Journal of Archaeological Science: Reports 31 (2020) 102283

Contents lists available at ScienceDirect

Journal of Archaeological Science: Reports

journal homepage: www.elsevier.com/locate/jasrep

The non-invention of the ceramic arrowhead in world archaeology

Michelle R. Bebber[a,*], Michael Wilson[a], Andrew Kramer[b], Richard S. Meindl[a], Briggs Buchanan[c], Metin I. Eren[a,d,*]

[a] Department of Anthropology, Kent State University, Kent, OH 44242, United States
[b] Department of Anthropology, University of Akron, Akron, OH 44325, United States
[c] Department of Anthropology, University of Tulsa, Tulsa, OK 74104, United States
[d] Department of Archaeology, Cleveland Museum of Natural History, Cleveland, OH 44106, United States

ABSTRACT

Why, despite over 30,000 years of ceramic technology and tool diversity documented in the archaeological record – including examples of knapped ceramic scraping tools – was the ceramic arrowhead never invented? Here, we first review the use of ceramic projectile technology and tool use in the archaeological record. Then, via controlled ballistics tests, we investigate whether functional constraints played a role in this global non-invention. By creating "best case" and "worst case" models of ceramic arrowhead, and pitting them both against replica chipped stone counterparts, we show that the former perform significantly worse than the latter in terms of target penetrability and overall durability. By investigating "theoretical" artifacts, we can better understand the evolution of prehistoric technology and why the archaeological record appears the way it does.

1. Introduction

Ceramic technology, whereby objects are created via hardening formed clay with heat (Rice, 2015), has been repeatedly invented, culturally transmitted, and physically transported by humans since the invention of ceramic figurines dating to 31,000 BP (Farbstein et al., 2012). The oldest functional pottery vessels documented thus far, dating to 20,000 B.P., have been found in Jiangxi, China (Cohen et al., 2017; Wu et al., 2012). While ceramic figurines and pottery vessels have been common, often abundant, objects found in Late Pleistocene and Holocene archaeological records around the world, ceramic technology has also served in a multitude of other functional capacities. For example, ceramic tools include protective coverings (Stanislawski, 1969), kiln roofs (Nicholson, 2010), pottery production tools (Alden, 1988; Henrickson, 1992: 6-8; Van Gijn and Hofman, 2008), clay sickles (Stein, 2012), and scraping tools for activities such as hide-scraping or wool harvesting (Delougaz and Kantor, 1996; Shamanaev, 2002; Sudo, 2003, 2010).

Despite the great antiquity of ceramic technology and its wide diversity of functional application, current archaeological evidence suggests that the ceramic arrowhead was never invented. This non-invention is peculiar for several reasons. First, numerous prehistoric societies concurrently produced ceramic technologies and bow and arrow technology, the latter itself possessing great antiquity and likely independently invented on several continents (Lombard and Phillipson, 2010; Lyman et al., 2009). The notion of clay projectile weaponry was conceived of as early as the Near Eastern Early Chalcolithic (ca. 8000 BP) in which case projectile clay sling bullets were contemporaneous with bow and arrow technology used for warfare, hunting, or defense of herd animals (Clare et al., 2008; Forouzan et al., 2012; Kirkbride, 1982; Korfmann, 1973; Kubíková, 2013; Matthews, 1996). Second, prehistoric people could, and at times did, knap or retouch ceramic sherds, treating them in a manner similar to stone. At the Syrian Chalcolithic (ca. 7000 BP) site of Tell Kosak Shamali clay tools served as "cheap substitutes" for flint tabular scrapers (Sudo, 2010). Third, producing arrowheads out of crypto-crystalline stone requires a substantial time investment in skill acquisition or apprenticeship (Lycett and Eren, 2018), whereas it is relatively easy to pinch out triangular projectile tips out of clay. Indeed, clay sling bullets appear to have been expediently produced as people moved across the landscape (Forouzan et al., 2012).

Nonetheless, despite the presence of the necessary "ingredients" and seemingly abundant opportunity for the ceramic arrowhead to emerge in the cultural evolutionary record, it was never invented. It is therefore reasonable to hypothesize whether the non-invention of the ceramic arrowhead was due to the functional constraints of fired clay relative to the properties of knapped stone. For example, experiments by Shamanaev (2002) and Van Gijn and Hofman (2008) indicated that hide scraping tools made from clay were at times friable and quickly deteriorated, or were simply ineffective, while clay woodworking tools broke. Van Gijn and Hofman (2008) suggest that even clay sherds fired to a "high temperature" do not provide the durability required to

* Corresponding authors at: Department of Anthropology, Kent State University, Kent, OH 44242, United States.
E-mail addresses: mbebber@kent.edu (M.R. Bebber), meren@kent.edu (M.I. Eren).

