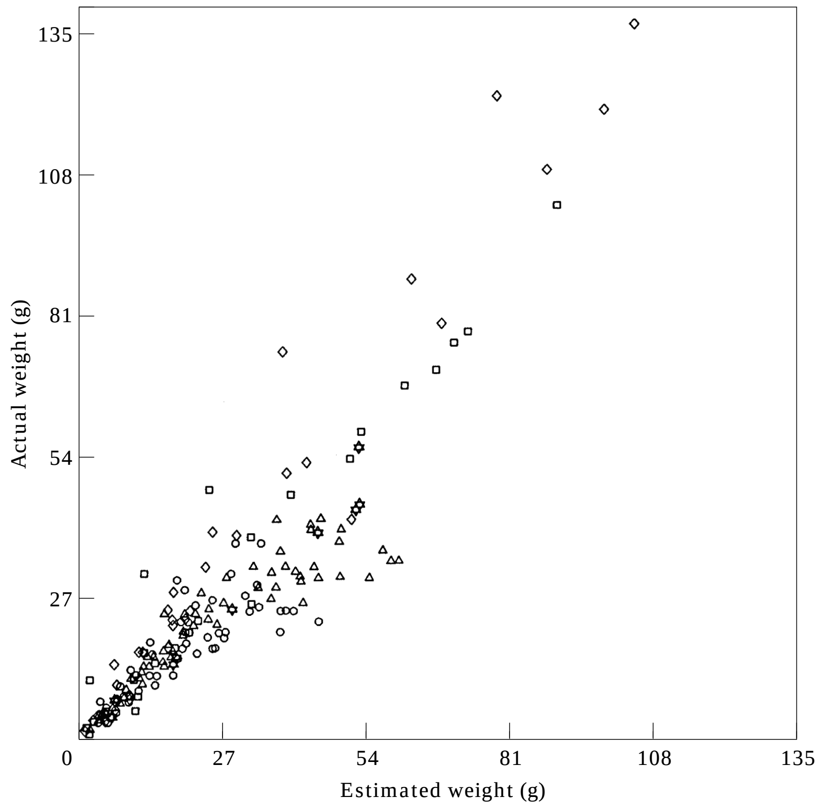

Figure 8. Plot of the estimated weight (based on exterior platform angle and platform thickness only) versus the actual weight for all flakes. Momentum: ○, 1100; △, 1500; ☆, 1900; □, 5500; ◇, 13,100. r = 0·903.

bearing (holding velocity constant) did have a significant effect on flake size because flakes struck with larger ball bearings were longer than those struck with smaller ball bearings. If we examine the mean weights of flakes produced by ball bearings, the present data show the same thing (Table 2).

However, these effects are not because heavier ball bearings themselves result in heavier flakes. A heavier ball bearing is able to detach a flake from a core with a higher exterior platform angle and greater platform thickness, thus producing a flake with a greater mass. In Figure 4, for example, the largest flakes are indeed the result of the larger ball bearings, but the important point is that the flakes still fall along the same line as flakes produced with smaller ball bearings. The application of higher momentum only increases the upper range of potential flake weights, but smaller flakes will also be produced depending on the characteristics of the platform. In other words, the relationship between flake mass and exterior platform angle and platform thickness remains almost exactly the same no matter what momentum.

Discussion

The experimental evidence presented above indicates that within the limits of the independent variables examined, the mass of a flake is almost entirely determined by the exterior platform angle and platform thickness. That these two variables have an effect on flake morphology has been known for some time on the basis of both replicative and controlled experiments. What is surprising, though, is that the velocity and mass of the indentor, as well as the combination of the two, exert so little influence on the mass of the resulting flake. Where these variables do have an effect is whether or not there is a successful detachment of a flake. Given the potential mass of a flake predicted by a certain combination of exterior platform angle and platform thickness, there is a certain minimum momentum necessary to realize that flake. If the velocity and mass of the indentor combine to exert less momentum that this, the result is only an incipient cone of percussion. The application of higher indentor velocity or mass will also detach a flake, but will affect flake morphology to only a small degree.

