Archaeol Anthropol Sci (2015) 7:27–38
DOI 10.1007/s12520-013-0136-5

ORIGINAL PAPER

Results of utilitarian and accidental breakage experiments on bone points

Justin Bradfield · Tyrone Brand

Received: 30 October 2012 / Accepted: 15 March 2013 / Published online: 2 April 2013

Abstract In this paper, we present the results of two new experiments that assess the formation of macrofractures on bone tools subject to non-hunting-related activities. Our experiments were designed to assess the formation of macrofracture types that develop on bone tools that have been accidentally dropped and those that have been used in domestic activities, in this case, hide piercing. Whilst acknowledging that macrofracture analysts should take into account a margin of error when interpreting macrofracture results, our results suggest that the classification criteria for potential bone-tipped hunting weapons be refined to exclude all fractures other than spin-off fractures larger than 6 mm. We concur with other researchers that macrofracture analysis, while constituting a heuristically profitable tool, should be used as part of a multi-analytical approach.

Keywords Macrofracture analysis · Bone tools · Hide piercing · Dropping damage · Use wear · Experimental archaeology

Introduction

The invention of bow-and-arrow technology, and with it the ability to hunt and kill dangerous animals from a safer distance, would have significantly altered social relations among human populations by allowing people to exploit a wider variety of game, thereby broadening their trophic niche (Shea 2011). For this reason, the advent of bow-and-arrow technology has received much attention in recent archaeological discourse (e.g. Brooks et al. 2006; Lombard and Parsons 2008; Sisk and Shea 2009; Lombard and Phillipson 2010; Lombard and Haidle 2012). One avenue of research that explores the issue of identifying past hunting weapon components is use trace studies, and in particular macrofracture analysis. Macrofracture analysis is based on the principles of fracture mechanics and explores the breakage properties of brittle solids subject to use (Hayden 1979; Odell 1981). It is used primarily in the examination of stone tools thought to be part of ancient hunting weapons (e.g. Fischer et al. 1984; Odell and Cowan 1986; Lombard 2005a; Lombard and Pargeter 2008; Villa et al. 2009a, b, 2010), but has been shown to be equally applicable to bone points (Bradfield 2011; Bradfield and Lombard 2011).

The study of human-induced bone tool breakage is not new (e.g. Tyzzer 1936; Currey 1979; Guthrie 1983; Arndt and Newcomer 1986; Knecht 1997; Choyke and Bartosiewicz 2001; Gates St-Pierre and Walker 2007; Legrand-Pineau et al. 2010). Nevertheless, the majority of the bone tool studies cited above focus on other use-wear indicators such as polishes and transverse striations rather than breakage patterns. The study of fracture patterns is just as informative as other use-trace indicators; yet, whereas there appears to be a standardised nomenclature to refer to and describe polishes and striations, the same cannot be said of fractures. In contrast, the advances made in fracture mechanics of lithic tools and the associated standardised terminology (see Hayden 1979; Fischer et al. 1984; Lombard 2005a; Lombard and Pargeter 2008; Bradfield and Lombard 2011) should be seen as an achievement worth emulating in the study of bone tools.

> Many of the techniques used to modify stone are also used on bone and some morphological responses appear analogous, for example, flakes with a platform and bulb.…Sharing a common approach and terminology facilitates communication and standardises methods and reinforces the relationship between the two technologies.…The question of what constitutes

J. Bradfield (✉) · T. Brand
Department of Anthropology and Development Studies,
University of Johannesburg, P.O. Box 524, Auckland Park
Campus, Johannesburg 2006, South Africa
e-mail: jbradfield8@gmail.com

> anthropic use-wear on bones necessitates the same rigorous, verifiable and demonstrable approach being taken as in lithic use-wear studies. (Johnson 1985, pp. 164–165)

We therefore apply the macrofracture method to our study of replicated bone tools, as well as use-wear analysis, to bring a degree of comparability to the two approaches. Future bone tool studies that seek to investigate past hunting function should take into consideration the heuristic potential of macrofracture analysis. Likewise, macrofracture analysts would benefit from a consideration of other use-wear indicators.

The aim of this study was to examine the macrofractures and other use-trace indicators that develop on bone points that have been dropped ‘accidentally’ or used in hide-piercing activities, such as would be expected of bone awls. We conducted two experimental series to test for these breakage patterns: Experimental Series I, which consisted of bone point replicas that were dropped from a fixed height, and Experimental Series II, which consisted of bone point replicas that were used to pierce fresh and dry animal skin. The rationale for such a study is to provide a dataset comparable with previous experimental macrofracture studies on bone points in order to better understand the nature of breakage patterns that develop through longitudinal impact or pressure unrelated to hunting. Our results are assessed in light of a larger suite of experimental studies designed to test the reliability of macrofracture analysis to identify ancient hunting weapons. Although part of our study examined the damage that would be expected to accrue on awls, our replica points did not follow the standard morphological descriptions of ‘awls’ in the southern African literature (e.g. Sampson 1974; Schweitzer 1979). Rather, we chose to fashion our tools to resemble bone points usually associated with arrowheads. We did this in order to make our results comparable with previous macrofracture studies on bone tools and because, hypothetically, such bone points could have been used in any activity, including leather work.

Background

In search of ancient weapons

In recent years, there has been a proliferation of research into the origins of projectile technology, which, due to the poor preservation of organic materials, has tended to focus on the better represented stone tools (e.g. Lombard 2005a, b, 2007, 2011; Lombard and Pargeter 2008; Sisk and Shea 2009; Yaroshevich et al. 2010). By ‘projectile technology’, we make the distinction between that which is thrown by hand, for example a spear, and that which is projected via an intermediary mechanism, such as an atlatl or bow. We use the term to refer to the latter activity. Quartz segments (small segment-shaped backed stone flakes) found in approximately 60,000-year-old deposits from KwaZulu-Natal, South Africa (Fig. 1), have been interpreted as arrow armatures based on morphology and use-wear studies (Wadley and Mohapi 2008; Lombard 2007, 2011; Lombard and Phillipson 2010). Together with a bone point from Sibudu (Backwell et al. 2008), these are currently thought to constitute the earliest evidence for mechanically projected flight weaponry, such as a bow and arrow.

