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Are Upper Paleolithic blade cores more productive than Middle Paleolithic discoidal cores? A replication experiment

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ABSTRACT

It is widely believed that the change from discoidal flake production to prismatic blade-making during the Middle–Upper Paleolithic transition in Europe led to enhanced technological efficiency. Specifically, blade-making is thought to promote higher rates of blank production, more efficient and complete reduction of the parent core, and a large increase in the total length of cutting edge per weight of stone. Controlled replication experiments using large samples, computer-assisted measurements, and statistical tests of several different measures failed to support any of these propositions. When resharpened, the use-life of flake edges actually surpasses that of blades of equivalent mass because the narrower blades are more rapidly exhausted by retouch. Our results highlight the need to replace static measurements of edge length that promote an illusion of efficiency with a more dynamic approach that takes the whole reduction sequence into account. An unexpected by-product of our replications was the discovery that real gains in cutting-edge length per weight of stone are linked to surface area. There is now a need to test the proposition that all the perceived advantages currently bestowed upon blades only occurred during the shift from macroblade to bladelet production. If our results are duplicated in further experiments, the notion of "economical" blades will have to be rejected and alternative explanations sought for their appearance in the early Upper Paleolithic. While Aurignacian bladelet (Dufour) production could signal the advent of composite tool technology (wooden handles or shafts with bladelet inserts), this does not help to explain why macroblades were also produced in large numbers. We may need to reexamine the notion that macroblades were of more symbolic than functional significance to their makers.

Introduction

The advent of the Upper Paleolithic in Europe has long been associated with the appearance of prismatic blade production. Although the apparently coterminous appearance of *Homo sapiens sapiens* suggests the most likely agent behind this proliferation of blades, the significance of their association is now widely challenged (Bar-Yosef and Kuhn, 1999). Blade technology was not introduced into Europe in the early Upper Paleolithic, but emerged independently in northwest Europe during the Middle Paleolithic, then faded from the record (Tuffreau and Somme, 1988; Conard, 1990; Meignen, 1994; Otte, 1994; Révillion and Tuffreau, 1994; Tuffreau et al., 1994; Révillion, 1995). This implies that Neandertals could make blades if they wished to, and that blade-making cannot be coupled to human cognition as a uniquely "modern" skill. Outside of Europe, the association also breaks down, with blade production reported in the Levantine terminal Lower Paleolithic (Bordes, 1977) and Middle Paleolithic (e.g., Bar-Yosef and Meignen, 2001), in North Africa (McBurney, 1967), and in the Middle Stone Age of sub-Saharan Africa (e.g., Wendorf and Schild, 1974; Wendorf et al., 1993; McBrearty and Brooks, 2000; Wurz, 2002; McCall, 2007; Soriano et al., 2007).

A pervasive assumption underpinning most discussions of Upper Paleolithic origins is that blade-making affords several adaptive advantages over discoidal or other forms of flake production. There are three parts to the assumption: (1) blade technology produces more blanks, and thus (2) unit volume of toolstone is more effectively and completely consumed and, most significantly, (3) vastly greater lengths of cutting edge per unit weight of toolstone are produced (e.g., Bar-Yosef and Kuhn, 1999: 324). These purported advantages of blade over flake production

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are repeated with varying emphasis in standard texts (e.g., Bordaz, 1970; Schick and Toth, 1993; Whittaker, 1994; Klein, 1999; Renfrew and Bahn, 2000), and in specialized papers (e.g., Sheets and Muto, 1972; Collins, 1999; Marks and Chabai, 2006) stressing the gains in cutting edge versus tool weight. Some go so far as to quantify the gains [e.g., up to two times the amount of cutting edge for blades, compared to Middle Paleolithic/Mousterian flakes (attributed to Loren Eiseley in Renfrew and Bahn, 2000: 321), or five times (Bordaz, 1970: 57), or even ten times (attributed to Leroi-Gourhan, 1957, 1993—quoted in Peregrine, 2003: 142; Shea, 1995: 763; Gamble, 2007: 181)].

The few opponents of this near-consensus view of blade efficiency argue that blade-core reduction is actually more wasteful because only better-quality stone, of specific shapes and sizes, can be selected. More effort and skill is needed in initial core shaping, during which much stone is lost. Because blades are fragile and break more easily than flakes, blade production is far more prone to fatal knapping errors that render the core useless (Hayden et al., 1996; Bar-Yosef and Kuhn, 1999). Furthermore flakes, being wider than blades, can be resharpened more times, thereby extending the use-life of their cutting edges. Thus, the blade's much-vaunted advantage in cutting-edge length is negated. Chazan (1995) argued for this in five major sequences covering the transition from flake-based Middle Paleolithic industries to blade-based Upper Paleolithic ones.

Surprisingly, these claims and counterclaims for the various advantages of blade production have not been subjected to systematic testing through replication. The first published study of blade cutting-edge length comes from the replication of Mesoamerican pressure blade technology using obsidian (Sheets and Muto, 1972), the relevance of which remains highly uncertain for Paleolithic studies (Bar-Yosef and Kuhn, 1999). Other landmark replications of prismatic blades focused on the attributes of direct percussion, indirect percussion, and pressure techniques, but not on edge length or technological efficiency (Sollberger and Patterson, 1976). A comparative replication by Rasic and Andrefsky (2001) of a single bifacial core versus a blade core revealed that the number of "usable blanks" per gram of toolstone was greater for the bifacial core than for the blade core, but it is not clear how many from the latter were blades. While their results appear to "refute a commonly accepted notion that blade cores are superior to all other reduction strategies in terms of raw material economy" (Rasic and Andrefsky, 2001: 75), the dearth of measurements and small sample size leave the issue of cutting-edge length unresolved. In similar fashion, Prasciunas (2007) compared products from bifacial cores with those of "amorphous" cores rather than prismatic blade cores.

Tactikos (2003) came closest to addressing the question directly in the course of her analysis of replicated and excavated assemblages from the entire Paleolithic sequence. However, shortcomings in experimental design undermine her passing observation that the blades examined did not register significant gains in cutting edge over the flakes from the discoid-Levallois reductions. The few replicated samples used were from a knapper who did not have this particular experiment in mind, leaving unclear whether he was attempting to maximize either blade or flake production in any of the sequences used. To compound matters, only randomly selected blanks from each assemblage were weighed and measured rather than the whole assemblage (usable blanks, preparation flakes, debris, and the core itself), needed for a meaningful measure of knapping efficiency. Finally, circumference measurements (including platforms and natural backing) were used as proxies for cutting-edge length. To what extent these three factors have masked potential differences between the summed cutting-edge lengths of the blade and flake samples remains unknown.