There are a number of other variables that have not been studied here but which may also contribute to variations in flake morphology. The angle at which the indentor strikes the core may be one of these (Speth, 1975), but earlier experiments (Dibble & Whittaker, 1981) did not find that it had any significant effect on flake mass. Current studies still in progress seem to confirm this, but they also suggest that, like hammer

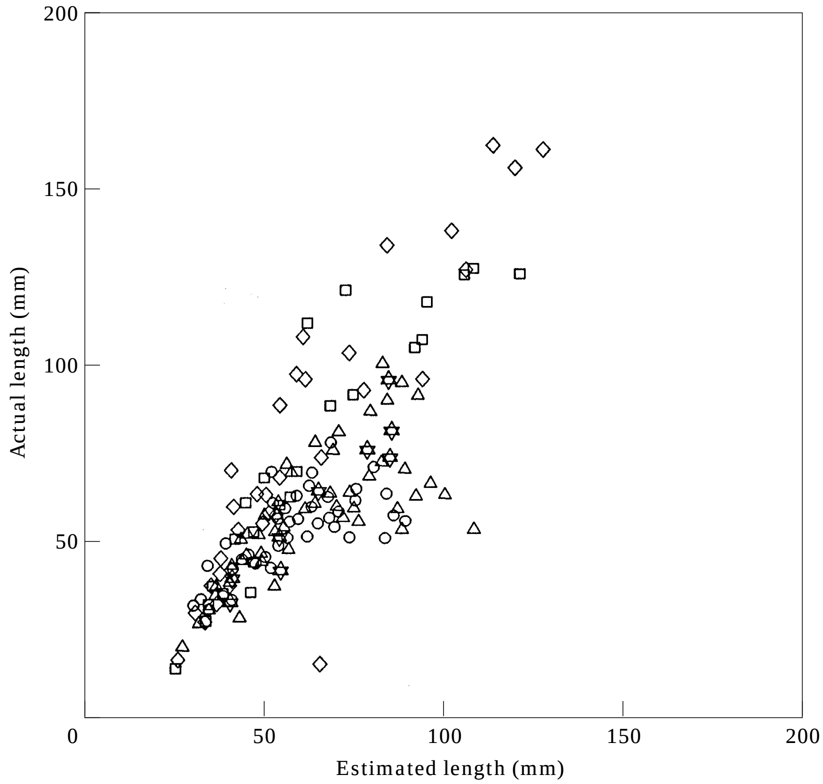

Figure 9. Plot of the estimated length (based on exterior platform angle and platform thickness only) versus the actual length for all flakes. Legend as for Figure 8. r=0·794.

velocity and mass, there may be optimal angles of blow for detaching flakes with certain exterior platform angles and platform thicknesses. Speth (1981) has also suggested that core size exerts some effect, though this was not confirmed in this study. The material that the indentor is composed of may also influence flake morphology (Hayden & Hutchings, 1989). However, flintknappers tend to set up different kinds of platforms for use with different hammer types, thus leaving open the question of whether it is the hammer itself giving rise to differences in flake morphology or the different platform characteristics. Further controlled experiments may help to determine which variable is more directly responsible. There is also the possibility that the diameter of the hammer has some influence.

A major and undeniable factor influencing flake morphology is the morphology of the flaking surface on the core itself. Further controlled experiments are being planned to study these effects in a more detailed fashion. However, preliminary studies that have been done so far suggest that while core surface morphology does largely determine the distribution of mass (and thus the shape of the flake), the actual amount of mass of the flake is still under the control of the exterior platform angle and platform thickness. Obviously, the effects of all of these independent variables must be further understood before these results are extended to archaeological materials.