One of the reasons why research into the origins of mechanically projected weapon systems is so popular is that it speaks directly to what it means to be human. Three features of the modern human mind are our ability to remember and relate subconscious thoughts and visions (Lewis-Williams 2002), our use of enhanced working memory (the ability to conceptualise multiple steps while performing tasks, e.g. Wadley et al. 2009; Wadley 2010) and our ability to conceptualise and simultaneously use multiple symbiotic technologies (Lombard and Haidle 2012). This is where each component in a technological system consists of multiple elements, each working together to perform the required task and where the whole cannot function without all the requisite parts. If we take the bow and arrow as an example, the arrow is made up of a number of discrete parts, each working synergistically to perform a single function. Likewise, the bow will consist of a wooden stave, knotted string and sinew binding, each serving, in its own unique way, to release the potential kinetic energy stored in the wood, thus propelling the arrow through the air. Neither can achieve on their own what they can when used together. The presence of symbiotic technologies signals a higher degree of cognitive flexibility compared to non-symbiotic technologies such as a wooden spear (see Lombard and Haidle 2012).

The challenge for archaeologists is recognising these weapon components and distinguishing between those tools that were used as thrusting or throwing spears and those that were used with the aid of an intermediary mechanism like a bow. One method that archaeologists have tended to focus on is the macrofracture method. Macrofracture analysis is based on the principles of the fracture mechanics of brittle solids and constitutes one aspect of use-trace studies. Simply put, the theory of fracture mechanics states that certain fractures will develop on brittle-solid tools used in a specific activity (e.g. Hayden 1979; Lawrence 1979; Dockall 1997). Fischer et al. (1984) conducted experiments on stone tools to isolate and define macrofractures that could be considered diagnostic of the type of impact associated with hunting. They referred to these macrofractures as diagnostic impact fractures (DIFs). These DIFs were step terminating bending fractures, unifacial and bifacial spin-off fractures and impact burinations. Later, the method was refined to exclude spin-off fractures smaller than 6 mm to

Fig. 1 Map of South Africa

avoid confusion with accidental breakage patterns (Fischer et al. 1984; Lombard 2005a). Although bone differs from stone in many respects, both share the properties of brittle solids and therefore follow similar fracture patterns (Lawn and Marshall 1979; LeMoine 1994), a fact that has been borne out in subsequent experimental studies (e.g. Griffitts 2006; Bradfield and Lombard 2011). Unfortunately, this method does not distinguish between hand-delivered and mechanically delivered weapons, nor does it necessarily distinguish between other causes of longitudinal impact (Lombard et al. 2004; Lombard 2005a).

Testing the validity of a method

The principle behind macrofracture analysis is remarkably simple, and the idea that a particular fracture type can inform on the past function of a tool seems almost too good to be true. To increase the heuristic potential of this method, a series of control tests has been conducted in recent years that test the degree to which macrofracture analysis can be used as a reliable indicator of hunting application. This was done by looking at the formation of macrofractures that occur on differing raw materials and tools used in varying activities unrelated to hunting (e.g. Lombard et al. 2004; Pargeter 2011a, b, 2013; Pargeter and Bradfield 2012). Some of these tests have included stone and bone raw materials, although, for the purposes of this paper, we concentrate primarily on those studies involving bone tools.

As mentioned above, macrofracture analysis is primarily intended to identify fractures that occur through longitudinal impact, which may or may not be related to hunting. Pargeter (2013) has noticed that knapping stone flakes produces macrofractures, including the so-called diagnostic impact fractures, similar to those encountered on experimental hunting tools. Post-depositional trampling produced DIFs on stone flakes trampled by humans and cattle (Pargeter 2011a, b) and on bone points trampled by small- to medium-sized bovids (Pargeter and Bradfield 2012). In the case of stone tools, DIFs occurred in ≤3 % of the experimental sample and, in the case of bone points, <6 % of the experimental sample. This margin of error should be taken into account when interpreting possible hunting weapons from archaeological contexts (Pargeter 2013). What is important to note from these studies is that, of the macrofractures originally considered to be diagnostic of longitudinal impact by Fischer et al. (1984), there is one type that is consistently absent in all experiments save those of hunting: spin-off fractures larger than 6 mm.

The current state of bone tool studies

So far, we have focused on the stone tool studies. What then of the bone points about which this paper is concerned? Pointed bone artefacts play an important part in the material culture of many hunter-gatherer societies, yet, like most organic materials, they rarely survive in archaeological deposits, resulting in little attention being afforded them in site reports. As a result, the way in which we frame our research and understanding of past hunter-gatherer material culture is based almost exclusively on stone tool technology. However, a growing body of research in Europe and the Americas has focused on identifying use-wear and manufacturing traces on the few bone and other organic tools that do survive (e.g. LeMoine 1994; Gates St-Pierre and Walker 2007; Legrand-Pineau et al. 2010; also see d'Errico et al. 2012a, b for comparable southern African studies).

It has long been known that the types of breakage encountered on bone tools have more heuristic potential than simple morphology (see Tyzzer 1936), yet, where these studies have focused on hunting-related fractures, they have tended to use a descriptive nomenclature different from that of comparable stone tool studies (cf. Fischer et al. 1984;

Arndt and Newcomer 1986; Griffitts 2006; Lombard 2005a, b). For example, terms such as spiral fracture, hairline fracture, snap or oblique fracture, bevelled fracture and transverse fracture have been applied, which are themselves simply morphological descriptions. Yet, several studies have noted the similarity in breakage mechanics between bone and stone (e.g. Lawn and Marshall 1979; Johnson 1985; Arndt and Newcomer 1986; Knecht 1997; Bradfield and Lombard 2011). It seems only appropriate, then, to apply the same terminology when it comes to use-related impact fractures.

Not all pointed bone tools would have functioned as weapon components. There are many descriptions from ethnographic and historical sources of pointed bone tools having been used for piercing leather, fishing, weaving baskets and scraping hides (see Deacon 1976, 1984; Schweitzer 1979; Mitchell 2002). As with putative hunting weapons, the functions ascribed to these tools are based on comparative morphology and, sometimes, simply intuition. Yet, given the time and energy needed to manufacture bone tools, it is quite possible that some tools had multiple functions. Each function would leave specific use traces on the tool, although, in the case of bone, usually only the most recent use traces are preserved (LeMoine 1994; Fisher 1995). Hide piercing, for example, is easily identified through use-wear studies (e.g. d'Errico et al. 2003; Gates St-Pierre 2007; Legrand and Sidera 2007). The act of piercing an animal hide with a bone point such as an awl involves a longitudinal motion. Given a long enough life span, bone awls can be expected to fracture through use. In the present paper, we explore the nature of this breakage through macrofracture analysis and relate the results back to previous tests on the validity and reliability of this method.