Thus, the widely held belief that blade-making produces more blanks, consumes more of the core, and yields (much) more cutting edge than discoidal flakes remains untested by replication. Here, we describe two tightly controlled experiments designed to verify or refute all three statements. Our first experiment examines production—i.e., from core to blanks. Our second experiment examines cutting-edge life history—i.e., from the flake (or blade) blank to the abandoned tool, exhausted through resharpening.

Materials

The toolstone used in Experiment 1 is a fine green sand silicate (flint) from the Cretaceous chalk cliffs at Seaton on the Devonshire coast, U.K. It has exceptional flaking quality, and was not heat-treated. For Experiment 2, a good-quality blue-gray chert of unknown origin was used, also not heat-treated.

All blanks from Experiment 1 were knapped (by MIE) with appropriate percussors: hammerstones for the discoid reductions and a boxwood billet (length = 232.78 mm, medial width = 61.14 mm, mass = 611.5 g) for the blade reductions. Small chinking and grinding stones were also used for blade-core preparations. The blanks for Experiment 2 were knapped (also by MIE) with two antler billets of similar dimension (Billet A: length = 207.62 mm, medial width = 54.42 mm, mass = 492.6 g; Billet B: length = 205.24 mm, medial width = 50.32 mm, mass = 493.3 g). The blanks were retouched with these same billets.

Measuring and recording equipment and software included: Mitutoyo Digimatic calipers, a Nikon Coolpix L18 digital camera (Experiment 1), a Nikon Coolpix 4300 digital camera (Experiment 2), a TI-83 Plus calculator, an AND EK-3000-I digital scale (Experiment 1), and a MyWeigh iBalance 5500 digital scale (Experiment 2). Data were recorded in Microsoft Excel. Photographs of lithic blanks were calibrated and adjusted in Adobe Photoshop (see Methods; also http://www.thinkcomputer.com/research). Cutting edges were measured using Adobe Illustrator (see Methods). The specimens used in this study were retained by the first author. All recorded data are available for download at http://www.thinkcomputer.com/research.

Methods

Experiment 1: the core reductions

The blade blanks came from seven prismatic blade reductions. We adopt here the least constraining definition of "blade,"—i.e., any elongated flake with an axial length (along its axis of

Table 1
Total mass of usable blanks and waste products after reduction of the blade cores B1–B7 and the discoidal cores F1–F7

Core	Original core block (g)	Exhausted core (g)	Waste chips (g)	Total waste mass (g)[a]	Total blanks mass (g)
B1	934.4	119.2	110.8	230.0	704.4
B2	1469.2	174.6	222.3	396.9	1072.3
B3	1208.4	201.6	175.9	377.5	830.9
B4	1499.8	332.9	171.5	504.4	995.4
B5	2375.1	200.6	248.6	449.2	1925.9
B6	803.1	134.0	187.4	321.4	481.7
B7	2411.1	169.7	268.6	438.3	1972.8
B1–B7	10,701.1	1332.6	1385.1	2717.7	7983.4
F1	980.4	57.3	137.4	194.7	785.7
F2	1361.9	105.1	113.4	218.5	1143.4
F3	697.1	56.5	176.8	233.4	463.7
F4	1311.1	96.9	68.5	165.4	1145.7
F5	1731.5	86.4	94.5	180.9	1550.6
F6	833.5	77.6	120.5	198.1	635.4
F7	2592.6	122.4	203.6	326.0	2266.6
F1–F7	9512.1	602.2	914.7	1517.0	7995.1

[a] Total waste mass equals the sum of the exhausted core and waste chips.

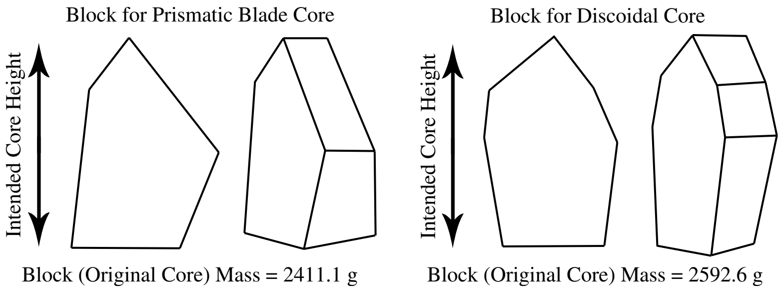

Fig. 1. Schematic shapes of the paired blocks (by mass) selected as blanks for the blade core B7 and the discoidal core F7. Block shapes of similar weight and cortex amount were roughly comparable but not identical.

percussion) at least two times longer than its width—i.e., its L:W ratio is at least 2:1 (e.g., Bar-Yosef and Kuhn, 1999). Most blades used in this experiment have L:W ratios of 3:1 and greater. In this series, the prismatic blade cores are called Cores B1–B7. The discoidal flake blanks used for comparisons came from seven discoid cores labeled Cores F1–F7. Some discoidal reductions also produced a few unintentional blades.

We chose not to start with identical saw-cut flint blocks, but to sacrifice absolute control of block size and shape for a more realistic framework in which the knapper's selective judgment was allowed free play. Although the selected blade-core blocks varied widely in size, the range of block sizes picked for the discoidal reductions is comparable (Table 1, column 2). A two-sample t-test showed that there was no statistically significant difference between the range of B1–B7 block masses and the F1–F7 block masses ($t = 0.4938$, $p = 0.6303$). Three blade-core blocks had close mass equivalence among the discoidal-core blocks. Overall, the blade-core reductions consumed about a kilogram (1189 g) more flint than the discoidal ones.

Blocks of comparable mass were also roughly matched by shape in the manner shown by the example in Fig. 1, but we have not otherwise attempted to quantify block shape.

Blade reductions with a wooden billet followed the Upper Paleolithic prepared-platform unidirectional technique on a bifacial pre-core (Fig. 2a), as described by Giria and Bradley (1998), and bidirectional flaking was also occasionally used to correct mistakes or prepare core ridges and convexities (described below). A long, crested blade was prepared and struck to start the core (Fig. 2b), and several more could be produced during core rejuvenations later in the same reduction.