https://doi.org/10.1016/j.jasrep.2020.102283
Received 20 July 2019; Received in revised form 25 February 2020; Accepted 4 March 2020
Available online 02 April 2020

process hard materials such as bone and wood. However, while these studies suggest functional differences between fired clay and flaked stone, scraping and cutting tasks are different from projectile mechanics. Indeed, the functional efficacy of projectile clay has been supported via analysis of skeletal remains which exhibit cranial trauma in the form of small round fractures, the size and shape of which is consistent with clay sling bullets (McMahon et al., 2011; Runnels et al., 2009). And, in modern warfare, ceramic materials have recently been experimented with as projectiles. Nechitailo (2008) demonstrated that ceramic points made from commercially available clay appear to perform better with increasing impact speed. Although these speeds (measured in terms of km/s) would not have been attainable using prehistoric weapon systems, Nechitailo's (2008) study is consistent with the idea that ceramic materials are, in specific circumstances, able to function effectively as projectiles.

Here, we explore the theoretical design space (McGhee, 1999) of the ceramic arrowhead to better understand why it never emerged. Via controlled experimental ballistics we compared the functional effectiveness of two types of fired clay arrowheads versus typical ones knapped from crypto-crystalline stone (Texas Georgetown chert) by testing two common measures of projectile performance: penetration depth into a target and arrowhead durability.

Two different sets of ceramic arrowheads were made with the goal of capturing "best-case" and "worse-case" scenarios that could have existed in the past. The first set of clay points was designed to represent what theoretically could have been produced in ancient complex societies possessing good control over clay selection and enclosed updraft kilns. For example, pottery kilns have been documented from the late Neolithic (ca. 8000 BP) in Hassuna, Halaf, and Samarra culture areas (Hansen Streily, 2000). Research has shown that Samarra pottery was fired to temperatures ranging from 850 to 1050 °C, upwards to 1150 °C, which would have required an enclosed kiln structure. Likewise, studies have shown that Halaf pottery was fired up to 1050 °C (Tite and Maniatis 1975). Slightly later Ubaid pottery (ca. 7500 BP) was also fired in enclosed kilns capable of reaching temperatures between 1050 and 1150 °C (Tite and Maniatis 1975). Therefore, we chose to fire our "best case" (i.e. high-fired points) to a temperature of 1063 °C for two main reasons, 1) the component of clay responsible for vitrification, feldspar, melts at 1050 °C which generates a harder, more durable ceramic compared to clays fired to lower temperatures, and 2) this temperature allowed us to recreate the type of ceramic that would have been achieved by potters experimenting with updraft kiln technology.

The second set of "worse-case" clay points was made from clay sourced from the Scioto River Valley (Ohio, U.S.A.) and low-fired to a temperature of 760 °C, representing what theoretically could have been produced by prehistoric North Americans using an open "bonfire" style firing regime. Ethno-archaeological data collected from open firings in different cultures around the world support this temperature range for open "bonfire" style firing (Gosselain, 1992; Smith 2001). According to Smith (2001), the mean temperature reached in open firings that use "heavy" fuels such as lumber or bark, is 762 °C.

2. Materials and methods

2.1. Production of stone arrowheads

Thirty-five flaked stone arrowheads were knapped by M.I.E. using Texas Georgetown Chert (Fig. 1) (see also Mika et al., 2020). First, flakes were knapped from chert nodules via hard-hammer direct percussion. Preforms were then produced using soft-hammer direct percussion. Finally, the triangular arrowheads were finished using pressure flaking. Measurements of each stone point before use are available in Data S1.

2.2. Production of high-fired and low-fired arrowheads

Thirty-five high-fired arrowheads and thirty-five low-fired arrowheads were produced by M.R.B. (Fig. 1). Measurements of each ceramic point before use are available in Data S1. Two types of clay were used to create duplicate copies of each of the stone points. To do so, the clay was shaped into a circular shape approximately 3 cm thick. This flattened form was then stretched to an even thickness of approximately 0.75 cm by throwing repeatedly onto a table surface. Each stone triangular point was placed on top of the clay and traced using a pin tool to cut out the exact point shape. Each clay point was dried until it reached a workable level of green strength and was then shaped via hand sculpting and carving to mimic the thickness and edge characteristics of each of the stone points.

The first set (i.e. "best case") of clay points was made of Standard #103 potter's clay and high-fired in an electric kiln to a temperature of 1063 °C. The second set (i.e. "worst case") of clay points was made from locally sourced glacial clay with the addition of silicate-based grit temper at 30% by volume, which is the amount commonly used in North America (Bebber, 2017). These points were fired in an electric kiln to a temperature of 760 °C which represents the temperature commonly found in open "bonfire" style firing regimes (Gosselain, 1992; Smith, 2001).