Experimental protocol

Eighty-eight bone points were manufactured for our experiments (Fig. 2). These were divided into two groups of 44 each. The first group, which was used in Experimental Series I (the dropping experiment), consisted of 44 impala (*Aepyceros melampus*) long bones that had been defleshed and left to dry for 12 months. The second group, Experimental Series II, which was used in the hide-piercing experiment, consisted of 22 impala long bones that had been defleshed and left to dry for 12 months and 22 ox (*Bos taurus*) long bones that had been defleshed and left to dry for 1 month. The impala bones were considered to be dry bones due to the extent of desiccation, whilst the ox bones were considered to be still fresh or green as they retained most of their grease and fat (see Nawrocki 1997).

The bone points were mechanically ground to the dimensions commonly accorded to archaeological bone points (e.g. Vinnicombe 1971; Smith and Poggenpoel 1988) and which matched those used in previous macrofracture experiments. To save time, we used a commercial Ryobi HBG6E bench grinder for the manufacture. Once complete, the bone points were stained with an ochre paint following Pargeter and Bradfield (2012) in order to increase the light absorption and visual contrast under a reflected light microscope. Manufacturing striations were recorded as a control prior to the commencement of the experiments. The average lengths in the two experimental series were 93 and 86 mm, respectively. However, because length is a variable parameter among archaeological bone tools, we focused on the width of the specimens. The average width of the bone points for Experimental Series I was 5.3 mm (Table 1), whilst the average width of bone points in Experimental Series II was 4.8 mm (Table 2). In both cases, the bone points followed the dimensions of those previously used in hunting and trampling experiments (see Bradfield and Lombard 2011; Pargeter and Bradfield 2012) rather than the dimensions typically associated with archaeological awls (e.g. Schweitzer 1979; Smith and Poggenpoel 1988; d'Errico et al. 2003; Gates St-Pierre 2007). The reason for this was to better compare macrofracture results between these and previously published experiments. Both experimental series made use of thick and thinner bone points in order to see whether, and to what degree, bone thickness is a factor in macrofracture formation. The thin points (<5 mm) averaged 4.3 and 4 mm, respectively, and the thick points (>5 mm) averaged 5.8 and 5.7 mm, respectively. Wet bone was only used in Experimental Series II.

Fig. 2 Examples of bone points used in the experiments

Table 1 Experimental Series I (the dropping experiment)

Cat. no.	Raw material	Length	Max. width	Width at 10 mm	Width at 30 mm	Duration of use	MFs
DRP01	*A. melampus*	130	4.9	2.8	3.8	1	X
DRP02	*A. melampus*	70	5	4.5	5	3	X
DRP03	*A. melampus*	89	6	2.3	4	2	X
DRP04	*A. melampus*	95	4.9	3.8	3.9	5	
DRP05	*A. melampus*	98	6.1	2.3	4.2	5	
DRP06	*A. melampus*	99	6.6	3.1	4.4	2	X
DRP07	*A. melampus*	91	6.7	4.7	5	5	
DRP08	*A. melampus*	82	5.6	2.9	4.1	5	
DRP09	*A. melampus*	89	5.6	3	4.8	5	
DRP10	*A. melampus*	94	5.7	3.9	4.2	5	
DRP11	*A. melampus*	56	4.6	2.5	3.4	5	
DRP12	*A. melampus*	101	5.1	2.1	3.4	5	
DRP13	*A. melampus*	95	5	2.9	4.8	1	XX
DRP14	*A. melampus*	54	5	3.2	4.3	5	
DRP15	*A. melampus*	78	5.1	2.1	4.3	5	
DRP16	*A. melampus*	70	4.1	3.1	4.1	5	
DRP17	*A. melampus*	125	4.9	3.2	3.5	5	
DRP18	*A. melampus*	93	5.2	1.9	2.8	5	
DRP19	*A. melampus*	86	6.5	3.6	5	5	
DRP20	*A. melampus*	116	8	4.6	4.9	5	
DRP21	*A. melampus*	79	5.5	3.4	4.5	5	
DRP22	*A. melampus*	87	7.4	4.4	4.6	5	
DRP23	*A. melampus*	81	4.1	2.6	3.9	5	
DRP24	*A. melampus*	78	5.2	2.1	3.3	5	
DRP25	*A. melampus*	97	3.9	3	3	5	
DRP26	*A. melampus*	92	6.1	3.6	5	5	
DRP27	*A. melampus*	110	4.5	2.8	3	1	X
DRP28	*A. melampus*	52	5.1	2.6	3.9	5	
DRP29	*A. melampus*	109	5.6	3.4	4.9	5	
DRP30	*A. melampus*	88	5.5	3.7	4.5	5	
DRP31	*A. melampus*	64	3.8	2.3	3.3	5	
DRP32	*A. melampus*	110	6	2.9	3.2	5	X
DRP33	*A. melampus*	73	4.3	2.7	4	2	X
DRP34	*A. melampus*	85	5.5	3.1	4.1	5	
DRP35	*A. melampus*	66	4.5	2.1	3.3	4	X
DRP36	*A. melampus*	78	5.4	3.3	4.5	5	
DRP37	*A. melampus*	80	6.7	4.6	6.4	4	X
DRP38	*A. melampus*	60	3.9	2.3	3.4	5	
DRP39	*A. melampus*	70	4.1	2.8	4	5	
DRP40	*A. melampus*	55	3.6	3	4	1	XX
DRP41	*A. melampus*	115	6	3.4	5	5	
DRP42	*A. melampus*	119	6	3.6	5.1	5	
DRP43	*A. melampus*	85	5	2	3.9	2	XX
DRP44	*A. melampus*	56	5	3.7	4.6	5	XX
Mean		86.3	5.3	3	4.1	4.2	

An ‘X’ in the MF column represents the presence of macrofractures; an ‘XX’ represents the presence of DIFs. Values are in millimetres

Table 2 Experimental Series II (the hide-piercing experiment)

