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Refuting the technological cornerstone of the Ice-Age Atlantic crossing hypothesis

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A B S T R A C T

The "North Atlantic Ice-Edge Corridor" hypothesis proposes that sometime during the Last Glacial Maximum, roughly 26,500–19,000 years ago, human populations from southern France and the Iberian Peninsula made their way across the North Atlantic and colonized North America. A key element of that hypothesis is the apparent similarity between stone-tool-production techniques of Solutrean peoples of Western Europe and Clovis and purportedly pre-Clovis peoples of eastern North America, most especially the supposed intentional use of "controlled overshot flaking," a technique for thinning a bifacial stone tool during manufacture. Overshot flakes, struck from prepared edges of the tool, travel across the face and remove part of the opposite margin. Experimental and archaeological data demonstrate, however, that the most parsimonious explanation for the production of overshot flakes is that they are accidental products created incidentally and inconsistently as knappers attempt to thin bifaces. Thus, instead of representing historical divergence, overshot flakes in Clovis and Solutrean assemblages mark convergence in the use of the same simple solution for thinning bifaces that produced analogous detritus.

1. Introduction

The "North Atlantic Ice-Edge Corridor" hypothesis (Stanford and Bradley, 2002; Bradley and Stanford, 2004, 2006; Stanford and Bradley, 2012) is the latest version of a repeatedly rejected claim that glacial-age peoples from Western Europe colonized North America via the Atlantic Ocean (for earlier efforts, see Abbott, 1877; Hibben, 1941; Greenman, 1963). The current version of the hypothesis holds that sometime during the Last Glacial Maximum, roughly 26,500–19,000 years ago (Clark et al., 2009), populations from southern France and the Iberian Peninsula made their way by small watercraft across the North Atlantic, a journey assumed to have been facilitated by a continuous, biologically fecund ice shelf that gave colonists a place to pull ashore for fresh water and food, such as harp seals, during their 6000-km traverse.

This hypothesis has entailments for both archaeological and nonarchaeological evidence, and it is fair to state that while it has attracted adherents, one of whom proclaimed that the purported Solutrean–Clovis connection is one of the most important discoveries in the history of North American archaeology (Runnels, 2012), it has also received considerable criticism on multiple grounds. For example, despite a very few archaeological similarities between European Paleolithic and North American Paleoindian assemblages, there are a far larger number of differences between these early archaeological records, thus suggesting that similarities (technological or otherwise) should be assumed *a priori* to be the result of convergence and not shared ancestry (Straus, 2000; Straus et al., 2005; Meltzer, 2009). Indeed, convergence of cultural entities is entirely to be expected (Mesoudi et al., 2004; McGhee, 2011; Mesoudi, 2011; Lycett, 2011), and specific examples of this have been empirically demonstrated in the case of stone tools (Lycett, 2009). Likewise, there is no genetic evidence (either from modern or ancient DNA) of any distinctive European markers in American populations, which is the case for other nonarchaeological evidence as well (skeletal, dental, and linguistic) (Goebel et al., 2008; O'Rourke and Raff, 2010; Dulik et al., 2012;

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Eriksson et al., 2012; Kashani et al., 2012). Oceanographic evidence suggests the ice shelf may not have existed, or if it did the Pleistocene North Atlantic was not an "icy wonderland" (Stanford and Bradley, 2012: 11) and could not have served as a suitable migration route (Westley and Dix, 2008). Similarly, there is virtually no evidence for marine-mammal hunting in either Solutrean or pre-Clovis or Clovis-age sites (Cannon and Meltzer, 2004; Straus et al., 2005), yet this was the presumptive subsistence strategy for the Pleistocene crossing of the North Atlantic.

Some of these criticisms were leveled prior to the publication of the most recent iteration of the hypothesis (Stanford and Bradley, 2012). In our view they still apply (see also Balter, 2012), and we remain highly skeptical of the validity of the hypothesis. However, a full assessment of it is beyond the scope of this paper, so we leave it to readers to judge for themselves whether these criticisms were successfully met in the latest work. Our goal here is to focus on what the advocates of a Solutrean crossing identify as providing the strongest support for their hypothesis: the presumptively intentional use of "controlled overshot flaking" by Solutrean and Clovis knappers in producing bifacial stone tools. In advance of our discussion, it is important to note that when initially proposed (Stanford and Bradley, 2002) the hypothesis was based on purported similarities between stone-tool-production techniques of Solutrean peoples from France, Spain, and Portugal and those of the North American Clovis culture. It was immediately observed, however, that there was a significant temporal gap between the European Solutrean (ca. 23,500–18,000 cal BP (Straus, 2000, 2005)) and North American Clovis (ca. 13,300–12,800 cal BP (Waters and Stafford, 2007)) technocomplexes. In response to those criticisms, a revised form of the hypothesis was introduced that claimed similarities existed between Solutrean and *pre*-Clovis technology, thus presumably closing the almost 5000-year chronological gap between Western Europe and North America (Stanford and Bradley, 2012: 183). Under this revised scenario, Solutrean peoples could have introduced production techniques to *pre*-Clovis populations they encountered once they migrated south along the East Coast of North America, or, alternatively, Solutrean peoples were the ones responsible for a pre-Clovis archaeological record on the East Coast.