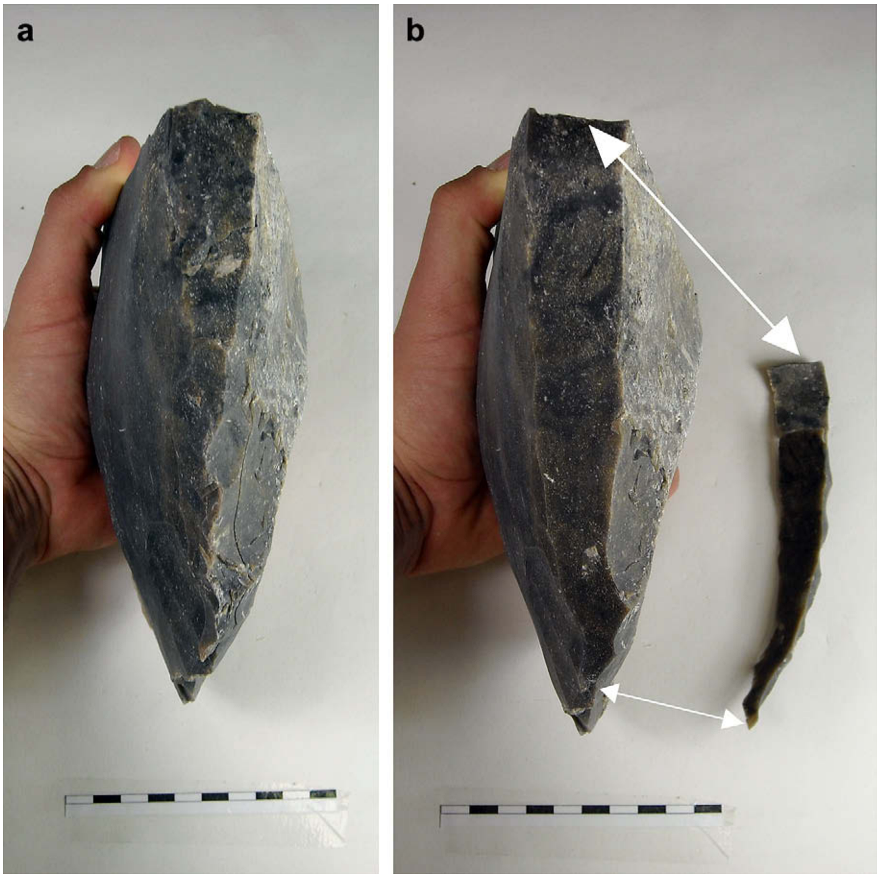

Fig. 2. (a) Side view of the fully prepared blade core B7. The initiating crested blade has been struck and refitted to the core (b) with crested blade removed, showing initial blade scar.

Discoid (radial) reductions with stone hammers followed the standard Middle Paleolithic discoid reduction sequence with (mostly) dihedral or facetted platforms. This is essentially a "tortoise core" Levallois reduction without the Levallois flakes, as defined by Bradley (1979).

At all times, the knapper's conscious aim was to get as many long blades as possible from the blade cores (Fig. 3a–c), and as many broad flakes from the discoidal cores (Fig. 3d–f). Inevitably, natural cleavages hindered some blank removals (resulting in chunky blanks, larger than desired), and there were a few mistakes. For example, Core B5 was partially spoiled when too heavy a blow during platform preparation knocked off the entire platform (Fig. 4a). The occasional step fracture encountered during reduction was easily corrected (Fig. 4b), as was the occasional hinged removal (Fig. 4c).

A large sheet under the knapping area was used to save all knapping products. Blanks were numbered in sequence so that core-reshaping episodes (mainly flakes) could be isolated from runs of blade detachment in any given series. Each blank was placed in its own numbered zip-lock bag after measurements were taken, including: axial length, width, thickness, maximum dimension, surface area, length-to-width ratio, maximum-dimension-to-width ratio, mass, cutting-edge length, and cutting-edge-length-to-mass ratio. Original data for 1289 blanks are available for download at http://www.thinkcomputer.com/research.

When the reduction of each block was complete (i.e., all working angles were exhausted and/or resulting flakes were too small to be used), the exhausted core mass was also recorded. A few cores retained their own usable cutting edges, but these were deemed to fall outside the goals of the experiment and were not recorded.

Residual chips and debris/dust were also bagged and weighed and the total wastage (exhausted core plus debris) was computed (Table 1).

Experiment 2: blank retouch until exhaustion

The second experiment addressed Chazan's (1995) assertion that (wider) flakes can be resharpened more often than (narrower) blades, thus extending the use-life of the flake's cutting edge and, by implication, the length of its available cutting edge. The edges of eleven chert blades and seven chert flakes were resharpened to exhaustion. First, specimens were weighed, and then all cutting edges were measured and summed by group. Unifacial retouch with antler billets was applied to each specimen in a series of resharpening events until exhaustion or breakage (Fig. 5). Following Davis and Shea (1998: 605), the edges of the blank were dulled with an abrader before each resharpening. After each event, the renewed cutting edge was again measured. When finally exhausted (i.e., the edge was too steep to be resharpened further), specimens were reweighed and all edge measurements were summed to obtain the specimen's accumulated cutting-edge length. Accumulated measures were then summed for all flakes and all blades, and each sum was compared with the group's original mass. Data for individual specimens may be viewed at http://www.thinkcomputer.com/research.