Cat. no.	Raw material	Length	Max. width	Width at 10 mm	Width at 30 mm	Duration of use	Hide condition	MFs	Polish
F1	*B. primigenius*	130	5.4	2.8	4.8	80	Dry		XX
F2	*B. primigenius*	123	5.1	3	4	80	Wet		X
F3	*B. primigenius*	146	6	3.3	4.5	80	Dry		X
F4 (n)	*B. primigenius*	108	5.6	2.3	3.3	80	Wet		XX
F5	*B. primigenius*	130	4.7	2.8	4.3	80	Dry		X
F6	*B. primigenius*	139	5.9	3.4	4.3	80	Dry		XX
F7	*B. primigenius*	122	5.1	2.5	4.5	27	Dry	X	XX
F8	*B. primigenius*	66	5.3	2.6	4	80	Wet		
F9	*B. primigenius*	95	5.4	3.3	4	80	Wet		XX
F10	*B. primigenius*	57	4.8	2.8	5	80	Wet		
F11 (n)	*B. primigenius*	99	4.3	2.1	3.3	80	Dry		
F12 (n)	*B. primigenius*	63	4.4	3.3	3.5	12	Dry	X	
F13 (n)	*B. primigenius*	107	2.9	2.4	2.8	80	Wet		X
F14 (n)	*B. primigenius*	98	3.4	2.3	2.8	80	Wet		
F15 (n)	*B. primigenius*	91	3.7	2.6	3	6	Dry	X	X
F16 (n)	*B. primigenius*	84	3.9	2.9	3.3	80	Dry		XX
F17 (n)	*B. primigenius*	99	4.1	2.4	2.5	1	Dry	X	
F18 (n)	*B. primigenius*	74	3.5	2.5	3.4	80	Wet		X
F19 (n)	*B. primigenius*	67	3.4	2.4	2.8	27	Wet	XX	
F20 (n)	*B. primigenius*	65	4.4	2.7	4.5	80	Wet		
F21	*B. primigenius*	75	4.8	2.9	4.7	80	Wet		X
F22 (n)	*B. primigenius*	69	4.1	2.8	5.7	80	Dry		X
D1	*A. melampus*	89	5.1	2.8	4	80	Wet		XX
D2	*A. melampus*	112	6.7	3.7	4.2	80	Wet		
D3	*A. melampus*	123	7	3.7	4.3	80	Dry		XX
D4	*A. melampus*	138	6.6	3.1	4.2	80	Wet		X
D5	*A. melampus*	96	6.2	3.6	4.3	24	Dry	X	XX
D6	*A. melampus*	88	5.5	3.2	4.4	80	Dry		
D7	*A. melampus*	71	6.1	3.3	4.7	80	Wet		X
D8	*A. melampus*	99	5.1	3.1	4.1	80	Dry		XX
D9	*A. melampus*	122	6.6	2.8	3.9	18	Dry	X	X
D10 (n)	*A. melampus*	92	5.4	3	4.1	80	Wet		X
D11 (n)	*A. melampus*	79	4.8	2.1	2.9	4	Dry	X	
D12 (n)	*A. melampus*	82	4.1	2.5	2.9	7	Dry	XX	X
D13	*A. melampus*	97	5.2	2.7	3.4	80	Wet	XX	X
D14	*A. melampus*	91	5	2.9	3.9	5	Dry	XX	
D15 (n)	*A. melampus*	81	3.9	2.1	2.4	1	Dry	XX	XX
D16 (n)	*A. melampus*	78	4.1	2.5	3	1	Wet	X	X
D17 (n)	*A. melampus*	42	3	2.3	3	3	Dry	XX	
D18 (n)	*A. melampus*	90	4.2	2.6	3.3	50	Wet	X	XX
D19 (n)	*A. melampus*	66	3.3	2.1	2.5	7	Wet	XX	
D20 (n)	*A. melampus*	88	4.8	2.2	2.9	16	Wet	X	X
D21	*A. melampus*	93	4.9	2.4	3.2	1	Wet	X	
D22 (n)	*A. melampus*	69	4.2	2	3.1	3	Dry	XX	XX
Mean		93	4.8	2.7	3.7	52.1			

An ‘X’ under the MF column represents the presence of macrofractures; an ‘XX’ represents the presence of DIFs. The presence of an ‘X’ under the polish column represents a weak presence, whilst ‘XX’ represents a higher degree of polish. Values are in millimetres, except for ‘duration of use’ which indicates the number of times used. F indicates wet bone, D indicates dry bone and (n) indicates thinner bone points akin to needles

In Experimental Series I, the 44 bone points were suspended horizontally 1.3 m off the ground. The bone points were then dropped onto a slate floor a maximum of five times or until a point broke. Impact against the floor was lateral to the points' main axes. In Experimental Series II, the 44 bone points were divided in half, each group containing 11 thin points and 11 thicker points, and used in a 'push-and-twist' motion to pierce fresh (1-day-old) and tanned gemsbok (*Oryx gazella*) hide. We held each awl at the proximal part—partly to increase the rate of breakage. If the awls were held closer to the point, breakage would have been reduced. Each hide was therefore penetrated by 22 points. Each point was used for a maximum of 80 penetrations; those that fractured were retired. In both experiments, the maximum duration of use was chosen arbitrarily. We felt that five drops and 80 penetrations gave a reasonable chance for macrofracture damage to occur whilst not exhausting the individual specimens.

All bone points in the experimental series were analysed and use-wear traces recorded at ×10 to ×65 magnification using an Olympus SXZ16 stereomicroscope with a mounted DP72 digital camera. Although magnifications of up to ×200 may sometimes be necessary to examine lightly developed volume deformation such as polishes (Legrand and Sidera 2007), we follow van Gijn (2007) and Olsen (2007) in our use of equipment and magnification ranges as bone develops abrasive features appreciatively quickly and, given the non-existence of taphonomic processes that may obscure results, a higher magnification was deemed unnecessary. Macrofractures can be identified fairly accurately with the naked eye, but low-powered magnification helps eliminate potentially ambiguous fractures, such as small step and hinge terminating fractures and spiral fracture terminations on wet bone. The higher powered magnification (although still considered low power) was needed to identify other use-wear indicators, such as polishing and edge rounding.

Results

The macrofracture results from the two experimental series are presented in Table 3. The three variables present in the hide-piercing experiment, namely the oil content of the bone tools, the condition of the hide and the thickness of the tools, are presented separately in the table. Three DIFs, comprising step terminating fractures, developed in Experimental Series I, whilst a single unifacial spin-off fracture, smaller than 6 mm, also developed. Non-DIF hinge and feather terminating fractures were the most prevalent in this experimental series. Three tools used in Experimental Series II developed DIFs, with the majority ($n=15$) developing hinge and feather terminating fractures. Five points developed unifacial spin-off fractures, but these were all smaller than 6 mm. No bifacial spin-off fractures were present. These figures are presented in Table 5 in the discussion section; for now, we confine ourselves to the different variables involved in Experimental Series II.