Nonetheless, it is still the case that the advocates of the hypothesis continue to focus their attention on the technological similarity of overshot flaking between Solutrean and Clovis, not Solutrean and pre-Clovis (e.g. "The similarities between Solutrean laurel leaf and Clovis point manufacture are remarkable" (Stanford and Bradley, 2012: 156)). Accordingly, we do so as well, though we will also address whether this presumptive similarity occurs in reported pre-Clovis assemblages.

2. Overshot flaking as a biface-thinning technique

Overshot flakes are ones that during the manufacture of a biface are struck from prepared edges of a piece and travel from one edge across the face and remove only "a small portion" of the opposite margin (Fig. 1) (Stanford and Bradley, 2012: 49–50; see also Bradley et al., 2010). Few modern flintknappers have mastered controlled overshot flaking, and even after many years of knapping, one of the co-authors (Bradley) of the North Atlantic Ice-Edge Corridor hypothesis still finds it to be "one of the most challenging techniques" (Stanford and Bradley, 2012: 49). Indeed, many modern knappers consider overshot flakes to be accidental (e.g., Bordes, as cited in Stanford and Bradley, 2012; Callahan, 1979; Whittaker, 1994).

Yet, despite the difficulty of overshot flaking, Stanford and Bradley (2012: 28) are "completely convinced" that the technique was *intentionally* used by Solutrean and Clovis peoples because of its presumed advantages, most prominently that overshot flaking is an "incredibly efficient" or "highly effective" strategy for rapidly thinning stone bifaces (Bradley and Stanford, 2004: 461; 2006: 708–710; Stanford and Bradley, 2012: 28). They then argue that because the intentional use of a complex and difficult strategy is unlikely to occur by chance, its presence in two separate groups "suggests that it is unlikely to have been independently invented" (Stanford and Bradley, 2012: 28). Thus, the occurrence of supposedly intentional overshot flaking on both

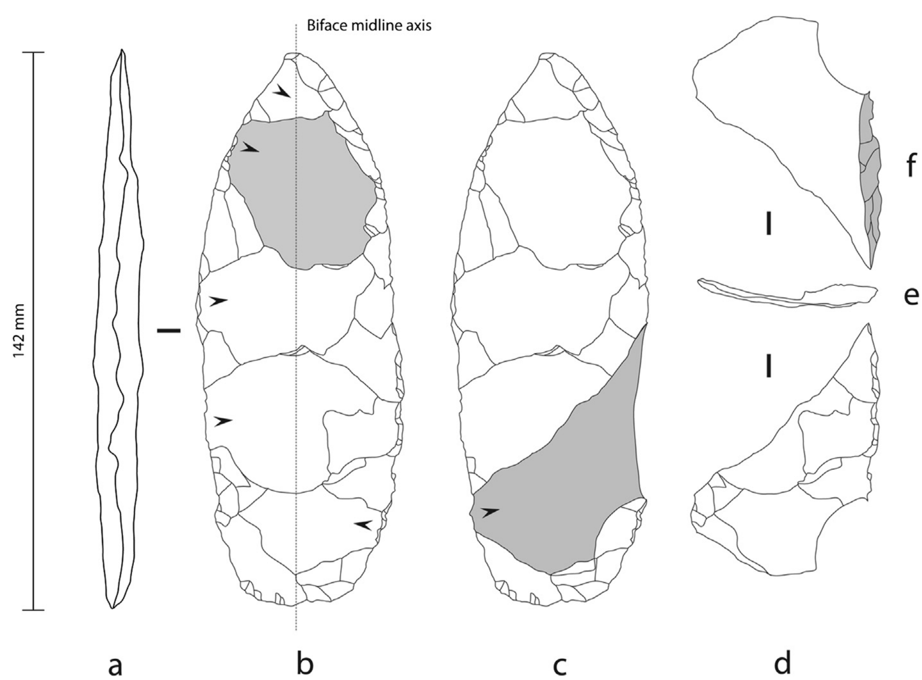

Fig. 1. Illustrated example of experimental biface #27 knapped by MIE: (a) side view of biface; (b) face view of biface before overshot flake removal, with overface biface-thinning flake scars marked with an arrow indicating direction of flake removal and ultrashot thinning scar shaded in gray; (c) face view of biface after overshot flake removal, with overshot flake scar shaded in gray; (d) removed overshot flake dorsal face; (e) side view of overshot flake; (f) overshot flake ventral face, with removed opposite margin shaded in gray.

sides of the Atlantic in Late Pleistocene times is said to "demonstrate historical connections between [the] technologies" (Stanford and Bradley, 2012: 138).