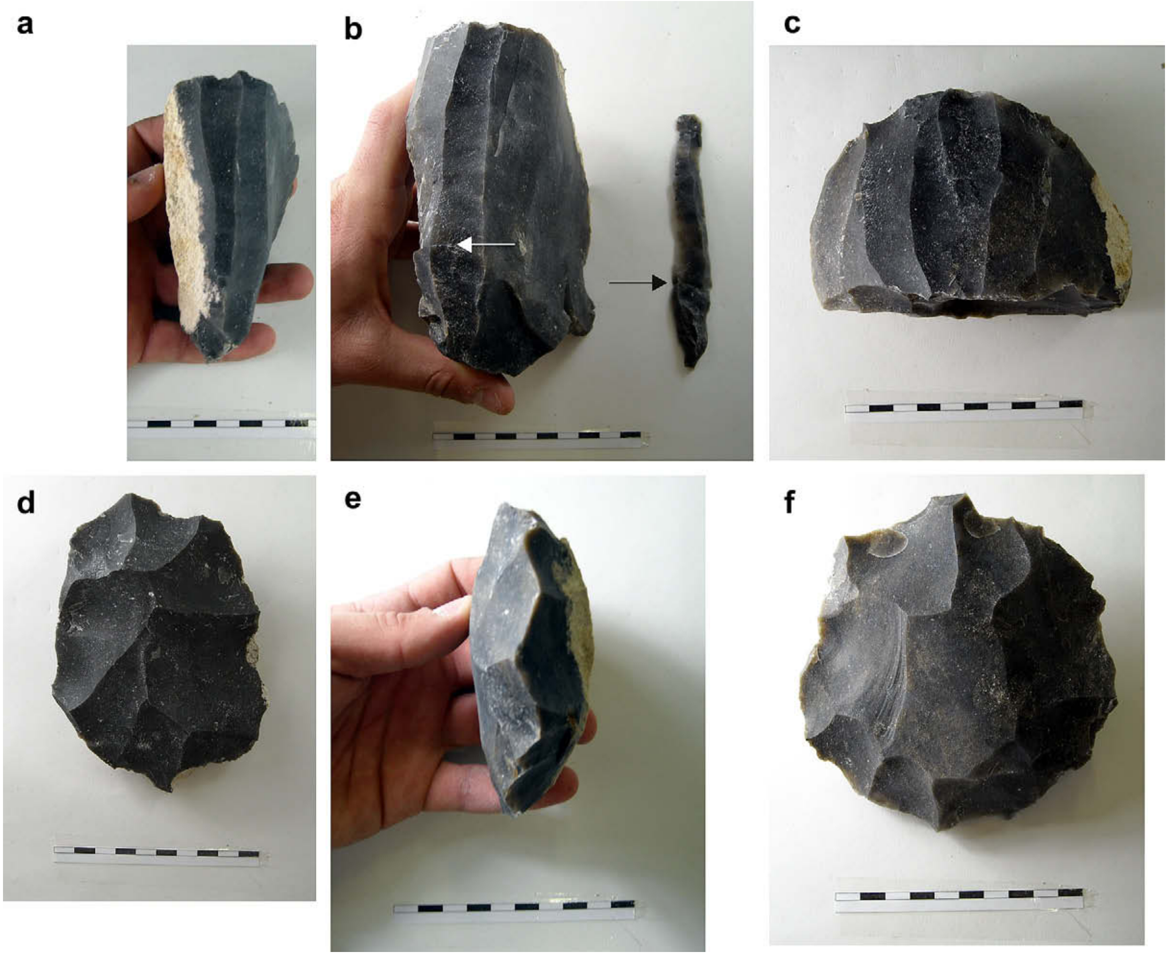

Fig. 3. (a) Blade core B6 midway through reduction. (b) Blade core B1 early in the reduction showing a natural cleavage in the core (arrow) that caused the removed blade to snap. (c) Blade core B7 late in the reduction. (d) Top view of discoidal core F1 midway through reduction. (e) Side view of discoidal core F3 midway through reduction. (f) Top view of discoidal core F5 early in the reduction.

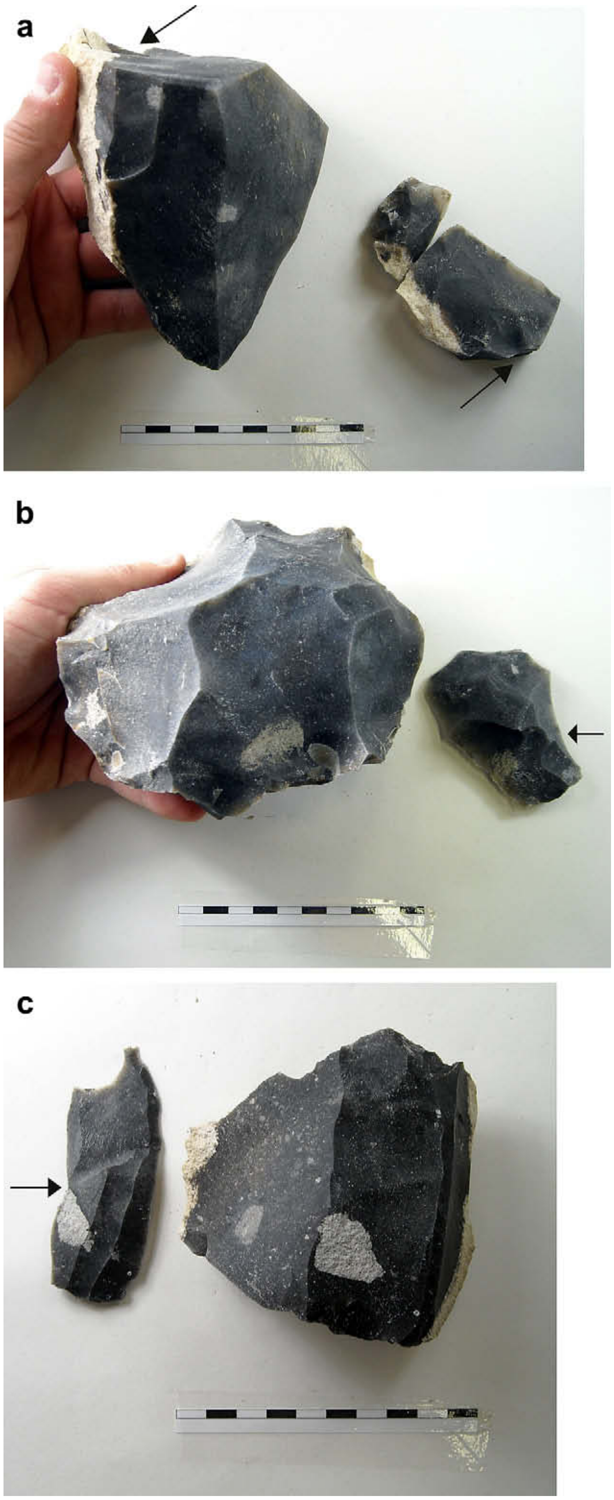

Fig. 4. (a) Blade core B5: the platform has been accidentally removed and new striking surface must be prepared. (b) Discoidal core F7: a hinge-fracture scar (arrow) has been cleared from the core surface. (c) Blade core B3: a hinge-fracture scar on the blade surface (arrow) was cleared from the core's working face by striking this wide blade from the opposed platform.