The first variable is the condition of the bone tools. The dry bone developed twice as many macrofractures and DIFs as the green bone. These included two step terminating fractures and the five unifacial spin-off fractures smaller than 6 mm. The spin-off fractures terminated in hinge or feather terminating fractures (Fig. 3). The fracture propagation in the green bones tended to follow a spiral pattern, typical of fracture properties in green bone. The dry hide caused 13 points to develop macrofractures compared to only seven on the fresh skin. In both cases, we had no trouble penetrating the hides with our bone points, although the dry hide did provide more resistance than the fresh skin. Diagnostic impact fractures developed more frequently on tools used to pierce the dry hide. As expected, the thinner points, or 'needles', accrued more than twice the number of macrofractures compared with the slightly thicker points. This, however, was not the case in Experimental Series I. Diagnostic impact fractures developed only on the 'needles' and not the slightly thicker points. In none of the cases where spin-off fractures were recorded did the fracture extend more than 6 mm in length. Green bone was the only variable that did not accrue spin-off fractures of any sort.

Table 4 presents the results of fracture location in the two experimental series as well as that of Bradfield and Lombard's (2011) hunting experiment for comparison. The bone points used for hide piercing experienced an almost equal distribution of fractures along the points' length. Not so with the dropping and hunting experiments, in which fractures tended to concentrate at the distal portion and tip of the piece. Distal fractures were only present on tools used to pierce the dry hide, although tip crushing developed mainly on the green bone. Five of the eight medial fractures developed on 'needles', whereas proximal fractures displayed a similar presence on 'needles' (5/6) and through use on dry hide (4/6).

In all cases, the results confirmed our predictions: dry, brittle bone was more susceptible to fracture; thinner points broke more easily; and tools used on the drier, harder hide fractured more frequently. Experimental Series I accrued predominantly distal fractures as this is the thinnest part of the point and the most likely to fracture. Likewise, distal fractures occurred only on tools used to pierce the dry hide in Experimental Series I, whilst 'needles' had the dominant fracture frequencies on the proximal and medial portions.

The results of the use-wear analysis, presented in Table 2, confirm the presence of polishing and tip rounding on 29 (66 %) bone points from Experimental Series II; no polish or other signs of use wear were detected in Experimental Series I. In general, polish was confined to the tip and did not

Table 3 Results of the macrofracture analysis from the dropping and hide-piercing experiments (Experimental Series I and II)

	EXPI thick (*n*=25)		EXPI thin (*n*=19)		Green bone (*n*=22)		Dry bone (*n*=22)		Dry hide (*n*=22)		Fresh skin (*n*=22)		Points (*n*=22)		Needles (*n*=22)	
	n	%	*n*	%	*n*	%	*n*	%	*n*	%	*n*	%	*n*	%	*n*	%
Snap	3	12	–	–	2	9.1	–	–	2	9.1	–	–	1	4.5	1	4.5
Step termination	1	4	2	10	1	4.5	2	9.1	2	9.1	1	4.5	–	–	3	13.6
BF spin-off	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
UF spin-off <6 mm	1	4	–	–	–	–	5	22.7	3	13.6	2	9.1	2	9.1	3	13.6
UF spin-off >6 mm	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Hinge/feather termination	4	16	2	10	3	13.6	14	63.6	9	9.1	6	27.3	5	22.7	10	45.4
Tip crushing	1	4	1	5.2	11	50	3	13.6	4	18.2	8	36.3	1	4.5	6	27.3
Tools with MFs	13	52	4	21	6	27.3	14	63.6	13	59.1	7	31.8	6	27.3	14	63.6
Tools with DIFs	1	4	2	10	1	4.5	2	9.1	2	9.1	1	4.5	–	–	3	13.6

BF bifacial, *EXPI* experimental series I, *UF* unifacial, *MFs* macrofractures, *DIFs* diagnostic impact fractures

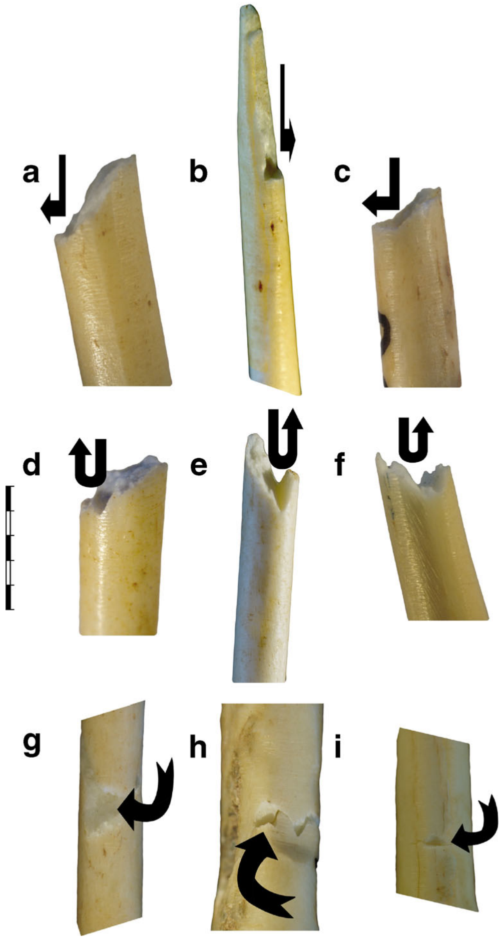

Fig. 3 Examples of spin-off fractures, step and hinge terminating fractures. **a** D12 step terminating fracture. **b** D7 step terminating fracture. **c** D22 step terminating fracture. **d** D9 hinge terminating fracture. **e** D20 hinge terminating fracture. **f** D11 hinge terminating fracture. **g** D19 spin-off fracture. **h** D14 spin-off fracture. **i** D13 spin-off fracture. *Arrows* indicate the direction of force from initiation to dissipation. *Scale bar*, 5 mm

extend below 50 mm from the tip. In most cases, the polish was faint, with manufacturing striations still clearly visible. The polish, which forms through abrasive actions (see LeMoine 1994), such as hide piercing, was not ubiquitous enough to obliterate the manufacturing striations, except at the tip, where 13 (30 %) bone points displayed a high degree of polish (see Fig. 4b). Tip rounding, similar to that of previous studies (e.g. Gates St-Pierre 2007; van Gijn 2007; Buc 2010), was also observed on 15 (34 %) bone points used during Experimental Series II.