Much of this argument is speculative and untestable: We cannot determine how challenging or difficult overshot flaking would have been to Pleistocene hunter–gatherers, who, unlike modern knappers, spent their lives making and using stone tools. However, Stanford and Bradley's claims of intentionality (and all arguments thereafter) rest on the premise that overshot flaking is an efficient means of thinning a biface, and *that* premise is amenable to testing through both experimental and archaeological data,[1] using parameters established by Stanford and Bradley. If the premise is false, then the layers of assumptions built on it that are central to linking Solutrean and Clovis technologies are left unsupported.

Bifacial thinning is a proportional reduction process, which means that the knapper reduces the thickness of a biface at a faster rate than its width is trimmed, in order to "massively thin and flatten" a specimen (Stanford and Bradley, 2012: 49). As Stanford and Bradley define it, the optimal strategy for accomplishing that would be for the knapper to minimize the loss of biface width, which is accomplished when the flake termination removes only "a portion of the opposite edge" (Stanford and Bradley, 2012: 26). Put another way, thinning increases the Width:Thickness (W:T) ratio of a biface. Minimizing removal of the opposite edge in overshot flaking is therefore critical, given that biface width is already being lost to platform preparation. Bradley and Stanford (2004: 465) acknowledge the challenge and costs of overshot flaking but then suggest there were payoffs to that strategy: "As knappers, we see [overshot flaking] as counter-intuitive: is not the removal of parts of both edges a disadvantage when trying to thin a biface proportionally? One would assume this to be the case, but, when carefully and intentionally executed, this method is incredibly efficient not only in biface thinning but in making bifaces with flat longitudinal cross-sections." In effect, there should be a difference in the W:T ratio of bifaces before and after thinning, but more importantly that difference in ratio before and after thinning should be greater—in Stanford and Bradley's (2012) terms, more "efficient"—in bifaces thinned with overshot flaking than in bifaces thinned without overshot flaking.

Unfortunately, there are few archaeological data on thinning flakes (overshot and nonovershot) and the bifaces from which they were struck. In fact, overshot flakes prove to be quite rare in Clovis assemblages (see Section 5.1, Archaeological Evidence, below). Thus, in order to explore the changes in W:T ratios of bifaces thinned using overshot versus nonovershot flaking, two of the authors (MIE, RJP), both skilled knappers working independently, set out to produce as many overshot flakes as possible while making bifaces that match the size and shape parameters of Clovis and/or Solutrean forms. We are aware, of course, that the context in which our overshot flakes were produced is different from that of Late Pleistocene knappers, but when compared to the archaeological data (below), the frequency and efficiency of overshot flakes produced experimentally exceeded that observed in available data from Clovis assemblages (there are no comparable data for Solutrean assemblages of which we are aware).

[1] Any assertion of behavioral intentionality in prehistory is always an inference from patterns in the archaeological record. The inference of intentionality does, however, have testable implications, and the data must be consistent with these predictions if this inference is to remain a reasonable one. For example, the inference can be strengthened if it can be demonstrated empirically that the material result is a frequent and regular occurrence not attributable to chance on the population level, and if the pattern cannot be explained by other factors as, for example, limitations on the stone available for use that might predetermine patterns in stone tool size or shape. One expects, as well, that the material result would have been beneficial to prehistoric people (Eren and Lycett, 2012).

3. Experimental methods and materials

3.1. Methods

During our biface production, and interspersed with overshot removals, overface flakes—those that terminate beyond the biface midline but prior to reaching the far edge (Smallwood, 2010, 2012; Jennings, 2012, 2013)—were produced either (1) intentionally, because it was predicted that pursuit of an overshot flake at specific points would result in a fatal knapping error, or (2) incidentally, as when an intended overshot attempt did not reach the opposite biface margin. Preparatory flakes—those whose mass along the axis of percussion did not cross the biface medial axis—and chips were saved but otherwise ignored. Immediately after each flake was removed, it was refitted onto its parent biface so that data could be recorded to measure the flake's contribution to thinning along the biface's medial axis. We used the following protocols:

1. Thinning was measured along the biface midline axis. Thus, data from flakes were recorded only when a flake's mass along its axis of percussion crossed the biface midline axis.
2. Once a knapper removed a flake from its parent biface, it was refitted onto that biface.
3. Six items were then recorded:
   a. Whether the flake was an overshot or non-overshot;
   b. (M1) Distance between flake's platform and distal-most point along its axis of percussion (vernier calipers);
   c. (M2) Distance across biface along M1 before flake's removal (vernier calipers);
   d. (M3) Distance across biface along M1 after flake's removal (vernier calipers);
   e (M4) Biface thickness at intersection point of biface medial axis and M2 before flake removal (outside calipers);
   f (M5) Flake thickness at intersection point of biface medial axis and M2 (outside calipers);
4. To measure each flake's contribution to thinning, M2 was divided by M4 to calculate the biface W:T ratio before flake removal (M6), and M3 was divided by [M4 minus M5] to calculate the biface W:T ratio after flake removal (M7). M6 was then subtracted from M7 to calculate an individual flake's contribution to biface thinning at the biface midline axis (M8).
5. Finally, flake length along the flake's axis of percussion as a percentage of biface width (M9) was calculated by dividing M1 by M2.