While these other independent variables must still be studied in greater details, the demonstration that velocity and mass of the indentor are so negligible in their effects on flake morphology has important implications for the study of archaeological materials. Obviously one of our main goals is to understand the behavioral patterns responsible for variability among lithic assemblages. One aspect of that variability is variation in the morphology of individual flakes. At that level many of the underlying factors presumed to be important in flake production, such as hammer mass and the velocity and angle of blow, are simply not visible archaeologically and therefore not amenable for study. However, the exterior platform angle and platform thickness are visible on archaeological flakes, as is the part of the core surface morphology that resulted in that flake. If these are the most important factors affecting flake morphology, and at the same time hammer mass and velocity are not nearly as significant, then it means that there is tremendous potential to analyse and reconstruct the more significant behavioral patterns underlying flake production from the archaeological materials themselves.

Just realizing the importance of exterior platform angle and platform thickness in affecting flake mass should help to document different flintknapping strategies. Given the fact that increasing either one results in larger flakes, there are potentially different

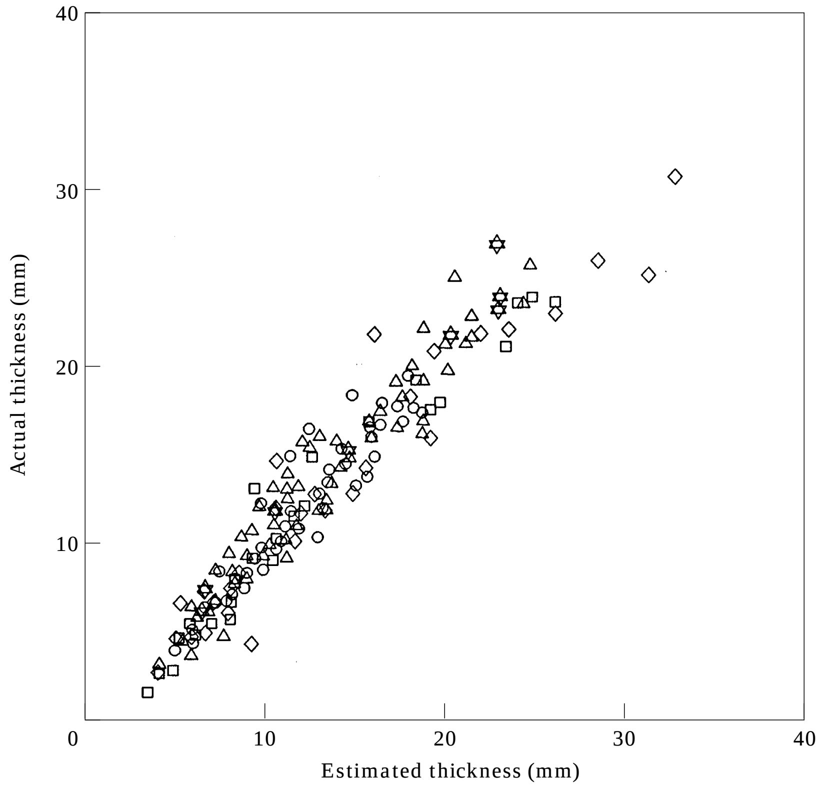

Figure 10. Plot of the estimated thickness (based on exterior platform angle and platform thickness only) versus the actual thickness for all flakes. Legend as for Figure 8. r=0·964.