The stone and fired clay arrowhead datasets were indistinguishable in terms of size and shape (see online Supplementary materials).

2.3. Arrowhead hafting

All arrowheads were hafted in an identical fashion (Figs. 2 and 3, see also Mika et al. 2020) to 105, 5/16″ diameter Port Orford cedar shafting (prefletched). Also used were auxiliary materials such as synthetic polyurethane sinew, "fer-lite" hot-melt adhesive, and finally, nitrocellulose lacquer for a finish coat to increase haft durability. The hafting process also required the utilization of several hand tools including files/rasps, a small knife, sand papers of varying grit, and a small "Sterno" heat pot.

The hafting process included six steps. The first step was to taper the shafts to accommodate the thickness, width, and length of the projectile to be hafted. This process was accomplished by means of a file/rasp. The second step was to cut the notch/socket in which the base of the projectile was to be seated. Third, this socket area needed to be trimmed, heat-treated, and the projectile "dry-fitted" and balanced by hand-spinning. Fourth in the process was the action of fixing the projectile in the socket. This step required the heating shaft, projectile, and the hot-melt adhesive. The process of fitting and balancing was repeated, and, with the application of the adhesive, the projectile was firmly fixed and excess adhesive trimmed and smoothed. Fifth, after letting the adhesive set, cool, and cure, the sinew wraps were applied. The sinew wrap consisted of a simple "loop-and-tail" whip knot. After wrapping, the tails were trimmed, and the whole area was mildly reheated for minor readjustments and smoothing. Lastly, a coat or nitrocellulose lacquer was applied, simulating hide glue, to improve durability.

Certain challenges arose during the hafting process. With respect to the points fashioned from low-fired ceramic, the main challenge concerned the handling and physical pressures applied to the points during the mounting and wrapping portion of the process; the slightest pressure upon them would result in damage. Several of them were broken at the tip and had to be repaired by means of gluing. The high-fired ceramic projectiles, while proving to be very durable during hafting, presented minor problems during balancing; presumably, being malleable, the points must have "drooped" while still green, before drying and being fired. This manifested a slightly "bent" or "bowed" condition occurring within its length. There were no issues or problems hafting the stone projectiles.

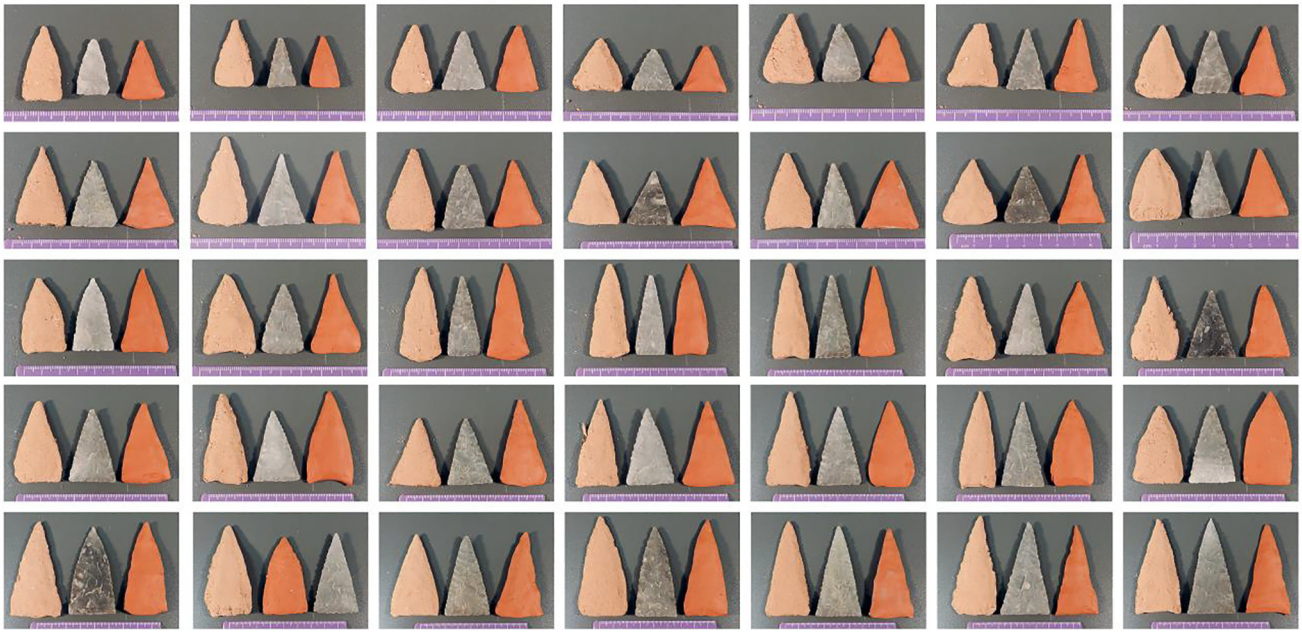

Fig. 1. Clay and stone triangular point data sets (n = 35 for each set) used for the experiments: low-fired ceramic (left), stone (middle), high-fired ceramic (right) in each set.