All data are provided in the Supplementary Materials (Dataset S1).

3.2. Materials

To avoid the vagaries of original stone-nodule shape and its possible distortions on biface thinning, each knapper started recording data on flakes from pre-knapped "early stage" bifaces, defined as having a W:T ratio of at least 3:1, with no major areas of high mass or other knapping obstacles on the bifaces such as natural cleavages. Basic morphometric data on each early stage biface are found in Table 1. Bifaces produced by MIE were knapped from high-quality chalk flint procured from England's Kent coast. Bifaces produced by RJP were knapped from high-quality cherts procured from gravel beds along the Pedernales River west of Austin, Texas. The knappers used antler billets and/or hammerstones during percussion knapping (see Table 2).

Table 1
Early stage, and finished, experimental biface morphometric data.

Knapper	Biface #	Early stage					Finished				
		Mass (g)	Length (mm)	Width (mm)	Thickness (mm)	W:T	Mass (g)	Length (mm)	Width (mm)	Thickness (mm)	W:T
MIE	1	296.64	173.00	86.00	21.00	4.10	72.46	148.00	37.00	7.96	4.65
MIE	2	268.77	159.00	72.00	16.00	4.50	76.27	151.50	39.94	8.07	4.95
MIE	3	264.16	155.00	76.00	20.00	3.80	81.46	153.48	43.32	8.66	5.00
MIE	4	198.61	128.00	71.00	14.00	5.07	56.42	123.50	40.40	7.89	5.12
MIE	5	187.84	145.00	62.00	19.00	3.26	49.08	128.80	35.49	7.24	4.90
MIE	6	205.78	158.00	62.00	17.00	3.65	67.85	151.45	38.01	8.00	4.75
MIE	7	181.74	155.00	65.00	16.00	4.06	66.87	136.89	38.74	7.75	5.00
MIE	8	145.47	120.00	62.00	16.00	3.88	44.66	117.05	33.78	8.48	3.98
MIE	9	220.30	140.00	70.00	19.00	3.68	61.14	132.20	36.73	9.36	3.92
MIE	10	294.66	181.00	73.00	18.00	4.06	55.46	108.00	42.01	9.06	4.64
MIE	11	210.77	180.00	61.00	16.00	3.81	62.06	118.69	37.42	10.67	3.51
MIE	12	108.45	124.00	53.00	13.00	4.08	49.87	124.70	36.24	9.34	3.88
MIE	13	299.44	116.00	76.00	25.00	3.04	52.87	120.04	37.23	6.93	5.37
MIE	14	156.40	110.00	65.00	19.00	3.42	58.36	108.06	43.06	8.48	5.08
MIE	15	163.19	112.00	62.00	20.00	3.10	38.99	106.07	33.50	8.18	4.10
MIE	16	161.20	116.00	66.00	18.00	3.67	38.19	100.60	35.90	7.98	4.50
MIE	17	230.05	125.00	71.00	22.00	3.23	52.47	116.09	38.55	8.00	4.82
MIE	18	240.85	153.00	64.00	19.00	3.37	102.77	145.88	47.74	9.90	4.82
MIE	19	387.00	183.00	79.00	25.00	3.16	46.15	122.11	34.47	9.30	3.71
MIE	20	252.14	145.00	70.00	23.00	3.04	80.92	132.92	42.81	9.65	4.44
MIE	21	345.78	165.00	75.00	21.00	3.57	129.34	155.00	55.64	11.17	4.98
MIE	22	134.16	123.00	57.00	15.00	3.80	60.64	116.86	43.12	8.79	4.91
MIE	23	146.99	132.00	58.00	17.00	3.41	70.66	119.69	43.86	9.12	4.81
MIE	24	181.21	144.00	63.00	19.00	3.32	64.01	125.41	41.53	9.03	4.60
MIE	25	201.68	142.00	68.00	17.00	4.00	113.47	141.31	53.41	12.06	4.43
MIE	26	284.37	178.00	71.00	19.00	3.74	91.40	151.82	44.05	8.37	5.26
MIE	27	302.73	151.00	80.00	20.00	4.00	98.58	142.39	50.90	11.17	4.56
MIE	28	178.57	140.00	62.00	20.00	3.10	54.85	115.83	40.72	10.11	4.03
MIE	29	168.30	134.00	63.00	15.00	4.20	44.11	100.37	38.25	9.21	4.15
MIE	30	240.49	160.00	68.00	18.00	3.78	61.55	134.23	39.58	8.59	4.61
MIE	31	193.59	134.00	68.00	19.00	3.58	105.03	129.48	49.99	11.34	4.41
MIE	32	193.61	132.00	68.00	20.00	3.40	50.53	117.00	36.39	9.40	3.87
RJP	A	331.00	130.50	93.30	22.50	4.15	118.50	120.40	72.30	15.60	4.63
RJP	B	615.00	165.00	100.30	34.80	2.88	177.00	162.00	63.60	13.10	4.85
RJP	C	742.00	185.00	104.10	34.00	3.06	313.00	106.60	85.20	20.10	4.24
RJP	D	590.50	176.00	95.60	31.50	3.03	152.00	159.00	67.80	13.40	5.06
RJP	E	559.50	173.00	101.80	27.10	3.76	147.50	158.00	66.70	14.40	4.63
RJP	F	787.00	182.00	107.40	30.00	3.58	322.00	178.00	79.30	17.40	4.56
RJP	G	1045.50	213.00	106.80	33.50	3.19	575.00	205.00	84.30	24.30	3.47