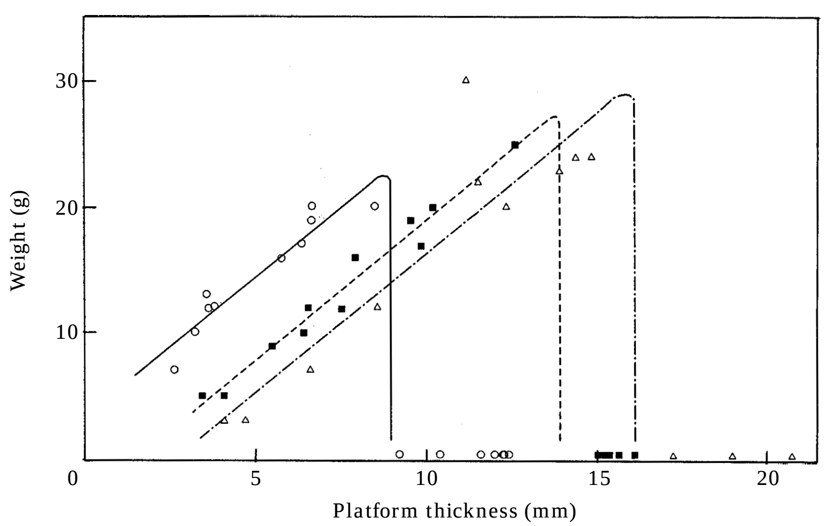

Figure 11. Graph of the platform thickness versus weight for the 45 g ball dropped from 1·25 m. Flakes with a weight of 0 g are incipient cones formed at platform thicknesses which are too great for the amount of momentum applied to the core. Note that as the exterior platform angle increases so the value of platform thickness which produces a flake decreases: △ and –·–, 55°; ■ and ––––, 65°; ○ and ——, 75°.

combinations of how these variables were being controlled according to different strategies of flintknapping. For example, it is clear that low exterior platforms allow a much greater latitude in the range of platform thicknesses that can detach flakes with a given momentum, and flake mass does not vary as greatly with different platform thicknesses. The use of high exterior platform angles, on the other hand, requires much more precision on the part of the flintknapper to get consistent results, though the

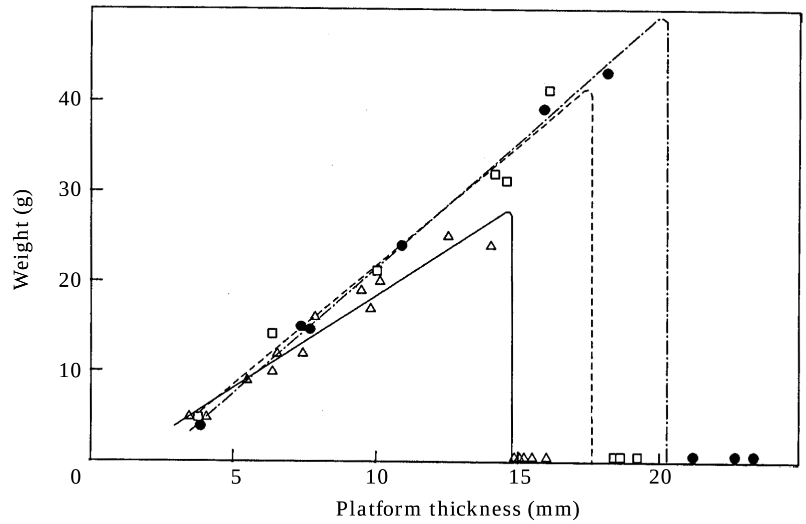

Figure 12. Graph of the platform thickness versus weight for the 45 g ball dropped from three different heights with cores having exterior platform angles of 65°: △ and ——, 1·25 m; □ and – – – –, 1·75 m; ● and – . –, 2·15 m. As the velocity of the ball is increased, so does the maximum value of the platform thickness which can produce a flake.

Table 2. Average weights for flakes produced by different ball bearings, but holding drop height at constant 1·25 m

	Ball weight		
	45 g	224 g	535 g
No. of flakes	60	28	36
Mean	17·500	29·071	34·806
S.D.	8·301	28·806	37·848

F = 5·759; *df* = 3, 121; *P* = 0·004.

maximum size of the flake that can be obtained is greater. It would not be surprising to find that certain prehistoric groups emphasized one of these basic strategies over the other.

Another important conclusion that can be drawn from this experiment is that any flake with an intact platform retains much of the information needed to accurately predict the mass of the flake. This also has important implications for archaeological analysis. For example, one of the current approaches in understanding typological variability concerns the relationship between the final artefact form and the degree to which tools have been reduced through repeated resharpening (Frison, 1968; Goodyear, 1974; Jelinek, 1976; Hoffman, 1985; Dibble, 1987; Barton, 1990). However, one of the difficult aspects of these studies is in reconstructing the original sizes of the tools to show how much reduction actually occurred (see Kuhn, 1990). If mass is not under the control of hammer mass and velocity, and given that platforms are usually left intact even on heavily reduced tools, then it should be possible to calculate almost exactly the amount of mass lost to resharpening.