Fig. 2. Hafted point specimens. Each point (n = 105) was hafted in an identical manner.

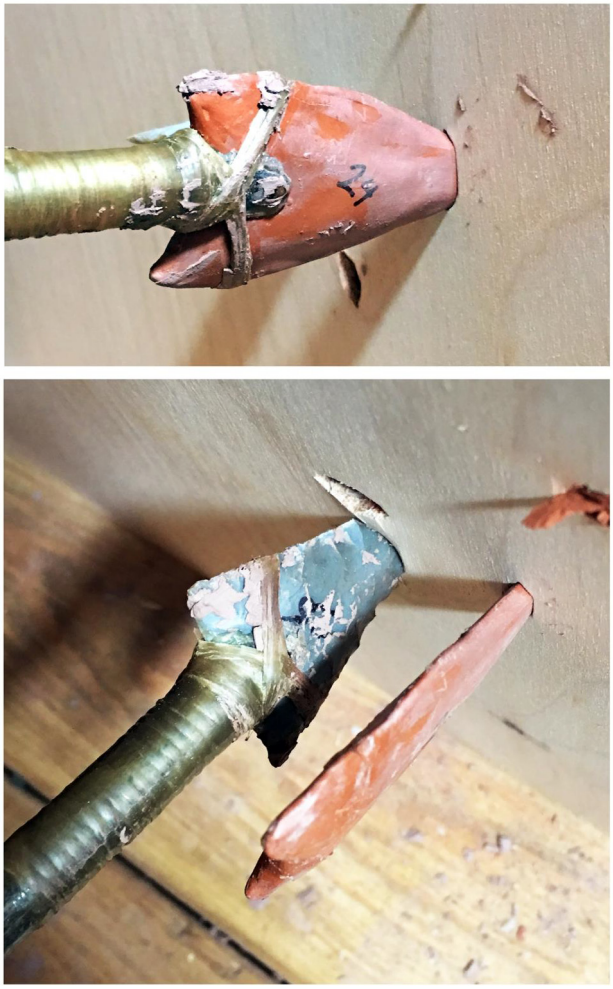

Fig. 3. High fired ceramic and stone arrowheads that penetrated the birch wood target.

2.4. Experiments

Our experiment here followed closely the procedures described in Werner et al. (2019), Key et al. (2018), Bebber and Eren (2018), and Lowe et al. (2019), and the stone points used here were also used in the recent analysis by Mika et al. (2020). The hafted specimens were shot in the Kent State University Experimental Archaeology Laboratory, a

controlled indoor setting. We used a compound bow (PSE Microburner Model, 29 lbs. draw weight) mounted on a bow-tuning machine (the Spot-Hogg Hooter Shooter).

A stationary target was used, 2.75 m from the bow. The projectiles were fired at a three-foot by three-foot piece of birch wood fastened against the target, or clay blocks. To measure projectile velocity, a Gamma Master Model Shooting Chrony Chronograph was used (Werner et al., 2019). Data on velocity readings throughout the experiment can be found in the Supplementary online materials.

With respect to target penetrability (i.e., point penetration depth), each arrowhead was shot into a clay target once (Key et al., 2018; see Mika et al. 2020). Penetration was measured by marking on the shaft with a pen the location at which the shaft was first exposed and not embedded in the clay target; a tape measure was used to measure from the pen mark on the shaft to the tip of the point (Werner et al., 2019). With respect to impact durability, each arrowhead was shot into a birch wood board once (Fig. 3). We assessed durability in two ways (Lowe et al., 2019). First, we assessed the frequency of breakage in terms of two simple categories: unbroken and broken. Second, we compared the amount of point lost due to breakage between the stone points and the high fired ceramic points. All raw data for calculating the results are available in the Supplementary online materials.