Stanford and Bradley (2012: 157) note that Clovis and Solutrean "preparation of flake platforms was the same. Both used isolated, projected, released ground platforms that were designed to be straight rather than convex. Both even had platform grinding that extended from the area of contact on the flake platform to the adjacent flake removal surface. In North America, flakes with these platform attributes are diagnostic of Clovis, and this is true for Solutrean in Europe as well." Both knappers used these techniques for almost every flake removed from the experimental bifaces.

Table 2
Types and measurements of knapping tools.

Knapper	Tool type	Weight (g)	Length (mm)	Width (mm)	Thickness (mm)
MIE	Moose antler billet	600	168	49	47
MIE	Moose antler billet	344	160	44	39
MIE	Red deer antler billet	206	188	27	26
MIE	Sandstone hammerstone/abrader	192	57	55	47
MIE	Small sandstone abrader	58	57	44	18
MIE	Shale platform preparation stone	65	68	46	12
RJP	Moose antler billet	624	188	52	47
RJP	Axis deer billet	368	234	36	31
RJP	Silicified sandstone hammerstone/abrader	59	47	39	29
RJP	Granite pebble hammer	49	66	31	17

Aubrey et al. (2008: 55, Fig. 2) suggest that the mean W:T ratio for finished Solutrean laurel leaves is 5.2, although we must exercise caution because this ratio is presumably calculated from only one site, Maîtreaux (France), and the data from which it was calculated are unreported. Data from Bradley et al. (2010: 92–93, Table 3.6) indicate the mean W:T ratio for finished Clovis bifaces is 4.05. We find it telling that these ratios are not the same. However, the mean W:T ratio of our finished experimental bifaces (4.54, Table 1) falls almost perfectly in between the Solutrean and Clovis samples, suggesting that our experimental specimens are representative of both.

4. Results

From 39 bifaces, the two knappers produced 666 thinning flakes that crossed the medial axes of their parent bifaces. Of these, 116 (17.4%) were overshot flakes and 550 (82.6%) were overface flakes. Fig. 2a shows the contribution of each flake to biface thinning, measured here as the difference in biface W:T ratio before and after flake removal. As can be seen, the population of overshot flakes does not possess a higher average contribution to biface thinning ($\mu = 0.7537$) than the population of overface flakes ($\mu = 0.7715$), and the difference is not statistically significant ($t = -0.3111$, df $= 192.75$, $p = 0.7559$).

There are three outliers in Fig. 2a, two of which are overshots and one is an overface. The highest-value overshot outlier (#1,

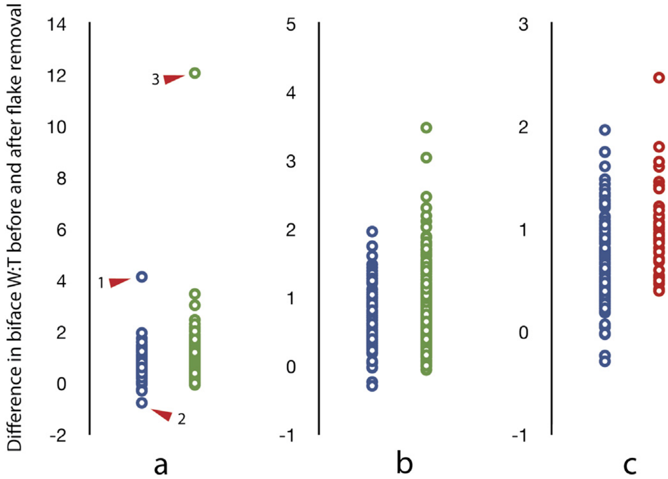

Fig. 2. Experimental data depicting the difference in Width:Thickness (W:T) ratio before and after overshot (blue circles), overface (green circles), and ultrashot (red circles) flake removal. Populations of overshots and overfaces were statistically identical in biface thinning efficiency with outliers included (a) or excluded (b). See text for discussion of outliers. Overshots were statistically less efficient than ultrashots in biface-thinning efficiency (c). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

Fig. 2a) possessed an odd shape and removed a large section of the opposite margin but not along the flake's axis of percussion. Because of the way in which W:T ratio is measured, this highly unusual overshot flake reflects only a thinning "benefit": a substantial amount of biface thickness was removed, but there was no indication of any corresponding loss of biface width. The lowest-value overshot outlier (#2, Fig. 2a) was a knapping error—a flake that dove early and took off so much of the opposite margin that it substantially thickened rather than thinned the biface. The overface outlier (#3, Fig. 2a) was a chunk accidentally removed from a biface via a striking platform that was too strong. When these outliers are removed from Fig. 2a, the average overshot flake-thinning contribution drops to $\mu = 0.7371$, the average overface flake-thinning contribution drops to $\mu = 0.7508$, but the populations remain statistically identical ($t = -0.3196$, df $= 172.51$, $p = 0.7495$, Fig. 2b).