Discussion

The macrofracture method as developed by Fischer et al. (1984) describes two types of fractures that they thought to be diagnostic of longitudinal impact, such as would result from use during hunting. These DIFs were step terminating bending fractures and spin-off fractures. These categories were subsequently modified to exclude unifacial spin-off fractures smaller than 6 mm (Lombard 2005a) in order to avoid accidental fractures from obscuring interpretations. The results of the macrofracture analysis from the

Table 4 Results of macrofracture analyses on three experimental series according to the location of the fractures

	Hide piercing (*n*=44)		Dropping (*n*=44)		Hunting (*n*=28)	
	n	%	*n*	%	*n*	%
Distal	7	16	10	23	11	39
Medial	9	20	-	-	5	18
Proximal	6	14	1	2	3	11

Hunting data are taken from Bradfield and Lombard (2011)

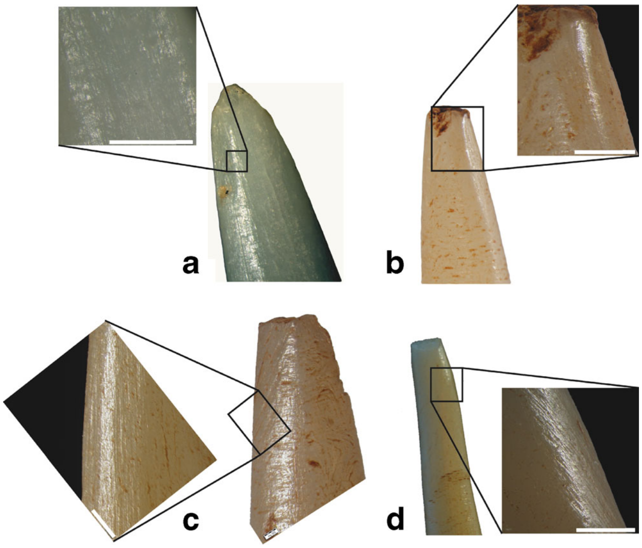

Fig. 4 Examples of polish on bone points used in Experimental Series II. **a** D18 light polish near the tip. **b** F1 heavy polish at the tip. **c** F12 light polish near the tip. **d** F7 light polish. *White scale bars*, 500 µm

two experiments presented in this paper validate this modification and serve to strengthen the interpretative potential of the method. No bifacial or unifacial spin-off fractures >6 mm were recorded in either experimental series presented here, nor were they present on previous trampling experiments (Pargeter and Bradfield 2012). Spin-off fractures <6 mm developed only on dry bone. The presence of these spin-off fractures can be attributed to the state of the bone; dry bone is more brittle than green bone and therefore behaves more like an inorganic material (Johnson 1985, p. 169). Indeed, these fractures are very similar to the notches that developed on bones that had been experimentally trampled (Blasco et al. 2008). We noticed this potential in the dry bone prior to the experiments as in several cases there were numerous microfissures present in the bone that were caused by weathering. As expected, 'needles' developed a higher incidence of fractures than the slightly thicker bone points, as too did points used to pierce the harder dry hide compared with those used to pierce the fresh skin.

Table 5 shows that in all cases, save that of trampling, hinge and feather terminating fractures were most prevalent. Step terminating fractures were present in all the experiments, and we are inclined to drop them from the DIF criteria for bone tools in the future. Likewise, unifacial spin-off fractures were present in all but the trampling experiment. Only the hunting experiment, however, developed spin-off fractures larger than 6 mm, which seems to confirm the validity of the arbitrary metric assigned to this category of fractures.

There was not much difference in the rate of breakage between dry and green bone or between the dry leather and the fresh skin. On average, dry bones fractured after 15.7 penetrations compared with 14.6 penetrations for the green bone. The placement of fractures along the length of the bone points in Experimental Series I was concentrated at the distal section of the piece, whereas in Experimental Series II they were fairly evenly distributed. This difference might be due to how we held the awls whilst performing the experiment. By comparison, fractures on bone points from southern African archaeological contexts and bone arrows from historical collections tend to concentrate at the distal end (cf. Bradfield 2012a, b).

The microwear traces that developed on our tools in Experimental Series II matched those expected on bone used to pierce animal hides (cf. Buc and Loponte 2007). Most of our specimens developed light polish—although this was more pronounced at the tips. As with similar hide-piercing experiments, polish did not extend farther than 50 mm from the tip (cf. Buc 2011). Tip rounding, once the most common use trace recorded on osseous materials to have undergone impact (Tyzzer 1936; Arndt and Newcomer 1986; Pokines 1998; Buc 2010), was present on 60 % of tools in Experimental Series II. Tip rounding was not recorded, however, on Bradfield and Lombard's (2011) experimental hunting weapons.

Table 5 Comparison of macrofracture results on bone points subject to four different activities

	Hunting (n=28)		Trampling (n=50)		Hide piercing (n=44)		Dropping (n=44)	
	n	%	*n*	%	*n*	%	*n*	%
Snap	1	4	1	2	2	5	3	7
Step termination	6	21	3	6	3	7	2	5
UF spin-off <6 mm	–	–	–	–	5	11	1	2
UF spin-off >6 mm	3	11	–	–	–	–	–	–
Hinge/feather termination	13	46	1	2	15	34	6	14
Tip crushing	4	14	2	4	14	32	2	5
Tools with DIFs	9	32	3	6	3	7	2	4

Data for the hunting experiment come from Bradfield and Lombard (2011) and for the trampling experiment from Pargeter and Bradfield (2012)

Conclusion

The two experiments presented in this paper contribute to a growing body of experimental work that seeks to interrogate the analytical reliability of the macrofracture method (see Pargeter 2013). In essence, each of these experiments serves as a control for the original hunting experiments by testing for DIFs in non-hunting-related activities. Recent moves to drop the term 'diagnostic' when referring to macrofractures related to hunting (Pargeter 2013) seems acceptable when given the degree of reasonable doubt associated with the formation of some of these fractures. The two experiments presented in this paper support suggestions to further modify the 'diagnostic impact criteria' to include only spin-off fractures larger than 6 mm for bone points (cf. Lombard 2005a; Pargeter and Bradfield 2012). It should be noted, though, that even on bone points of known hunting function, spin-off fractures occur only on a minority of specimens (Bradfield 2012b). In other words, while a spin-off fracture will indicate longitudinal impact consistent with hunting use, its absence does not necessarily rule out this activity. Further analytical criteria are needed in conjunction with macrofracture analysis to isolate potential hunting weapons (e.g. Bradfield 2013). Use-wear analysis seems to hold much promise, even if its usefulness is only in ruling out other possible functions in a process of elimination strategy.

Finally, macrofracture analysis and other use-trace studies are integral for the interpretation of past functions of tools and should not be used mutually exclusively of one another. In this paper, we have used both approaches, although our results of the use-wear analysis merely serve to confirm results obtained through previous hide-piercing experiments. The method has its limitations, but these should not obscure its potential to aid researchers' understanding of past hunting function. Ideally, macrofracture analysis should form part of a synergistic multi-analytical research design that considers other use traces.