The measurements

Following Rasic and Andrefsky (2001), only blanks greater than 25 mm in maximum dimension were used for quantifying cutting edge. Hand measurements of lithic cutting edge (string and ruler, rolling the cutting edge in play dough, and measuring the incision) were found to be extremely inaccurate. We present an alternative procedure that yields consistently reproducible measurements using either PC or Mac computers. Specifics for each computer type are available at http://www.thinkcomputer.com/research and/or by contacting AG. The following steps are common to both computers:

(1) Each blank was photographed along with a metric scale. To eliminate shadows that might be misinterpreted as part of the blank's cutting edge, the specimen was photographed on a glass sheet positioned ~75 cm above the background surface. Potential parallax errors were avoided by zooming in on the target edges. This was tested by photographing a sheet of graph paper and measuring the resulting grids in Adobe Photoshop.
(2) Each image was opened in Adobe Photoshop and adjusted to full scale.
(3) Where needed, brightness and/or contrast were adjusted to highlight the blank edge against its background. The flint used in Experiment 1 contrasted best with a white background. The gray-blue chert used in Experiment 2 contrasted most sharply against a black ground.
(4) The background was then deleted, leaving only the image of the lithic blank.
(5) Each finished image was then "placed" in a layer of a new file opened in Adobe Illustrator. Here, the image was converted into a thin black outline by using the "Trace" tool (Mac) or "Auto-Trace" tool (PC). By using the "direct-selection tool," any parts of the outline that are unusable edge segments (the platform, obtuse edge angles, step-fracture edges, hinged edges, 90° edge angles with or without cortex) were deleted. The remaining outline (i.e., the usable cutting edge) was measured in Adobe Illustrator using the window "Document Info." Multiple repeats using the same image yielded identical results. Measurements were recorded in Microsoft Excel. All cutting-edge outlines were saved as Adobe Illustrator files.

Results

Table 2 shows the proportions of flake and blade blanks produced from each core. Overall, blade production from the set of seven blade cores was 48.5% of usable blanks. The seven discoidal cores also produced a few (3.7%) unintentional blades. Thus, the knapper's goal to produce more blades from the blade cores and more flakes from the discoid cores was fully met. Unsurprisingly, a two-sample *t*-test comparing the percentages of flakes and blades produced by each set of cores indicates a statistically significant difference in the number of flakes ($t = -13.4948$, $p < 0.00001$) and blades ($t = 13.4909$, $p < 0.00001$). This is independently reflected in the sharp contrast between mean L:W ratios of blank sets struck from the two series of cores (Table 3, column 3). The overall quality and consistency of the blade sets may also be gauged from their high L:W ratios (Table 3, columns 6–7).

Do blades provide more cutting edge than flakes?

This is the most widely held perception of blade efficiency, and is based wholly on appearances. As noted, claims for blades run from two to ten times more cutting edge than flakes. Our large and precisely measured samples allow a first test of such claims. Our 300 blades derived from cores B1–B7 provide 39.59 m of cutting edge for an average of 132 mm per blade. Our 645 flakes (we exclude the few unintended blades) from the discoidal cores F1–F7 provide 55.86 m of cutting edge for an overage of 86.6 mm of cutting edge per flake (Table 4, column 2). On average, the blades have 1.52 times more cutting edge than the flakes—below the most modest estimates provided in the literature but nonetheless supporting the consensus view.

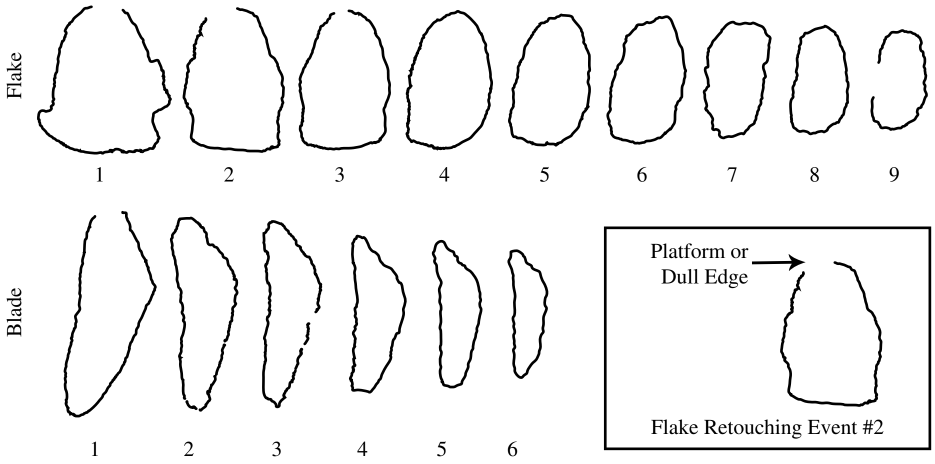

Fig. 5. Computer-drawn images of a discoidal-flake edge (top row) and a blade edge (bottom row) when unretouched (1) and following successive retouch events until exhausted for the flake (9) and for the blade (6). Since the flake can be retouched more times than the blade, its accumulated edge length eventually exceeds that of the blade.

Do blades provide more cutting edge per weight of stone than flakes?

A more telling estimate of blade efficiency is to calculate how much stone is consumed to obtain the cutting edge; indeed, most published estimates are expressed in such terms. The consensus view is that a centimeter of flake's cutting edge uses up more stone than that of a blade and is consequently more expensive. We tested this by dividing total cutting-edge length of our flakes by their combined mass and comparing this result with that for blades (Table 4, column 4). Our flakes yielded on average 7.0 mm of cutting edge for one gram of flint, while our blades yielded 11.0 mm. Thus, the blades provided 1.57 times more cutting edge per weight of stone than the flakes, still below the most conservative published estimates of such a measure. In some ways, the values for the individual sets of blanks are more revealing than the averages. While the output of cutting edge per gram from the discoidal reductions is remarkably consistent, output from the blade cores varies wildly, with the best set yielding nearly three times that of the worst. This lends eloquent support to points made by opponents of blade efficiency that blade-making is a riskier business that is more prone to failures.

