



HAL
open science

An Introduction to the Experimental Study of Prehistoric Projectile Points

Jean-Marc Pétillon, Pierre Cattelain

► **To cite this version:**

Jean-Marc Pétillon, Pierre Cattelain. An Introduction to the Experimental Study of Prehistoric Projectile Points. Monica Mărgărit and Adina Boroneanț. *Recreating artefacts and ancient skills: from experiment to interpretation*, Cetatea de scaun, pp.143-162, 2022, 978-606-537-565-9. hal-03764748

HAL Id: hal-03764748

<https://hal.science/hal-03764748>

Submitted on 30 Aug 2022

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

RECREATING ARTEFACTS AND ANCIENT SKILLS FROM EXPERIMENT TO INTERPRETATION



Edited by
Monica Mărgărit and Adina Boroneanț

**RECREATING ARTEFACTS
AND ANCIENT SKILLS:
FROM EXPERIMENT TO INTERPRETATION**

Edited by
Monica Mărgărit and Adina Boroneanț

Cover: Dan Iulian Mărgărit

Descrierea CIP a Bibliotecii Naționale a României

Recreating artefacts and ancient skills : from experiment to

interpretation / ed. by Monica Mărgărit and Adina Boroneanț. –

Târgoviște : Cetatea de scaun, 2022

Conține bibliografie

ISBN 978-606-537-565-9

I. Mărgărit, Monica (ed.)

II. Boroneanț, Adina (ed.)

902

This book was edited with the financial support of the grant offered by the Romanian Ministry of Education and Research, CCCDI - UEFISCDI, project number PN-III-P2-2.1-PED-2019-1279, within PNCDI III.

Editura Cetatea de Scaun, Târgoviște, 2022

ISBN 978-606-537-565-9

editura@cetateadescaun.ro, www.cetateadescaun.ro

Printed in Romania

CONTENTS

Foreword	7
EXPERIMENTAL REPLICATION	
Marie-Cécile Soulier, Sandrine Costamagno, Emilie Claud, Marianne Deschamps - <i>Tracing the past: butchering a bison with Middle Palaeolithic stone tools</i>	13
Wulf Hein - <i>Recreating the Palaeolithic Lion Man statuette from the Swabian Alb. Experimenting with mammoth ivory</i>	33
Grzegorz Osipowicz, Justyna Orłowska, Justyna Kuriga, Alicja Bieniek, Dominik Chlachula, Jeljer Huisman, Hildegard Müller, Tabea Müller, Matteo Orsi, Marijn Rudolphie, Claudio Simoni, Sanne Smit, Dorota Wojtczak - <i>Reconstructing prehistoric boats. A report on two experiments carried out during the first International Camp of Experimental Archaeology, Toruń 2021</i>	43
Ana Ilie - <i>From archaeological finds to understanding vegetal fibre extraction and thread production through experiment. A study case from Eneolithic Romania</i>	63
Ion Torcică - <i>Experimental replication of the antler arrow points from Vitănești Măgurice-tell settlement</i>	79
Marius Gheorghe Barbu, Mihaela Maria Barbu, Ioan Alexandru Bărbat - <i>Eneolithic archers of southeastern Europe through the eyes of experimental archaeology</i>	103
Angie Wickenden - <i>Revealing the technological identity of the Cornish Bronze Age pottery</i>	119
PATHS TO FUNCTIONALITY	
Jean-Marc Pétillon, Pierre Cattelain - <i>An introduction to the experimental study of prehistoric projectile points</i>	143
Monica Mărgărit - <i>Shell gastropods as prehistoric adornments at the Lower Danube: archaeological and experimental data</i>	163
Leïla Hoareau, Sylvie Beyries - <i>Insights into use-wear development on shell beads through macro- and micro-analysis of experimental ornaments</i>	183
Vesna Vučković - <i>Neolithic grinding technology in the Central Balkans and the mechanical properties of the rocks</i>	201
Ekaterina N. Golubeva, Madina Sh. Galimova, Vera N. Bakhmatova - <i>Stone pendants from the Eneolithic burials at the Kama – Volga confluence: use-wear and experiment</i>	221