The overface-flake population used in the above comparisons included flakes that traveled just past the biface medial axis. These flakes contributed little to biface thinning, given that they feathered out at the point where thinning was recorded, i.e., the medial axis of the biface. As noted, because biface thinning is a proportional process, the optimal strategy for thinning, according to Stanford and Bradley (2012), would be for the knapper to maximize thickness reduction while minimizing the loss of width. Yet, in light of the additional width that is lost with overshot flaking, a better strategy would be to avoid overshot flaking altogether.

Given that the thickest part of a flake is generally at its midsection, to maximize biface thinning the knapper should align the flake midsection with the biface medial axis. Although this can be achieved with overshot flaking, less width is lost with the removal of overface flakes that come as close as possible to the opposite margin but do not overshoot it, say, ones that travel between 95.0% and 99.9% of biface width. We refer to the latter as "ultrashots," a number of which were produced experimentally ($n = 41$, $\mu = 0.9606$). Comparison of the relative biface-thinning contribution of overshots versus ultrashots reveals that overshot flakes were significantly less efficient (again, as measured by changes in W:T ratios) than ultrashot flakes in thinning bifaces ($t = -2.9064$, df $= 68.80$, $p = 0.0049$, Fig. 2c).

Note that these results do not change if each knapper's data are examined on their own (Dataset S1). We also note that in one of the very few cases where there are reported archaeological data on the amount of biface width removed by overshot flakes, Waters et al. (2011a, 2011b) report that the 10 complete noncortical overshot flakes from the Gault site, Texas, removed anywhere from 3% to 32% of biface width, with a mean of 14%. In comparison, the 116 experimental overshot flakes produced in the present study predominantly removed only 0.0%–26.6% of biface width (with one specimen removing 40.8%), with a mean of 6.8%. Given that the experimental overshots removed on average less than half of biface width compared to what the archaeological overshot specimens removed, and have been shown to be inefficient for biface thinning, it becomes difficult to think that overshots found in the archaeological record were anything other than mistakes. In other words, we gave the overshot-flaking technique the best possible chance to efficiently thin our experimental bifaces, and it still failed. Overshot flakes did not more effectively thin bifaces than the overface flakes, and when compared to the production of ultrashot flakes, overshot flaking was significantly less efficient at thinning bifaces. Thus, the empirical premise upon which Stanford and Bradley base their chain of inference for a Solutrean–Clovis link fails. Given that the premise fails, the inferences built on it—that this complex and difficult strategy must have been intentionally applied and thus is unlikely to have occurred by chance and thus its presence in two groups widely separated in time and space indicates historical relatedness—are left unsupported.

5. Discussion and conclusions

If Solutrean and Clovis knappers intentionally practiced controlled overshot flaking, they were consciously choosing a technique that is not only difficult to learn and difficult to control but one that provides no additional benefit to, and indeed undermines, the goal of optimally thinning a biface (as defined by Stanford and Bradley, 2012: 49). Although it is inappropriate to blindly impose modern knapper intuition onto the archaeological record, if some modern knappers' intuition suggests to them that overshot flaking is an efficient strategy for biface thinning, perhaps Late Pleistocene knappers saw it this way too and were mistakenly encouraged to persist. We will never know, of course, but we find it highly unlikely that Clovis and Solutrean knappers, fully aware of the risks and costs of overshot flaking, would be taken in by appearances alone (Eren et al., 2008). Thus, given that our experimental data clearly show overface flaking to be no less efficient than overshot flaking, and ultrashot flaking to be significantly more efficient, and given that overface and ultrashot flakes are less difficult to produce than overshots, our results clearly suggest Clovis and Solutrean knappers most likely converged upon a simple, effective technique for thinning bifaces that happened to produce the analogous detritus of overshot flakes.