It would seem, then, that the general perception of blade efficiency is correct if somewhat exaggerated, and there is nothing more to discuss. But we argue below that these descriptive data give an entirely false picture because our blade and flake samples have been measured in total isolation from the reduction sequences that produced them. We have been comparing blades and flakes, not blade-making versus discoidal flake production. When the latter are compared, a very different picture emerges.

We now present the results of three tests arranged in the same order as the propositions outlined above: (1) blade-making generates more blanks; hence (2) unit volume of toolstone is more effectively and completely consumed and, most significantly, (3) vastly greater lengths of cutting edge per unit weight of toolstone are produced.

Does blade-making produce more blanks per core?

There are two ways to test this proposition. The numbers of usable blanks generated from the cores can be simply counted, but in such a test, the sizes of the original blocks are not considered. However, larger blocks are likely to produce more blanks than smaller ones. The simplest solution is to divide the number of usable blanks by the original block's mass.

In the simple count-the-blanks approach, a two-sample *t*-test shows no statistical difference ($t = -0.4408$, $p = 0.6672$) between the number of usable blanks produced from the blade-core sample vs. the discoidal-flake-core sample (Table 2, column 1). This result is due to the fact that our blade-core reductions did not generate significantly more usable blanks than our discoidal ones.

Table 2
Proportions of usable blade and flake blanks struck from the blade cores B1–B7 and the discoidal cores F1–F7

Core	Total blanks	Flakes	Blades
B1	73	52.05% ($n = 38$)	47.95% ($n = 35$)
B2	109	39.44% ($n = 43$)	60.55% ($n = 66$)
B3	72	63.88% ($n = 46$)	36.11% ($n = 26$)
B4	83	48.19% ($n = 40$)	51.81% ($n = 43$)
B5	91	45.05% ($n = 41$)	54.95% ($n = 50$)
B6	50	54.00% ($n = 27$)	46.00% ($n = 23$)
B7	141	59.57% ($n = 84$)	40.42% ($n = 57$)
B1–B7	619	51.50% ($n = 319$)	48.50% ($n = 300$)
F1	71	92.96% ($n = 66$)	7.04% ($n = 5$)
F2	101	95.05% ($n = 96$)	4.95% ($n = 5$)
F3	57	100.00% ($n = 57$)	0.00% ($n = 0$)
F4	94	98.94% ($n = 93$)	1.06% ($n = 1$)
F5	121	97.52% ($n = 118$)	2.48% ($n = 3$)
F6	75	97.37% ($n = 73$)	2.63% ($n = 2$)
F7	151	94.03% ($n = 142$)	5.96% ($n = 9$)
F1–F7	670	96.30% ($n = 645$)	3.70% ($n = 25$)

Table 3
Mean length-to-width (L:W) ratios of all sets of blanks struck from blade cores B1–B7 and from discoidal cores F1–F7

Core	All blanks			Blades only		
	n	Mean	SD	*n*	Mean	SD
B1	73	2.42	1.87	35	3.89	1.72
B2	109	2.76	1.63	66	3.77	1.31
B3	72	1.79	1.42	26	3.61	1.16
B4	83	2.54	1.73	43	3.78	1.54
B5	91	2.51	1.64	50	3.61	1.45
B6	50	2.50	1.71	23	4.03	1.35
B7	141	2.26	1.69	57	3.93	1.47
B1–B7	619	2.43	1.68	300	3.79	1.43
F1	71	1.23	0.76			
F2	101	1.22	0.42			
F3	57	1.05	0.28			
F4	94	1.16	0.37			
F5	121	1.14	0.45			
F6	75	1.17	0.41			
F7	151	1.27	0.65			
F1–F7	670	1.19	0.51			

Table 4
Total cutting edge (CE) length and mass of all blade blanks from blade cores B1–B7, and all flake blanks from discoidal cores F1–F7

Core	CE length (mm)	CE mass (g)	CE (mm/g)
B1	4586.80	254.20	18.04
B2	9012.78	727.10	12.40
B3	2883.70	448.90	6.42
B4	5218.85	380.20	13.73
B5	6428.95	636.90	10.09
B6	2510.64	304.30	8.25
B7	8944.99	853.30	10.48
All blades	39,586.71	3604.90	10.98
F1	5379.45	763.80	7.04
F2	8134.41	1123.40	7.24
F3	3711.49	463.80	8.00
F4	8598.98	1143.60	7.52
F5	11,092.27	1546.90	7.17
F6	5141.87	632.60	8.13
F7	13,804.00	2239.90	6.16
All flakes	55,862.47	7914.00	7.06

But our blade reductions consumed a kilogram more flint. We clearly need to take into account the mass of the original block. When this is done (Table 5, column 4), it emerges that for every 100 g of flint consumed, our discoidal cores produced on average 1.22 more blanks than the blade cores. When the same test as before is applied to the number of blanks per gram of original blade-core block versus original discoidal-core block, the two are statistically different, in favor of the discoidal cores ($t = -3.8806$, $p = 0.0039$). Of course, far fewer blades could be produced per 100 g flint (Table 5, column 5), but it is meaningless to compare the blades in isolation from their companion flake blanks with discoidal flakes. This would unreasonably assume that early Upper Paleolithic knappers made no use of their core preparation/maintenance flakes, and treated them as waste.

Does blade-making consume more toolstone?

The simplest measure of this proposition is the total mass of flaked products as a percentage of the total mass of the original core block (Table 6, column 6). The same two-sample *t*-test used above shows that there is a slight statistical difference between the percentages of core mass exploited from the seven blade cores versus the seven discoidal cores, in favor of the discoidal cores ($t = -2.1609$, $p = 0.0516$). For the same reason as before, there are no grounds for comparing the percentages of blades in isolation with the discoidal flakes.