Recreating artefacts and ancient skills: from experiment to interpretation

Romina Silvestre, Natacha Buc, Daniel Loponte, Alejandro Acosta - <i>Shell artefacts and microwear patterns: experimental and archaeological analysis of shell and lithic tools from the Lower Paraná Basin, Argentina</i>	233
--	-----

FRESH APPROACHES TO EXPERIMENTAL INTERPRETATION

Elsbeth Hayes, Nina Kononenko - <i>Investigating the survival of microscopic animal residues on experimental skin working tools after discard and burial</i>	257
--	-----

Vasile Opreș, Adina Boroneanț, Marta Petruneac, Mihaela Golea, Marin Focșăneanu, Robert Sîrbu, Clive Bonsall - <i>Early Neolithic pottery at Schela Cladovei. A comparative study of archaeological and experimental vessels from the perspective of computed tomography</i>	279
--	-----

Darya A. Derzhavets - <i>Smoke Screening: An experimental approach to understanding the function of Late Iron Age-Archaic "Bucchero Incense Burners" in the Po Valley, Italy</i>	295
--	-----

Yannis Chatzikonstantinou - <i>The use of fire in the manipulation of the deceased through experimental approaches</i>	307
--	-----

LIST OF CONTRIBUTORS

Alejandro Acosta, CONICET, National Institute of Anthropology and Latin American Thought, Argentina, acostaalejandroalberto@gmail.com

Vera N. Bakhmatova, Institute of Archaeology named after A.Kh. Khalikov of the Tatarstan Academy of Sciences, Kazan, lyna-87@yandex.ru

Marius Gheorghe Barbu, Museum of Dacian and Roman Civilisation, Deva, Romania, barbumarius0216@yahoo.com

Mihaela Maria Barbu, Museum of Dacian and Roman Civilisation, Deva, Romania, mishu_maria@yahoo.com

Ioan Alexandru Bărbat, Museum of Dacian and Roman Civilisation, Deva, Romania, ioan_alexandru_barbat@yahoo.com

Sylvie Beyries, Université Côte d'Azur, CNRS, CEPAM, Nice, France, sylvie.beyries@cepam.cnrs.fr

Alicja Bieniek, Institute of Archaeology, Nicolaus Copernicus University, Toruń, Poland, Alicjabieniek98@wp.pl

Clive Bonsall, University of Edinburgh, United Kingdom, Clive.Bonsall@ed.ac.uk

Adina Boroneanț, "Vasile Pârvoan" Institute of Archeology, Romanian Academy, Bucharest, Romania, boro30@gmail.com

Natacha Buc, CONICET, National Institute of Anthropology and Latin American Thought, Argentina, natachabuc@gmail.com

Pierre Cattelain, Cedarc/Musée du Malgré-Tout; Université libre de Bruxelles - CRÉA/Patrimoine; Université de Liège - Service de Préhistoire, Belgique, pierre.cattelain@ulb.be

Yannis Chatzikonstantinou, Department of Archaeology, Aristotle University of Thessaloniki, Greece, itchatzi@hist.auth.gr

Dominik Chlachula, Paleolithic and Paleoethnology Research Center, Institute of Archaeology, Brno, Czech Republic/ Department of Archaeology and Museology, Masaryk University, Brno, Czech Republic, d.chlachula@seznam.cz

Emilie Claud, INRAP, Centre Archéologique de Poitiers, Poitiers, France, emilie.claud@inrap.fr

Sandrine Costamagno, CNRS UMR 5608-TRACES, Université de Toulouse Jean Jaurès, Toulouse, France, costamag@univ-tlse2.fr

Darya A. Derzhavets, Leiden University, The Netherlands, d.a.derzhavets@umail.leidenuniv.nl

Marianne Deschamps, CNRS UMR 5608-TRACES, Université de Toulouse Jean Jaurès, Toulouse, France/ UNIARQ, Faculdade de Letras da Universidade de Lisboa, Lisboa, Portugal, mardesch1690@gmail.com

Marin Focșăneanu, National Research-Development Institute for Physics and Nuclear Engineering "Horia Hulubei", Bucharest, Romania, focsaneanumarin@gmail.com