Acknowledgments The authors wish to thank Greg Nell from Aloe Hills Game Farm for supplying the skin. Marlize Lombard, Justin Pargeter and two anonymous referees provided valuable suggestions for the improvement of the manuscript. JB acknowledges the financial support provided by the South African National Department of Arts and Culture, the South African Archaeological Society's Kent Bequest and the Palaeontological Scientific Trust (PAST) and its Scatterlings of Africa programmes during various stages of this project.

References

Arndt SH, Newcomer M (1986) Breakage patterns of prehistoric bone points: an experimental study. In: Roe D (ed) Studies in the Upper Palaeolithic of Britain and Northwest Europe. British Archaeological Reports International Series 296, Oxford, pp 165–173

Backwell L, d'Errico F, Wadley L (2008) Middle Stone Age bone tools from the Howiesons Poort layers, Sibudu Cave, South Africa. J Archaeol Sci 35:1566–1580

Blasco R, Rosell J, Fernández Peris J, Cáceres I, Vergès JM (2008) A new element of trampling: an experimental application on the level XII faunal record of Bolomor Cave (Valencia, Spain). J Archaeol Sci 35:1605–1618

Bradfield J (2011) Macrofracture analysis as a method for identifying bone-tipped weapons: a functional approach to the recognition of Stone Age hunting points. Lambert Academic, Saarbruchen

Bradfield J (2012a) A comparison of three Later Stone Age bone point assemblages from South Africa. South African Archaeol Bull 67:32–43

Bradfield J (2012b) Macrofractures on bone-tipped arrows: analysis of hunter-gatherer arrows in the Fourie collection from Namibia. Antiquity 86:1179–1191

Bradfield J (2013) Investigating the potential of micro-focus computed tomography in the study of ancient bone tool function: results from actualistic experiments. J Archaeol Sci 40:2606–2613

Bradfield J, Lombard M (2011) A macrofracture study of bone points used in experimental hunting with reference to the South African Middle Stone Age. South African Archaeol Bull 66:67–76

Brooks S, Yellen J, Nevell L, Hartman G (2006) Projectile technologies of the African MSA: implications for modern human origins. In: Hovers E, Kuhn S (eds) Transitions before the transition. Springer, New York, pp 233–256

Buc N (2010) Testing functional hypothesis of Late Holocene bone bipoints from the Lower Parana Wetlands (Argentina). In: Legrand-Pineau A, Sidera I (eds) Ancient and modern bone artefacts from America to Russia: cultural, technological and functional signature. British Archaeological Reports, International Series 2136, Oxford, B.A.R, pp 217–225

Buc N (2011) Experimental series and use-wear in bone tools. J Archaeol Sci 38:546–557

Buc N, Loponte D (2007) Bone tool types and microwear patterns: some examples from the Pampa region, South America. In: Gates St-Pierre C, Walker RB (eds) Bones as tools: current methods and interpretations in worked bone studies. British Archaeological Reports, International Series 1622, Oxford, B.A.R., pp 143–157

Choyke A, Bartosiewicz L (2001) Crafting bone: skeletal technologies through time and space. Proceedings of the 2nd Meeting of the (ICAZ) Worked Bone Research Group, Budapest. BAR International Series 937, Oxford

Currey JD (1979) Mechanical properties of bone tissues with greatly differing functions. J Biomech 12:313–319

Deacon H (1976) Where hunters gathered: a study of Stone Age people in the Eastern Cape. South African Archaeological Society Monographs 1. South African Archaeological Society, Claremont

Deacon J (1984) The Later Stone Age of southernmost Africa. Cambridge Monographs in African Archaeology 12. British Archaeological Reports International Series 213. Archaeopress, Oxford

d'Errico F, Julien M, Liolios D, Vanhaeren M, Baffier D (2003) Many awls in our argument. Bone tools manufacture and use in the Chatelperronian and Aurignacian levels of the Grotte du Renne at Arcy-sur-Cure. In: Zilhao J, d'Errico F (eds) The chronology of the Aurignation and of the transitional technocomplexes: dating, stratigraphies, cultural implications. Instituto Portugues de Arqueologia, Lisbon, pp 247–270

d'Errico F, Backwell L, Wadley L (2012a) Identifying regional variability in Middle Stone Age bone technology. The case of Sibudu Cave. J Archaeol Sci 39:2479–2495

d'Errico F, Backwell L, Villa P, Deganog I, Lucejkog J, Bamford M, Higham T, Colombini MP, Beaumont P (2012b) Early evidence of San material culture represented by organic artifacts from Border Cave, South Africa. Proc Natl Acad Sci 109(33):13214–13219

Dockall J (1997) Wear traces and projectile impact: a review of the experimental and archaeological evidence. J Field Archaeol 24:321–331

Fischer A, Vemming Jansen P, Rasmussen P (1984) Macro and micro wear traces on lithic projectile points: experimental results and prehistoric examples. J Danish Archaeol 3:19–46

Fisher J (1995) Bone surface modifications in zooarchaeology. J Archaeol Method Theory 2:7–68

Gates St-Pierre C (2007) Bone awls of the St. Lawrence Iroquoians: a microwear analysis. In: Gates St-Pierre C, Walker RB (eds) Bones as tools: current methods and interpretations in worked bone studies. British Archaeological Reports, International Series 1622, Oxford, B.A.R., pp 107–118

Gates St-Pierre C, Walker RB (eds) (2007) Bones as tools: current methods and interpretations in worked bone studies. British Archaeological Reports, International Series 1622. Archaeopress, Oxford

Griffitts J (2006) Bone tools and technological choice: change and stability on the northern plains. Unpublished PhD thesis, University of Arizona, Texas

Guthrie RD (1983) Osseous projectile points: biological considerations affecting raw material selection and design among Paleolithic and Paleoindian peoples. In: Clutton-Brook J, Grigson C (eds) Animals and archaeology. 1. Hunters and their prey. British Archaeological Reports, International Series 163. Archaeopress, Oxford, pp 273–294

Hayden B (ed) (1979) Lithic use wear analysis Academic, New York

Johnson E (1985) Current developments in bone technology. Adv Archaeol Method Theory 8:157–235

Knecht H (1997) Projectile points of bone, antler and stone: experimental explorations of manufacture and use. In: Knecht H (ed) Projectile technology. Plenum, London, pp 193–212

Lawn BR, Marshall DB (1979) Mechanisms of microcontact fracture in brittle solids. In: Hayden B (ed) Lithic use wear analysis. Academic, New York, pp 63–82

Lawrence RA (1979) Experimental evidence for the significance of attributes used in edge-damage analysis. In: Hayden B (ed) Lithic use wear analysis. Academic, New York, pp 35–38