Thus, while the reconstruction of reduction sequences of cores and tools offers a great deal of information concerning prehistoric behavior, it is clear that there is still a great deal of potential in understanding variability even at the level of individual flakes. It is largely through controlled experiments such as the one presented here that we will be able to further our understanding of exactly how and to what degree different factors influence flake morphology. It is on this basis that we will understand better how those factors might have been controlled by prehistoric flint-knappers as well as how best to interpret many of the various attributes observable on their products.

References

Barton, C. (1990). Beyond style and function: a view from the Middle Paleolithic. *American Anthropologist* **92,** 57–72.

Bordes, F. & Crabtree, D. (1968). The Corbiac blade technique and other experiments. *Tebiwa* **12,** 1–21.

Cotterell, B. & Kamminga, J. (1987). The formation of flakes. *American Antiquity* **52,** 675–708.

Cotterell, B., Kamminga, J. & Dickson, F. D. (1985). The essential mechanics of concoidal flaking. *International Journal of Fracture* **20,** 205–221.

Crabtree, D. (1966). A stoneworker's approach to analysing and replicating the Lindenmeier Folsom. *Tebiwa* **9,** 3–39.

Crabtree, D. (1972*a*). *An introduction to flintworking*. Pocatello: Idaho State University Museum.

Crabtree, D. (1972*b*). The cone fracture principle and the manufacture of lithic materials. *Tebiwa* **15,** 29 – 36.

Dibble, H. (1987). The interpretation of Middle Paleolithic scraper morphology. *American Antiquity* **52,** 109–117.

Dibble, H. L. & Whittaker, J. (1981). New experimental evidence on the relation between percussion flaking flake variation. *Journal of Archaeological Science* **6,** 283–296.

Frison, G. (1968). A functional analysis of certain chipped stone tools. *American Antiquity* **33,** 149–155.

Goodyear, A. (1974). *The Brand Site: A Techno-Functional Study of a Dalton Site in Northeast Arkansas*. Fayetteville, AR: Akansas Archaeological Survey No. 7.

Hayden, B. & Hutchings, W. (1989). Whither the billet flake? In (D. Amick & R. Mauldin, Eds) *Experiments in Lithic Technology*. British Archaeological Reports, British Series **528,** 235–258.

Hoffman, C. (1985). Projectile point maintenance and typology: asessment with factor analysis and Canonical Correlation. In (C. Carr, Ed.) *For Concordance in Archaeological Analysis: Bridging Data Structure, Quantitative Technique, and Theory*. Fayetteville, AR: Westport Publishers, pp. 566–612.

Jelinek, A. (1976). Form, function and style in lithic analysis. In (C. E. Cleland, Ed.) *Cultural Change and Continuity: Essays in Honor of James Bennett Griffin*. New York: Academic Press, pp. 19–33.

Kuhn, S. L. (1990). A geometric index of reduction for unifacial stone tools. *Journal of Archaeological Science* **17,** 583–593.

Neumann, T. W. & Johnson, E. (1979). Patrow Site lithic analysis. *Midcontinental Journal of Archaeology* **4,** 79–111.

Patten, R. (1980). Soft stonehammer percussion. *Flintknapper's Exchange* **3,** 17.

Patterson, L. W. (1981). The analysis of striking platform geometry. *Flintknapper's Exchange* **4,** 18–20.

Speth, J. (1972). Mechanical basis of percussion flaking. *American Antiquity* **37,** 34–60.

Speth, J. (1974). Experimental investigations of hard-hammer percussion flaking. *Tebiwa* **17,** 7–36.

Speth, J. (1975). Miscellaneous studies in hard-hammer percussion flaking: the effects of oblique impact. *American Antiquity* **40,** 203–207.

Speth, J. (1981). The role of platform angle and core size in hard hammer percussion flaking. *Lithic Technology* **10,** 16–21.

Toth, N. (1982). *The stone technologies of early hominids at Koobi Fora, Kenya: an experimental approach*. University of Michigan (Microfilm).