Madina Sh. Galimova, Institute of Archaeology named after A.Kh. Khalikov of the Tatarstan Academy of Sciences, Kazan, mgalimova@yandex.ru

Mihaela Golea, "Vasile Pârvoan" Institute of Archeology, Romanian Academy, Bucharest, Romania, mihaelas.golea@yahoo.com

Ekaterina N. Golubeva, Institute of Archaeology named after A.Kh. Khalikov of the Tatarstan Academy of Sciences, Kazan, kategol@mail.ru

Elsbeth Hayes, Centre for Archaeological Science, School of Earth, Atmospheric and Life Sciences, University of Wollongong; MicroTrace Archaeology, New South Wales, Australia, ehayes@uow.edu.au

Wulf Hein, Independent researcher, Germany, info@archaeo-technik.de

Recreating artefacts and ancient skills: from experiment to interpretation

Leïla Hoareau, *Université Côte d'Azur, CNRS, CEPAM, Nice, France*, leila.hoareau@cepam.cnrs.fr

Jeljer Huisman, *Groningen Institute of Archaeology, University of Groningen, Groningen, Netherlands*, jeljerhuisman1995@live.nl

Ana Ilie, *Princely Court National Museum Complex from Târgoviște, Târgoviște, Romania*, anailietaralunga@gmail.com

Nina Kononenko, *Geosciences and Archaeology, Australian Museum; University of Sydney, Sydney, Australia*, Nina.Kononenko@Australian.Museum

Justyna Kuriga, *Institute of Archaeology, Nicolaus Copernicus University, Toruń, Poland*, justyna.kuriga@gmail.com

Daniel Loponte, *CONICET, National Institute of Anthropology and Latin American Thought, Argentina*, dashtown@gmail.com

Monica Mărgărit, *Valahia University of Târgoviște, Romania*, monicamargarit@yahoo.com

Hildegard Müller, *University of Basel, Basel, Switzerland*, hildegard_mueller@outlook.com

Tabea Müller, *University of Basel, Basel, Switzerland*, tabea.m@hotmail.com

Vasile Opris, *Bucharest Municipality Museum, Bucharest, Romania*, vasilelieopris@yahoo.com

Justyna Orłowska, *Institute of Archaeology, Nicolaus Copernicus University, Toruń, Poland*, Justyna.orłowska@umk.pl

Matteo Orsi, *Department of Cultural Heritage and Environment, Università degli Studi di Milano, Milano, Italy*, matteo.orsi1@studenti.unimi.it

Grzegorz Osipowicz, *Institute of Archaeology, Nicolaus Copernicus University, Toruń, Poland*, grezegor@umk.pl

Jean-Marc Pétilion, *CNRS, laboratoire TRACES, Toulouse, France*, petillon@univ-tlse2.fr

Marta Petruneac, *National Research-Development Institute for Physics and Nuclear Engineering "Horia Hulubei", Bucharest, Romania*, marta.petruneac@gmail.com

Marijn Rudolphie, *Groningen Institute of Archaeology, University of Groningen, Groningen, Netherlands*, m.e.rudolphie@student.rug.nl

Romina Silvestre, *National Institute of Anthropology and Latin American Thought; Social Sciences and Humanities Faculty, National University of Misiones, Argentina*, romisilvestre@gmail.com

Claudio Simoni, *University of Basel, Basel, Switzerland*, claudio.simoni@unibas.ch

Robert Sîrbu, *National Research-Development Institute for Physics and Nuclear Engineering "Horia Hulubei", Bucharest, Romania*, sirbu.robert@ymail.com

Sanne Smit, *Groningen Institute of Archaeology, University of Groningen, Groningen, Netherlands*, s.smit.12@student.rug.nl

Marie-Cécile Soulier, *CNRS UMR 5608-TRACES, Université de Toulouse Jean Jaurès, Toulouse, France*, marie-cecile.soulier@cnrs.fr

Ion Torcică, *Teleorman County Museum, Alexandria, România*, iontorcica@yahoo.com

Vesna Vučković, *University of Haifa, Zinman Institute of Archaeology, Haifa, Israel*, vesna.p.vuckovic@gmail.com

Angie Wickenden, *Inst. Flameworks Creative Arts Facility, Devon, UK*, wicksend66@yahoo.com