5.1. Archaeological evidence

Stanford and Bradley claim there is "clear archaeological evidence of widespread use" of overshot flaking by Clovis and Solutrean knappers, "especially during the early and middle stages" of biface production (Stanford and Bradley, 2012: 28, 157). Although they provide data to support the claim that the percentages of overshot flaking in Solutrean and Clovis assemblages are comparable and that these decline from early and middle stages to late and finished stages of bifaces (Stanford and Bradley, 2012: Table 6.1), those data are flawed by simple arithmetic errors: row sums were miscalculated, yielding erroneous percentage values. When those errors are corrected, they weaken the percentage differences through the stages (Supplementary Materials, Table S1). To determine if there are, in fact, significant patterns in the occurrence of overshot flaking in these data, we subjected the corrected data to contingency-table analysis. This revealed that the frequency of overshot flaking between Solutrean and Clovis assemblages is, in fact, significantly different and, moreover, does not conform to the claims made in regard to trends in early and middle stages to late and finished stages. Rather, overshot flaking is significantly *under*represented in early stage bifaces in Clovis assemblages but significantly *over*represented in Solutrean assemblages; the reverse is true for middle-stage bifaces. And, overshot flaking is significantly *over*represented in late-stage Solutrean bifaces (Supplementary Materials, Table S1). These results call into question the claim that the "level of correspondence between technologies is amazing" (Stanford and Bradley, 2012: 157).

The results might simply reflect the character of the assemblages used in that particular sample, but because no source information is provided for the data in this sample, further analysis cannot be done. Thus, to give Stanford and Bradley's claim of widespread occurrence of overshot flaking the best possible chance for success, we searched the literature for the presence of overshot flakes at Clovis sites, following their lead by using sites in which overshot flakes ought to be expected to occur: sites on or near raw-material sources, where the earlier stages of biface manufacture occurred (we know of no Solutrean data that speak to the frequency of overshot flaking relative to assemblage size).

There are few sites for which data are available on the frequency of overshot flakes relative to the size of the assemblages from which they derive. However, some reports tally the incidence of overshot flake scars on specimens, which provide a proxy for the use of overshot flaking. In neither case do the data support the claim for the widespread use of overshot flaking in Clovis-age assemblages. We count only 8 lateral overshot scars on 58 bifaces (13.7%) from Adams, a Clovis lithic workshop in Kentucky (Sanders, 1990: specimens 17a, 20a, 21d, 23, 24b, 25c, 26c, 26d), and some of these are reported to be knapping errors leading to rejection. Further, Sanders (1990) states that overshot terminations at the Adams site are associated almost exclusively with early stage fluting mistakes rather than with bifacial thinning. Smallwood (2010) reported that at the Clovis workshop at the Topper site in South Carolina overface flake scars that travel past the biface midline outnumber overshot flake scars by 280 to 46 (a ratio of 6.1:1). More recently, Smallwood (2012: 702, Table 5) documented the frequency of Clovis bifaces possessing overshot flake scars at the sites of Carson-Con-Short (Tennessee), Topper, and Williamson (Virginia). At Carson-Con-Short, only 14 of 122 (11%) bifaces exhibited at least one overshot; at Topper only 27 of 133 (20%); and at Williamson only 9 of 165 (5%). At the Gault site, Texas, Bradley et al. (2010) report 96 (61%) of a sample of 156 bifaces exhibit an overshot scar. This may seem like a high frequency, but we note that their 156 bifaces were neither a complete sample from the site, nor do the authors state that it was a random sample. We also note that counting the number of bifaces that possess an overshot scar is misleading and can exaggerate overshot frequency. The incidence of overshot frequency would be far lower if overshot scars were counted as a percentage of *all* flake scars, as Smallwood (2010) correctly does. Indeed, in another study of the Gault site that counts flakes rather than bifaces, the frequency of overshot flakes ($n = 79$) as a percentage of identifiable, complete bifacial thinning flakes ($n = 440$) suggest the frequency of overshot flaking is far lower (15.2%) (Waters et al., 2011a, 2011b), but given that there were 61,361 pieces of debitage recovered, there is good reason to suspect that there exist many more bifacial thinning flakes—as yet unidentified—that would substantially lower this estimated overshot percentage even further. In the Clovis horizon at the Debra Friedkin site, Texas, 3 of 8 late-stage bifaces exhibit an overshot scar, but there were no overshot flakes in the recovered sample of 612 specimens (Waters et al., 2011a, 2011b). In an exploratory survey of the Arc site assemblage in New York, Eren et al. (2011b) counted only 25 overshot flakes out of 1100 tools and over 10,000 pieces of debitage (Eren, 2011). Some researchers describing raw material at Clovis sites merely state that overshot flakes or flake scars are present (e.g., Emanon Pond, New York (Tankersley, 1995), and Pavo Real, Texas (Collins et al., 2003)) but do not list the frequencies or label them as "breaks," whereas others do not note or illustrate the presence of overshot flakes (e.g., West Athens Hill, New York (Funk, 2004)). Clovis caches are often thought to exhibit high incidents of overshot scars, thus indicating knapper intention, but data from the most recent survey of all Clovis caches (Kilby, 2008) do not support this notion (Supplementary Materials, Table S2).