3. Results

Point penetration data were analyzed using SPSS statistical software version 23, Program GLM, which uses Type III sums of squares in factorial designs. Variation in penetration depth was assessed among three raw material groups controlling for any remaining size discrepancies in the original untested projectile points. Homoscedasticity and other assumptions of classical, parametric procedures are sound. The one-way analysis of variance in penetration due to group (main effect), correcting for size (covariate) includes post-hoc Bonferroni tests. The full analysis of covariance shows that the slopes (regressions of penetration depth on size) were similar in all three material groups ($F(2,99) = 1.42$, $p > .20$, the full ANCOVA table, i.e., the one with an interaction term, not shown), and therefore the use of a common regression correction is valid. The appropriately reduced model (see ANCOVA table in the Supplementary online materials) indicates a robust covariate ($F(1,101) = 191.2$, $P < .001$) as well as a significant (covariate-adjusted) difference between at least two groups ($F(2,101) = 3.71$, $p < .03$). Post-hoc Bonferroni comparisons using the estimated adjusted mean penetrations by Group reveals where these difference(s) probably are. That is, shafts tipped with the poorer quality, low-fired clay points penetrated significantly less than those with stone points ($t = 2.60$, $p < .05$), low-fired clay vs. high-fired clay only approached significance ($t = 2.01$, $p < .15$), and the difference in penetration between stone points and high-fired clay points was negligible ($t = 0.62$, $p > .90$). This last inference represents our main conclusion regarding point penetration ability (Fig. 4).

The arrowhead durability data were analyzed in two stages: the first was based on frequency of breakage; the second, on the percentage of point length lost upon breakage. All but one low-fired ceramic point broke catastrophically upon impact, while only 25% of the other types of points failed. Since low-fired clay clearly demonstrates its lack of any durability as a projectile point, the analysis of breakage frequencies of the remaining two types did not include low-fired clay. Accordingly, a single-degree-of freedom contingency table was used to compare the frequencies of breakage between the high-fired ceramic points and chert points. The difference between these points was significant ($\chi^2 = 5.71$, $p = .017$). In fact, a risk-ratio analysis reveals that high-fired clay points broke 3.67 times as often as stone points. The amount of breakage per point—that is, the continuous variable, percentage point tip lost—between the broken high-fired ceramic points and the broken chert points was compared using the normal-theory procedure. The results show that when there was a break the stone points lost a bit less tip than did the high-fired ceramic points (23.1% vs. 20.0%), however, the results were not significant ($t = 1.39$, $p > .15$), and the effect size is small (Cohen's $d = 0.38$) (Fig. 5).

4. Conclusion

To our knowledge, ceramic arrowhead technology has not been found in the global archaeological record. In some ways, this should not be surprising: Schiffer (2010) notes that the vast majority of inventions, as one-of-a-kind items selected against, are apt to leave only subtle archaeological traces. Our experimental results, however, explain for the first time why the invention of fired clay arrowheads would have been selected against. Both "best-case" scenario and "worst-case" scenario fired clay arrowheads showed significant deficiencies in function relative to those knapped from stone.

The data show that firing temperature is the key factor affecting the overall performance of the clay projectiles. The points made from low-fired glacial clay demonstrate significantly worse performance characteristics to both the points made from high-fired clay and those made of stone. These data signal that low firing temperatures were likely the limiting factors which prevented the development of ceramic projectile points, at least during the early stages of ceramic evolution. Prior to the development of enclosed kiln technology, ceramics would have been fired in an open-air bonfire setting to an average temperature of 762 °C (Gosselain, 1992; Smith, 2001). In such firing conditions, it is almost impossible to reach the temperatures needed for complete maturation of the clay minerals (> 1050 °C) therefore, the resulting ceramic is much more friable than it would have been if fired in a kiln, which explains the poor performance of the low-fired clay points.

In contrast, at the temperature used in this study for the high-fired clay points, 1063 °C, the clay would have reached maturity and been partially vitrified. A mature ceramic is very hard and almost glasslike, thus resulting in a performance similar to stone. Given that our results show no significant difference in penetration depth between high-fired clay points and stone points, suggesting that it was quite possible to make a functionally equivalent ceramic point, at least in terms of penetration depth, there must have been some other factor preventing the evolution of ceramic projectiles as high temperature pottery kilns evolved in the late Neolithic (Hansen Streily, 2000; Tite and Maniatis, 1975). This is likely due to the chronological proximity between the invention of high-fire kiln technology and advent of metals during the Chalcolithic hampered the "window of invention" for the experimentation and development of high-fired ceramic arrowheads as people increasingly focused their efforts on the production of metal tools (Roberts and Thornton, 2014; Tylecote, 1992). Indeed, at the onset of the 8th millennium BP, when potters were innovating new types of kilns to achieve increased temperatures, contemporary metallurgists were developing processes to melt and smelt copper (Craddock, 2000). Successful melting and casting of projectiles would have essentially filled the niche where ceramic projectiles could have theoretically evolved.

While our results demonstrate that specific functional constraints related to penetration and durability, likely played a role in the selection against ceramic arrowhead technology, perhaps a predominate one, it is plausible that other functional or cultural factors also contributed. For example, ceramic arrowheads may not be as sharp as their stone counterparts, and hence internal damage to prey or enemies via cutting and slicing would likely be absent. Thus, while arrowhead breakage upon impact, analogous to a modern fragmentation bullet and a factor in which both sets of fired-clay points excelled, is sometimes thought to be beneficial to killing (Engelbrecht, 2015; Wilkins et al., 2012), this is because of massive hemorrhaging. Such hemorrhaging upon arrowhead fragmentation is less likely to occur in absence of sharp arrowhead edges, although this could have been aided by serrating the ceramic points.