Dorota Wojtczak, *Department of Environmental Sciences, IPAS Integrative Prehistory and Archaeological Science, University of Basel, Basel, Switzerland*, dorota.wojtczak@unibas.ch

FOREWORD

“If we hope to achieve the aim of reconstructing culture history, we must develop means for using archaeological remains as a record of the past and as a source of data for testing propositions which we set forth regarding past events”.
(L. Binford 1968. 11)

Early archaeological experiments focused on replicating ancient structures or artefacts using materials, tools and techniques allegedly used by people in the past. Experiments were employed when conventional methods of archaeology no longer worked, attempting to test, explain and ultimately reconstruct crafting practices, technical facilities, and work methods.

At present, experimental archaeology has long passed its infancy, and much has changed since its 19th century debut (e.g. Evans, 1872). It was during the 1950s that S.A. Semenov (1964) innovated the field of functional analysis, and since then experimental archaeology was recognized as essential to usewear studies and its impact slowly but steadily extended over other archaeological fields of study. The number of publications has increased significantly, triggered by conferences and workgroups on experimental archaeology and use-wear analysis (e.g. Alonso *et al.* (eds.) 2017; Beyries *et al.* (eds.) 2021, as the most recent).

But, comparatively speaking, experimental archaeology plays a rather a marginal role, still, despite its immense potential for reconstructing the past and the strides it has made in asserting and developing itself: if early experimentations were mainly ‘replicative’ focusing on obtaining the exact aspect of specific archaeological artefacts/structures, at present, particular attention is given to the scientific framework of the archaeological experimentation, focusing on the design and control of the experiments for testing specific hypotheses about past activities. At the moment, experimental archaeology and use-wear analysis are combined in order to better understand the multifaceted aspects of an object’s life, among which manufacture and use are usually seen as the most significant.

This volume focuses on the role and means of archaeological experimentation in understanding the processes involved in the design, manufacture and use of past artefacts. We set out looking for contributions that would test existing theoretical hypotheses but also others that bring forth innovative approaches. When asking for contributions, we suggested the five stages of an experimental approach as main-themes: 1. Selection and acquisition of raw materials, identical to those present in the archaeological assemblages. 2. Production of replicas following the technological transformation schemes identified by the direct study of archaeological items. 3. Experimental use as indicated by the publications/ethnographic comparisons or as suggested by the morphology/use-wear evolution of the archaeological items. 4. Microscopical analysis of use-wear patterns. 5. Comparison of experimental data with archaeological data in order to validate the existing hypotheses on their manufacture and use by the human communities. A second aim was for the invited authors to come from various archaeological backgrounds and cover a broad spatial and temporal interval.

Recreating artefacts and ancient skills: from experiment to interpretation

As a result, this volume comprises 17 studies organized in three sections, dictated by the various aspects of experimental archaeology they represent: from the more traditional experimental replication, understanding and interpretation of artefact functionality, and relatively recent (and less trodden) directions in experimental archaeology. It also comes to show that experimental archaeology is as well suited for Palaeolithic studies as it is for the Neo-Eneolithic and the Bronze Age. Although most papers refer geographically to Europe, interesting contributions take us to Argentina and Australia.

The seven papers falling into the section *Experimental replication* present experimental projects dealing with: animal butchering techniques in the Middle Paleolithic (Marie-Cécile Soulier, Sandrine Costamagno, Emilie Claud and Marianne Deschamps); ivory processing during the Aurignacian period (Wulf Hein); reconstruction of prehistoric boats (Grzegorz Osipowicz, Justyna Orłowska, Justyna Kuriga, Alicja Bieniek, Dominik Chlachula, Jeljer Huisman, Hildegard Müller, Tabea Müller, Matteo Orsi, Marijn Rudolphie, Claudio Simoni, Sanne Smit, and Dorota Wojtczak); Eneolithic fibre production (Ana Ilie); manufacture and use of arrowheads during the Eneolithic (Ion Torciță and Marius Gheorghe Barbu, Mihaela Maria Barbu and Ioan Alexandru Bărbat); Bronze Age pottery making (Angie Wickenden).