Legrand A, Sidera I (2007) Methods, means and results when studying European bone industries. In: St-Pierre C, Walker R (eds) Bones as tools: current methods and interpretations in worked bone studies. British Archaeological Reports, International Series 1622. Archaeopress, Oxford, pp 67–79

Legrand-Pineau A, Sidera I, Buc N, David E, Scheinsohn V (eds) (2010) Ancient and modern bone artefacts from America to Russia: cultural, technological and functional signature. British Archaeological Reports, International Series 2136. Archaeopress, Oxford

LeMoine GM (1994) Use wear on bone and antler tools from the Mackenzie Delta, Northwest Territories. Am Antiq 59:316–334

Lewis-Williams D (2002) Mind in the cave. Thames & Hudson, London

Lombard M (2005a) A method for identifying Stone Age hunting tools. South African Archaeological Bull 60:115–120

Lombard M (2005b) Hunting and hafting during the MSA at Sibudu cave, KwaZulu-Natal, South Africa: a multianalytical approach. J Hum Evol 48:279–300

Lombard M (2007) Evidence for change in Middle Stone Age hunting behaviour at Blombos Cave: results of a macrofracture Analysis. South African Archaeological Bull 62:62–67

Lombard M (2011) Quartz-tipped arrows older than 60 ka: further use-trace evidence from Sibudu, KwaZulu-Natal, South Africa. J Archaeol Sci 38:1918–1930

Lombard M, Pargeter J (2008) Hunting with Howiesons Poort segments: pilot experimental study and the functional interpretation of archaeological tools. J Archaeol Sci 35:26–41

Lombard M, Parsons I (2008) Blade and bladelet function and variability in risk management during the last 2000 years in the Northern Cape. South African Archaeological Bull 63:18–27

Lombard M, Phillipson L (2010) Indications of bow and stone-tipped arrow use 64,000 years ago in KwaZulu-Natal, South Africa. Antiquity 84:1–14

Lombard M, Haidle M (2012) Thinking a bow-and-arrow set: cognitive implications of Middle Stone Age bow and stone-tipped arrow technology. Camb Archaeol J 22:237–264

Lombard M, Parsons I, van der Ryst MM (2004) Middle Stone Age lithic point experimentation for macro-fracture and residue analyses: the process and preliminary results with reference to Sibudu Cave points. South African J Sci 100:159–166

Mitchell P (2002) The archaeology of Southern Africa. Cambridge University Press, Cambridge

Nawrocki S (1997) Cleaning bones. http://archlab.uindy.edu/Documents/CleaningBones/. Accessed 27 August 2012

Odell G (1981) The mechanics of use and breakage on stone tools: some testable hypotheses. J Field Archaeol 8:197–209

Odell G, Cowan F (1986) Experiments with spears and arrows on animal targets. J Field Archaeol 13:195–212

Olsen S (2007) Conclusions: bone artifacts and their importance to archaeology. In: Gates St-Pierre C, Walker RB (eds) Bones as tools: current methods and interpretations in worked bone studies. British Archaeological Reports, International Series 1622, Oxford, pp 175–182

Pargeter J (2011a) Assessing the macrofracture method for identifying Stone Age hunting weaponry. J Archaeol Sci 38:2882–2888

Pargeter J (2011b) Human and cattle trampling experiments in Malawi to understand macrofracture formation on Stone Age hunting weaponry. Antiquity 85. http://www.antiquity.ac.uk/projgall/pargeter327/. Accessed 3 May 2012

Pargeter J (2013) Rock type variability and impact fracture formation: implications for probabilistic sampling of assemblages for micro-level functional analyses. J Anthropol Archaeol Sci (under review)

Pargeter J, Bradfield J (2012) The effects of class I and II sized bovids on macrofracture formation and tool displacement: results of a trampling experiment in a southern African Stone Age context. J Field Archaeol 37:238–251

Pokines J (1998) Experimental replication and use of Cantabrian Lower Magdalenian antler projectile points. J Archaeol Sci 25:875–886

Sampson CG (1974) The Stone Age archaeology of Southern Africa. Academic, New York

Schweitzer F (1979) Excavations at Die Kelders, Cape Province, South Africa: the Holocene deposits. Ann South African Museum 78:101–233

Sisk ML, Shea J (2009) Experimental use and quantitative performance analysis of triangular flakes (Levallois points) used as arrowheads. J Archaeol Sci 36:2039–2047

Shea J (2011) Stone tool analysis and human origins research: some advice from Uncle Screwtape. Evol Anthropol 20:48–53

Smith A, Poggenpoel C (1988) The technology of bone tool fabrication in the South-Western Cape, South Africa. World Archaeol 20:103–114

Tyzzer EE (1936) The "simple bone point" of the shell-heaps of the northeastern Algonkian area and its probable significance. Am Antiq 1:261–279

van Gijn A (2007) The use of bone and antler tools: two examples from the Late Mesolithic in the Dutch coastal zone. In: Gates St-Pierre C, Walker RB (eds) Bones as tools: current methods and interpretations in worked bone studies. British Archaeological Reports, International Series 1622, Oxford, pp 81–92

Villa P, Soressi M, Henshilwood CS, Mourre V (2009a) The Still Bay points of Blombos Cave (South Africa). J Archaeol Sci 36:441–460

Villa P, Boscato P, Ranaldo F, Ronchitelli A (2009b) Stone tools for the hunt: points with impact scars from a Middle Paleolithic site in southern Italy. J Archaeol Sci 36:850–859

Villa P, Soriano S, Teyssandier N, Wurz S (2010) The Howiesons Poort and MSA III at Klasies River main site, Cave 1A. J Archaeol Sci 37:630–655

Vinnicombe P (1971) A Bushman hunting kit from the Natal Drakensberg. Ann Natal Museum 20:611–625

Wadley L (2010) Compound-adhesive manufacture as a behavioural proxy for complex cognition in the Middle Stone Age. Curr Anthropol 51:S111–S119

Wadley L, Mohapi M (2008) A segment is not a monolith: evidence from the Howiesons Poort of Sibudu, South Africa. J Archaeol Sci 35:2594–2605

Wadley L, Hodgskiss T, Grant M (2009) Implications for complex cognition from the hafting of tools with compound adhesives in the Middle Stone Age, South Africa. Proc Natl Acad Sci 106(24):9590–9594

Yaroshevich A, Kaufman D, Nuzhnyy D, Bar-Yosef O, Weinstein-Evron M (2010) Design and performance of microlith implemented projectiles during the Middle and the Late Epipaleolithic of the Levant: experimental and archaeological evidence. J Archaeol Sci 37:368–388