Table 5
Yields of blanks per 100 g of original core block from blade cores B1–B7, and from discoidal cores F1–F7

Core	Blanks (*n*)	Original block mass (g)	Blanks/100 g	Blades/100 g
B1	73	934.40	7.81	3.75
B2	109	1469.20	7.49	4.49
B3	72	1208.40	5.95	2.15
B4	83	1499.80	5.53	2.87
B5	91	2375.10	3.83	2.11
B6	50	803.10	6.22	2.86
B7	141	2411.10	5.85	2.36
B1–B7	619	10,701.10	5.78	2.80
F1	71	980.40	7.24	
F2	101	1361.90	7.42	
F3	57	697.10	8.17	
F4	94	1311.10	7.17	
F5	121	1731.50	6.99	
F6	75	833.50	9.00	
F7	151	2592.60	5.82	
F1–F7	670	9512.10	7.04	

Table 6
Core, waste, and usable blanks as percentages of the original core mass for the blade cores B1–B7 and the discoidal cores F1–F7

Core	Original core block (g)	Exhausted core %	Waste chips %	Combined waste %	Total blanks %
B1	934.40	12.76	11.86	24.61	75.39
B2	1469.20	11.88	15.13	27.01	72.99
B3	1208.40	16.68	14.56	31.24	68.76
B4	1499.80	22.20	11.43	33.63	66.37
B5	2375.10	8.44	10.47	18.91	81.09
B6	803.10	16.68	23.33	40.02	59.98
B7	2411.10	7.04	11.14	18.18	81.82
B1–B7	10,701.10	12.45	12.94	25.40	74.6
F1	980.40	5.84	14.02	19.86	80.14
F2	1361.90	7.72	8.32	16.04	83.96
F3	697.10	8.11	25.36	33.48	66.52
F4	1311.10	7.39	5.22	12.61	87.39
F5	1731.50	4.99	5.46	10.45	89.55
F6	833.50	9.31	14.45	23.77	76.23
F7	2592.60	4.72	7.85	12.57	87.43
F1–F7	9512.10	6.33	9.62	15.95	84.05

Of far greater interest here is the proportion of the exhausted core mass to its original block mass (Table 6, column 3). Again, our discoidal cores consumed statistically more core mass than the blade cores ($t = 3.2494$, $p = 0.0134$). Additionally, discoid reduction appears to waste less total raw material (core plus waste chips; Table 6, column 5) than blade reduction. Here the difference is nearly statistically significant ($t = 2.1598$, $p = 0.0517$). None of these tests lends support to the axiom that blade reduction promotes more effective consumption of toolstone.

Does blade-making (greatly) increase cutting edge per weight of stone?

Our first comparisons were between our blades and flake blanks. We revisit those comparisons, now taking into account the reductions that produced them. The most straightforward measure is to repeat the comparison (total length of combined cutting edges divided by that sample's combined mass), but this time including *all* usable blanks, be they blades or flakes, in each reduction set. Here we adopt the terminology of Sheets and Muto (1972) and call this the "cutting edge to product mass (CE:PM) ratio" (Table 7,

Table 7
Cutting edge to product mass (CE:PM) ratios and cutting edge to core mass (CE:CM) ratios of total blanks from each blade core B1–B7 and each discoidal core F1–F7

Core	CE:PM[a]	CE[a]:CM[b]
B1	10.6371[c]	8.0165
B2	11.4917	8.2309
B3	6.1946	4.2594
B4	8.9076	5.9119
B5	5.1568	4.1752
B6	9.5307	5.7165
B7	8.9748	7.3466
B1–B7	8.2674	6.1506
F1	7.4026	5.9325
F2	7.5145	6.3089
F3	8.0024	5.3242
F4	7.5628	6.6088
F5	7.2565	6.4983
F6	8.2835	6.3147
F7	6.4075	5.6018
F1–F7	7.2358	6.0789

[a] All usable blanks.
[b] Original core block.
[c] Millimeters per gram.

Table 8
Resharpening events per specimen in Experiment 2

Specimen	Number of resharpening events	Reason for discard
Blade 1	3	Exhaustion
Blade 2	1	Exhaustion
Blade 3	1	Breakage
Blade 4	2	Exhaustion
Blade 5	1	Breakage
Blade 6	4	Exhaustion
Blade 7	1	Exhaustion
Blade 8	5	Exhaustion
Blade 9	4	Exhaustion
Blade 10	4	Exhaustion
Blade 11	1	Exhaustion
Blades 1–11	Mean = 2.45	
Flake 1	7	Exhaustion
Flake 2	3	Breakage
Flake 3	6	Breakage
Flake 4	8	Exhaustion
Flake 5	8	Exhaustion
Flake 6	3	Breakage
Flake 7	1	Breakage
Flakes 1–7	Mean = 5.14	

column 2). When CE:PM ratios of the complete reduction sets are compared (blade versus discoid) using a two-sample *t*-test, there is no statistical difference between them ($t = 1.3575$, $p = 0.2178$).

The more revealing approach is to compare total cutting edge to the mass of the original block, because this comes closer to measuring how efficiently the original piece of toolstone was exploited. Following Sheets and Muto (1972), we call this measure the "cutting edge to core mass (CE:CM) ratio," in which the cutting edge produced from a core is summed and divided by the original mass of the unmodified block (Table 7, column 3). When values for the blade-core sets are compared to discoidal-core sets using a two-sample *t*-test, there is no statistical difference ($t = 0.2311$, $p = 0.8239$). Our blade-making did not greatly advance the amount of available cutting edge beyond that produced by our discoidal flake reductions. The proposition is not supported by either variant of the test.

Effects of resharpening on accumulated cutting-edge length

The chert blades used in this small pilot experiment underwent 27 resharpening events before they were discarded when the edge was exhausted or they broke (Table 8, top). As Chazan (1995) predicted, we were able to resharpen the flake edges many more times (36 events), although they were unexpectedly more prone to breaking, thus lowering the average rate of resharpening (Table 8, bottom). The two sets of tools were assembled to have equivalent combined masses at the start (Table 9, column 2), but without concern for total cutting-edge length. The blades started out with 1.53 times more cutting edge than the flakes (Table 9, column 3), and 1.49 times more cutting edge per weight of chert (Table 9, column 4)—comparable to our results from the much larger large-flint samples. By the time all specimens were exhausted and/or discarded, the flakes had accumulated 1.12 times more cutting edge than the blades (Table 9, column 5), and 1.15 more cutting edge per weight of stone (Table 1, column 6). This confirms that the use-life of flakes can be greater than that of blades of equivalent mass, and the accumulated cutting-edge length of flakes will outstrip that of blades (Chazan, 1995).