Additionally, it has been demonstrated that other raw materials,

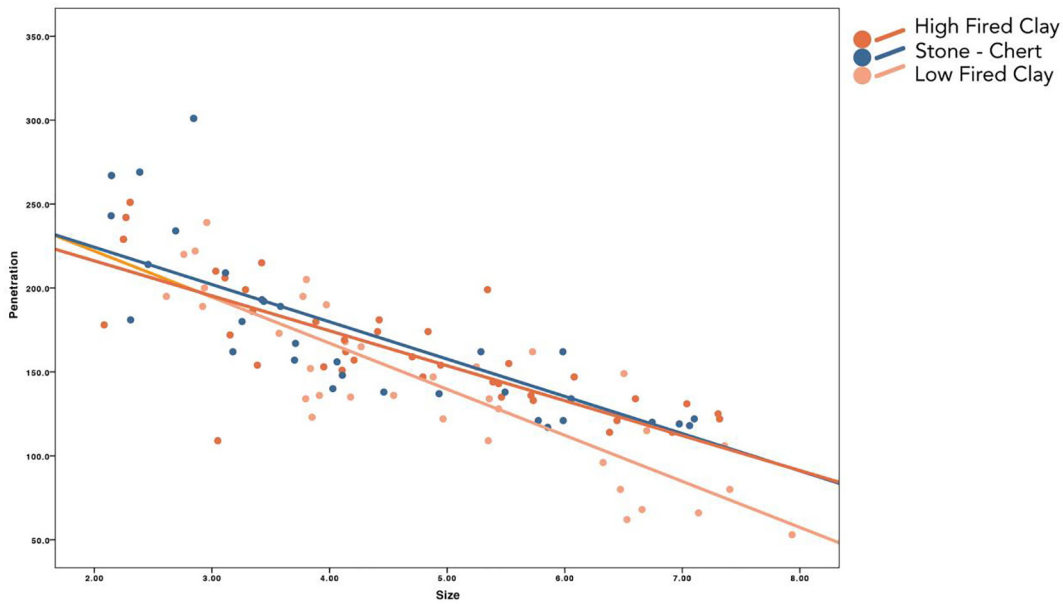

Fig. 4. The one-way analysis of variance in penetration due to *Group* (main effect), correcting for *Size* (covariate) includes post-hoc Bonferroni tests. Post hoc testing shows no significant difference between the high fired clay and stone points ($t = 0.62$, $p > .90$). However, the low fired clay penetrated significantly less than stone points ($t = 2.60$, $p < .05$).

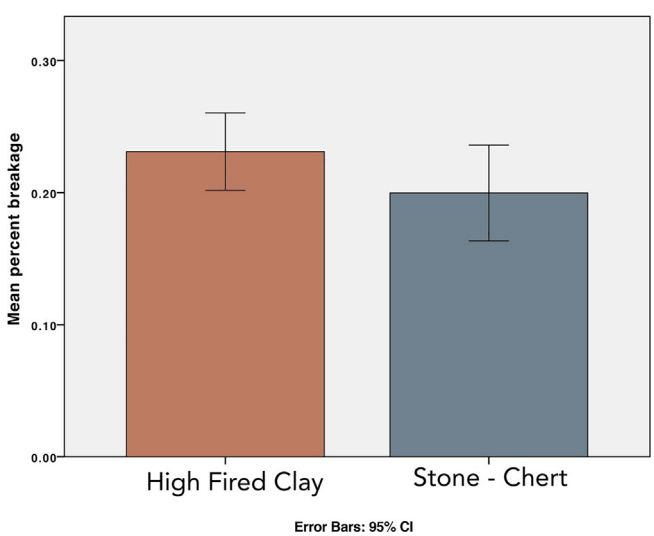

Fig. 5. Our results show that the stone points lost less tip than did the high-fired ceramic points (23.1% vs. 20.0%), however, the results were not significant ($t = 1.39$, $p > .15$).

such as wood or antler (Stodiek, 2000; Waguespack et al., 2009), function equally as well as stone in many instances, but are not widely used prehistorically or ethnographically. This suggests the influence of other non-utilitarian factors, possibly linked to social signaling, perceived lethality, or simply cultural inertia, may have also been responsible for the non-invention of the ceramic arrowhead.