Although the frequency and regularity of overshot flakes in the archaeological record is poorly documented, and this clearly indicates future studies should better record the relative frequencies of overface and overshot flakes and scars in Clovis, Solutrean, and other contexts, the data presented above do not refute the notion that overshot flakes could have been produced by "chance" as an outcome of any number of factors. Knapper error and skill may have been one such factor, as Eren et al. (2011a) empirically demonstrated for the Levallois reduction sequence, where a novice knapper produced significantly more overshot flakes than did an expert knapper. Also, overshots are greatly facilitated by biface shapes that are already flat to begin with, for example Clovis and Solutrean projectile points. This phenomenon is well known to modern knappers (Callahan, 1979; Van Peer, 1992; Whittaker, 1994; Ellis and Deller, 2000; Patten, 2005, 2009; Waldorf, 2006). Overshot flakes are also more common when a strong, firm grasp is used to support the biface in the nonstriking hand, a technical requirement for increasing the distance flakes travel across biface width (Patten, 2005, 2009). Although untested, it is also reasonable to suspect that overshot flakes occur more frequently on brittle, silicious, high-grade tool stones because platforms might require less energy to release than would be the case on tougher raw materials (Patten, 2005). Finally, we note that flake removals follow arrises present on a biface surface. An arris extending across the width of a biface, incidentally created from previous overface and ultrashot flake removals, would facilitate overshot accidents. If such an overshot accident occurs, an "overshot arris" would be created that a subsequent, adjacent flake will be inclined to follow, increasing the probability of another overshot accident. Thus, when three adjacent overshot removals are present on a biface—which occurs occasionally on Clovis-cache bifaces—it may have little to do with intention and all to do with morphology. Given that Clovis-cache bifaces are made of the finest high-grade tool stones (Stanford and Bradley, 2012: 170), and a strong support grip is required to extend flake reach across a biface, it becomes easy to see how adjacent overshot accidents, in some cases increasingly difficult to avoid, could appear like an intentional pattern.

Thus, not only do our experimental data fail to support the notion that overshot flaking was efficient, and the little archaeological data available fail to show a frequent, regular presence of overshot flakes, there also exist simple mechanisms for explaining the variable occurrence of overshot flakes and flake scars in the archaeological record, such as knapper error or skill, nodule and/or biface morphology, knapper-support preference, raw-material type, or basic flaking mechanics.

Given all of the above, the most parsimonious explanation for the presence of overshot flakes in Clovis and Solutrean archaeological assemblages is that they are accidental products created incidentally and inconsistently as knappers pursued the more-efficient strategy for thinning bifaces, namely, the removal of ultrashots. We can therefore reject the validity of overshot flaking as an intentional knapping strategy for thinning bifaces.

Thus, it follows that the central premise of the North Atlantic Ice-Edge Corridor—that a controlled overshot flaking knapping strategy was historically transmitted from Solutrean to Clovis—is unsupported.

That, of course, begs the question of whether that strategy is evident in *pre*-Clovis assemblages, for as has been noted by advocates of the North Atlantic Ice-Edge Corridor hypothesis, whenever and wherever people move, they take with them their traditions and technologies, and a strategy such as overshot flaking "had to develop out of a previous archaeological culture … a missing link" (Stanford and Bradley, 2012: 89). Accordingly, the incidence of overshot flaking in pre-Clovis assemblages ought to be *more* abundant than in Clovis assemblages.

We do not accept the 14 pre-Clovis sites listed by Stanford and Bradley (2012: 90) as valid, either because they are not securely dated or are not well described. Still, we observe that Stanford and Bradley (2012: 106–107, Fig. 4.10d) report *only one* overshot flake from these 14 assemblages. Bifacial projectile points at proposed pre-Clovis sites such as Meadowcroft, Pennsylvania (Adovasio, 1993), Cactus Hill, Virginia (McAvoy and McAvoy, 1997), and Miles Point, Maryland (Lowery et al., 2010), fail to exhibit overshot flake scars, and in fact rarely are scars present that travel past the biface medial axis. With respect to the purported pre-Clovis deposits at Debra Friedkin, Waters et al. (2011b: S30) state that "most Buttermilk Creek Complex bifaces show no evidence of past-the-midline flaking, suggesting this was not a dominant late stage thinning strategy." The absence of evidence of overshot flaking in pre-Clovis sites identified by Stanford and Bradley (2012) indicates there remains a 5000-year gap in the appearance of this technique on either side of the Atlantic Ocean.

5.2. Conclusions

The low incidence of overshot flaking in Clovis archaeological assemblages, together with the experimental results that point to overshot flaking being a less-efficient means of thinning bifaces, suggests that any similarity between Solutrean and Clovis in terms of overshot flaking frequency (which, as noted, does not occur) can support only the proposition that Clovis and Solutrean knappers converged on a technique for thinning bifaces that happened to produce the analogous detritus of overshot flakes.

As these results refute what Stanford and Bradley (2012) identify as the most significant archaeological trait linking Solutrean and Clovis, and given the lack of support from genetic, linguistic, skeletal, dental, oceanographic, and other archaeological evidence, it is likely this current iteration of a cross-Atlantic colonization in Pleistocene times will ultimately go the way of its failed predecessors.

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Appendix A. Supplementary data

Supplementary data related to this article can be found at http://dx.doi.org/10.1016/j.jas.2013.02.031.

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