Table 9
Cutting-edge-to-mass ratios of blades and flakes before retouch and after resharpening to exhaustion

	Combined mass (g)	Total initial cutting edge (mm)	Cutting edge to mass (mm/g) before retouch	Cutting edge after repeated resharpening (mm)	Accumulated cutting edge to mass (mm/g)
Blades ($n = 11$)	188.10	2003.40	10.65	6231.1	33.13
Flakes ($n = 7$)	183.20	1310.90	7.16	6999.5	38.21

Discussion

If other skilled knappers duplicate the results presented here, we may reasonably ask why blade production proliferated at all at the beginning of the European Upper Paleolithic. Bar-Yosef and Kuhn (1999) have already noted that the supposed "economy" of prismatic blade production needs to be demonstrated and should not be presupposed. In light of our experiments, the future of the "economic blade" as an explanatory device for the proliferation of blade technologies by direct percussion is now in doubt and is probably doomed, along with any models underpinned by the blades-are-better assumption (blades are better for when mobility increases, blades are better where quality toolstone becomes scarce, and so forth).

If lithic analysts see the blade's lengthened edge as an advantage, perhaps early Upper Paleolithic knappers saw it this way too, and were mistakenly encouraged to persist. Of course we shall never know for certain, but we must question whether a knapper, fully aware of the risks and costs of blade-core reduction, would be taken in by appearances alone. So why did they make blades? Given that Neandertals and early modern humans procured and processed similar faunal resources (Adler et al., 2006), it remains to be shown that blades are in any way better butchery tools than flakes. It may be time to seriously reconsider the notion that blades make a fashion statement and that their only purpose was symbolic. For early modern humans colonizing Europe, a shared and flashy-looking technology could conceivably serve as one form of cognitive glue by which larger social networks were bonded (Adler et al., 2006; Gamble, 2007). It is interesting to note that the proliferation of a single lithic technotypological trait occurs in two other colonization/migration episodes: late Pleistocene North America (bifacial fluting; Meltzer, 2002) and the Australian interior (backed pieces; Hiscock and O'Connor, 2005).

Some may be tempted to see parallels here with the axioms of signaling theory (e.g., Zahavi, 1977; Zahavi and Zahavi, 1997; Bliege Bird and Smith, 2005), wherein the blade-making "innovation" (sensu Roux and Bril, 2005) becomes an advertisement for the fitness of the knapper as potential mate, one willing to make more effort, take risks, one to be trusted—as the flintknapper John Shea (pers. comm.) pithily notes, it is difficult to fake prismatic blade production, and costly to attempt it if one is not already competent. Both hypotheses require innovative tests—experimental and archaeological—for their eventual acceptance or otherwise.

One unexpected outcome of our experiments was a clear negative correlation between the cutting-edge-to-mass (CE:M) ratio of total blanks and mass of all blanks ($r = -0.437$). Even more interesting was an equally clear negative correlation between the CE:M ratio of total blanks and blank surface area ($r = -0.5518$). What this means is that cutting-edge yields increase as the overall size of the blank becomes smaller. Just as intriguing is that the L:W ratio (reflecting "bladeyness") of total blanks in no way correlates with the CE:M ratio ($r = 0.2343$). Smaller (not narrower) products yielded by far the greatest lengths of cutting edge. This also holds true for flakes, a point perhaps not lost on Neandertals. Dibble and McPherron (2006) showed that small Middle Paleolithic flake production in Pech de l'Azé IV cannot be tied to toolstone shortages or declines in supply. While Neandertal hand anatomy, hafting, or even children's knapping (Shea, 2006a,b) may be invoked, the gains in cutting edge provide the more parsimonious explanation for the anomalous small flakes originally assigned by Bordes (1975) to the "Asinipodian."

From the blade-maker's viewpoint, it pays to reduce both mass *and surface area* of target blade blanks. To maximize cutting-edge production, the blank should be as small as possible. This could mean that the surge in adaptive efficiency mistakenly credited to blade-making should really be sought in microblade (bladelet) production. Hafting of composite tools now looks like a more promising candidate as the major explanation for Upper Paleolithic blade proliferation. These require interchangeable lithic inserts, for which bladelets are ideally suited (e.g., Bar-Yosef and Kuhn, 1999). If the onset of the Upper Paleolithic in Europe was marked by the introduction of hafting technologies, the need for bladelets might quickly follow. The Aurignacian lithic system may have emerged around the production of Dufour bladelets for this very purpose. If so, then we are left to explain how the macroblade component of the Aurignacian tool kit came about.

Conclusions

Our replicated samples verify the commonly held but inadequately tested assertion that blades yield more cutting edge than flakes, but estimates in print of the amount of extra edge are unrealistically generous. Our blades average only 1.57 times more cutting edge per weight of stone than our flakes. This is based on several exact replications of Upper Paleolithic prismatic blade reduction, and of Middle Paleolithic discoidal (radial) reductions. Controls were tight throughout (same flint, same knapper, same hammerstones/billets), and very large samples of blanks were generated. We used computer-based measurements of cutting edge and appropriate statistical tests of several measures.

However, we draw no comfort from this result because it, like all the claims it sets out to test, is illusory. Yes, blades yield longer cutting edges, but blade-making does not. The illusion of enhanced efficiency/economy of blades is created when the objects being measured are forcibly separated from the reduction sequences that created them. Our analysis of complete sets of blanks from blade reductions did not produce more blanks per gram of stone than our discoidal flake reductions. Our blade reductions were the more wasteful of the two, and did not consume the parent block more efficiently. Furthermore it did not produce more cutting edge per gram of parent stone. In sum, our blade *production* was not statistically more efficient than our discoidal reduction—quite the reverse.

With things already looking bad for blades, our pilot retouching experiment lends support to the assertion that discoidal flakes have longer use-lives than blades because they can be resharpened more times. Consequently, the flakes produced more accumulated cutting edge than the blades. We propose this to be the last straw for purported gains in blade-endowed efficiency at the Middle–Upper Paleolithic transition.

The central challenge in blade-making is to consistently produce complete reductions with high blade output and relatively few preparation and maintenance flakes. When things go well, blades may soar to two-thirds of the output. When there are flaws in the block, or mistakes are made, they plummet to around one-third of product. Such events are corrected more swiftly and with less waste during radial reduction of a discoid core—hence the steadier output. The skill and experience of the knapper lies at the heart of the matter, and the first challenge to our data should come from a more accomplished blade-maker who can perform more consistently, repeatedly pushing the cutting-edge numbers of whole blade reductions (not just the blades) across the threshold to where they outperform discoidal flakes. It remains to be seen if anyone can accomplish this task.

Replication experiments raise questions and do not provide answers. But they help here to correct the skewed perspective that arises when lithic artifacts are evaluated without due concern for the reduction sequence that produced them.

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