CRediT authorship contribution statement

Michelle R. Bebber: Conceptualization, Formal analysis, Investigation, Methodology, Project administration, Resources, Supervision, Writing - original draft, Writing - review & editing. **Michael Wilson:** Investigation, Methodology, Resources, Writing - original draft, Writing - review & editing. **Andrew Kramer:** Methodology, Resources, Writing - original draft, Writing - review & editing. **Richard S. Meindl:** Formal analysis, Investigation, Methodology, Supervision, Writing - original draft, Writing - review & editing. **Briggs Buchanan:** Formal analysis, Investigation, Methodology, Supervision, Writing - original draft, Writing - review & editing. **Metin I. Eren:** Conceptualization, Formal analysis, Investigation, Methodology, Project administration, Resources, Supervision, Writing - original draft, Writing - review & editing.

Acknowledgements

Funding: The College of Arts and Sciences and the Mark F. Seeman Fund at Kent State University. Author contributions: Conceptualization: MRB, MIE; Formal analysis: MRB, MIE, RM, BB; Investigation: MRB, MIE, MW, AK; Methodology: MRB, MIE, MW, AK; Writing – original draft: MRB, MIE, MW, AK, MR, BB; Writing – review & editing: MRB, MIE, MW, AK, MR, BB. Competing interests: Authors declare no competing interests. Data and materials availability: All data is available in the Supplementary materials.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jasrep.2020.102283.

References

Alden, J.R., 1988. Ceramic ring scrapers: an Uruk period pottery production tool. Paléorient 143–150.
Bebber, M.R., 2017. Tempered Strength: a controlled experiment assessing opportunity costs of adding temper to clay. J. Archaeol. Sci. 86, 1–13.
Bebber, M.R., Eren, M.I., 2018. Toward a functional understanding of the North American Old Copper Culture "technomic devolution". J. Archaeol. Sci. 98, 34–44.
Clare, L., Rohling, E.J., Weninger, B., Hilpert, J., 2008. Warfare in Late Neolithic\Early Chalcolithic Pisidia, southwestern Turkey. Climate induced social unrest in the late 7th millennium calBC. Documenta Praehistorica 35, 65–92.
Cohen, D.J., Bar-Yosef, O., Wu, X., Patania, I., Goldberg, P., 2017. The emergence of pottery in China: recent dating of two early pottery cave sites in South China. Quat. Int. 441, 36–48.
Craddock, P.T., 2000. From hearth to furnace: evidences for the earliest metal smelting technologies in the eastern Mediterranean. Paléorient 151–165.
Delougaz, P., Kantor, H. J., 1996. Chogha Mish (Vol. 1). Oriental Institute of the University of Chicago.
Engelbrecht, W., 2015. Interpreting broken arrow points. Am. Antiq. 80 (4), 760–766.
Farbstein, R., Radić, D., Brajković, D., Miracle, P.T., 2012. First Epigravettian Ceramic Figurines from Europe (Vela Spila, Croatia). PLoS One 7 (7), e41437.

Forouzan, F., Glover, J.B., Williams, F., Deocampo, D., 2012. Portable XRF analysis of zoomorphic figurines, "tokens", and sling bullets from Chogha Gavaneh, Iran. J. Archaeol. Sci. 39 (12), 3534–3541.
Gosselain, O.P., 1992. Bonfire of the enquiries. Pottery firing temperatures in archaeology: what for?. J. Archaeol. Sci. 19, 243–259.
Hansen Streily, A., 2000. Early pottery kilns in the Middle East. Paléorient 69–81.
Henrickson, R.C., 1992. Analysis of use wear on ceramic potter's tools. MRS Online Proceedings Library Archive, 267. Cambridge University Press, Cambridge.
Key, A., Young, J., Fisch, M.R., Chaney, M.E., Kramer, A., Eren, M.I., 2018. Comparing the use of meat and clay during cutting and projectile research. Eng. Fract. Mech. 192, 163–175.
Kirkbride, D., 1982. In Fifty Years of Mesopotamian Discovery, British School of Archaeology in Iraq.
Korfmann, M., 1973. The sling as a weapon. Sci. Am. 229 (4), 34–46.
Kubíková, B., 2013. Re-assessment of Objects Referred to as Sling Missiles in the Prehistoric Archaeology of the Near East (Doctoral dissertation, Masarykova univerzita, Filozofická fakulta).
Lombard, M., Phillipson, L., 2010. Indications of bow and stone-tipped arrow use 64 000 years ago in KwaZulu-Natal, South Africa. Antiquity 84 (325), 635–648.
Lowe, Corey, Kramer, Andrew, Wilson, Michael, Meindl, Richard, Spurlock, Linda, Eren, Metin I., 2019. An experimental assessment of ground, percussion-flaked, and pressure-flaked projectile point impact durability: implications for archaeological method and theory. J. Archaeolog. Sci.: Rep. 24, 677–682.
Lycett, S.J., Eren, M.I., 2018. Built-in misdirection: on the difficulties of learning to knap. Lithic Technol. 1–14.
Lyman, R.L., VanPool, T.L., O'Brien, M.J., 2009. The diversity of North American projectile-point types, before and after the bow and arrow. J. Anthropol. Archaeol. 28 (1), 1–13.
Matthews, R.J., 1996. Excavations at Tell Brak. Iraq 58, 65–77.
McGhee, G.R., 1999. Theoretical morphology: the concept and its applications. Columbia University Press.
McMahon, A., Sołtysiak, A., Weber, J., 2011. Late Chalcolithic mass graves at Tell Brak, Syria, and violent conflict during the growth of early city-states. J. Field Archaeol. 36 (3), 201–220.
Nechitailo, N.V., 2008. Advanced high-speed ceramic projectiles against hard targets. In Electromagnetic Launch Technology, 2008 14th Symposium on (pp. 1-6). IEEE.
Nicholson, P., 2010. Kilns and firing structures. UCLA Encyclopedia of Egyptology UEE, Los Angeles.
Rice, R., 2015. Pottery Analysis. The University of Chicago Press, 2nd Ed.
Roberts, B.W., Thornton, C.P. (Eds.), 2014. Archaeometallurgy in Global Perspective: Methods and Syntheses. Springer Science & Business Media.
Mika, Anna, Flood, Kat, Norris, James, Wilson, Michael, Key, Alastair, Buchanan, Briggs, Redmond, Brian, Pargeter, Justin, Bebber, Michelle, Eren, Metin, 2020. Miniaturization optimized weapon killing power during the social stress of the late pre-contact North America. PLoS ONE 15 (3), e0230348. https://doi.org/10.1371/journal.pone.0230348.
Runnels, C.N., Payne, C., Rifkind, N.V., White, C., Wolff, N.P., LeBlanc, S.A., 2009. Warfare in Neolithic Thessaly: a case study. Hesperia 165–194.
Schiffer, M.B., 2010. Can archaeologists study processes of invention? In: O'Brien, M., Shennan, S., (eds.) Innovation in Cultural Systems: Contributions from Evolutionary Anthropology, pp. 235-249. MIT Press, Cambridge.
Shamanaev, A.V., 2002. Reused pottery fragments as a focus of functional analysis: Life after death: an example from Uppåkra. Acta Archaeol. Lundensia (36), 143–148.
Smith, A.L., 2001. Bonfire II: the return of pottery firing temperatures. J. Archaeol. Sci. 28, 991–1003.
Stanislawski, M.B., 1969. What good is a broken pot? An experiment in Hopi-Tewa ethnoarchaeology. Southwestern Lore 35 (1), 11–18.
Stein, G.J., 2012. The development of indigenous social complexity in Late Chalcolithic Upper Mesopotamia in the 5th–4th millennia BC—an initial assessment. Origini 34, 125–151.
Stodiek, U., 2000. Preliminary results of an experimental investigation of Magdalenian antler points. Anthropol. Prehistoire 111, 70–78.
Sudo, H., 2003. The Chalcolithic small finds from Tell Kosak Shamali: various aspects of village activity. In: Tell Kosak Shamali Vol. 2: The Chalcolithic Technology and Subsistence, The University Museum, University of Tokyo and Oxbow Books.
Sudo, H., 2010. In Studies in Ancient Oriental Civilization (The Oriental Institute of The University of Chicago, 2010).
Tylecote, R.F., 1992. A History of Metallurgy. London: Institute of Materials.
Tite, M., Maniatis, Y., 1975. Examination of ancient pottery using the scanning electron microscope. Nature 257 (5522), 122–123.
Van Gijn, A., Hofman, C.L., 2008. Were they used as tools? An exploratory functional study of abraded potsherds from two pre-colonial sites on the island of Guadeloupe, northern Lesser Antilles. Carib. J. Sci. 44 (1), 21–35.
Waguespack, N.M., Surovell, T.A., Denoyer, A., Dallow, A., Savage, A., Hyneman, J., Tapster, D., 2009. Making a point: wood-versus stone-tipped projectiles. Antiquity 83 (321), 786–800.
Werner, A., Kramer, A., Reedy, C., Bebber, M.R., Pargeter, J., Eren, M.I., 2019. Experimental assessment of proximal-lateral edge grinding on haft damage using replicated Late Pleistocene (Clovis) stone projectile points. Archaeol. Anthropol. Sci. 11, 5833–5849.
Wilkins, J., Schoville, B.J., Brown, K.S., Chazan, M., 2012. Evidence for early hafted hunting technology. Science 338 (6109), 942–946.
Wu, X., Zhang, C., Goldberg, P., Cohen, D., Pan, Y., Arpin, T., Bar-Yosef, O., 2012. Early pottery at 20,000 years ago in Xianrendong Cave, China. Science 336 (6089), 1696–1700.