The following section - *Paths to functionality* - debuts with an overview of the prehistoric projectile points (Jean-Marc Pétilion, Pierre Cattelain), followed by contributions on the use of different types of personal adornments (Monica Mărgărit; Leïla Hoareau, Sylvie Beyries; Ekaterina N. Golubeva, Madina Sh. Galimova and Vera N. Bakhmatova), grinding technology as triggered by rock properties (Vesna Vučković); functionality of shell and lithic tools inferred from microwear traces (Romina Silvestre, Natacha Buc, Daniel Loponte and Alejandro Acosta).

The final section - *Fresh approaches to experimental interpretation* - brings forth four experimental programs that had employed methodologies less frequently undertaken: inferring functionality of skin working tools by the study of microscopic animal residues (Elspeth Hayes, Nina Kononenko); identification of vessel manufacturing techniques using computed tomography (Vasile Opreș, Adina Boroneanț, Marta Petroneac, Mihaela Golea, Marin Focșăneanu, Robert Sîrbu and Clive Bonsall); ascertaining the function of the *bucchero* incense burners (Darya A. Derzhavets) or re-discussing the results of fire use in the manipulation of the dead (Yannis Chatzikonstantinou).

Hopefully, the present collection of works will convince once again of the importance of archaeological experiments and their significant contribution to the understanding of the human life- and deathways of the past. It also makes a convincing plea, we believe, for interdisciplinarity and the use of new techniques and methods pertaining to the physical and chemical sciences, but not only. Last but not least, it shows that there are almost no limits to testing archaeological hypotheses by means of well developed, science-based experiments.

We would like to thank all contributors who answered our call, and with patience and goodwill helped us complete this volume in less than a year. Each paper was submitted to external reviews. Therefore, our gratitude goes to our colleagues who anonymously reviewed the contributions, offering comments and suggestions that improved the overall content of the volume.

The Editors

Recreating artefacts and ancient skills: from experiment to interpretation

References

Alonso, R., Canales, D., Baena, J. (eds.). 2017. *Playing with the time. Experimental archeology and the study of the past*. Servicio de Publicaciones de la Universidad Autónoma de Madrid, Madrid.

Beyries, S., Hamon, C., Maigrot, Y (eds.). 2021. *Beyond use-wear traces. Going from tools to people by means of archaeological wear and residue analyses*. Sidestone Press, Leiden.

Binford, L. R. 1968. Archaeological Perspectives. in Binford, S.R., Binford, L.R. (ed.), *New Perspectives in Archaeology*. Aldine Publishing Company, Chicago 5-32.

Evans, J. 1872. *The Ancient Stone Implements, Weapons and Ornaments of Great Britain*. D. Appleton and Company, New York.

Semenov, S.A. 1964. *Prehistoric Technology. An Experimental Study of the oldest Tools and Artefacts from traces of Manufacture and Wear*. Adams&Dart, Bath.

AN INTRODUCTION TO THE EXPERIMENTAL STUDY OF PREHISTORIC PROJECTILE POINTS

Jean-Marc Pétilion
CNRS, laboratoire TRACES, Toulouse, France
petillon@univ-tlse2.fr

Pierre Cattelain
Cedarc/Musée du Malgré-Tout; Université libre de Bruxelles - CRéA/Patrimoine;
Université de Liège - Service de Préhistoire, Belgique
pierre.cattelain@ulb.be

Abstract: The experimental study of prehistoric projectile points has been an active field of research over the last forty years. This contribution is an introduction to the discipline and presents an overview of its main issues, methods and results. Experimental protocols are routinely designed to address a particular archaeological question. This normally involves the reconstitution of a prehistoric delivery system, which can be done either in “replicative” or “controlled” conditions, both approaches presenting advantages and drawbacks. The main goals of projectile experiments are fourfold: determining whether certain artefacts are projectile weapons based on the identification of diagnostic traces of projectile impact; reconstructing their hafting arrangement, identifying the propulsion system, with a special emphasis on the appearance of the spear-thrower and bow; and assessing the performance of different types of weapon tips in terms of efficiency, solidity and maintenance. Future projectile research should include increased feedback between “replicative” and “controlled” experiments and more frequent meta-analyses, both of which require more standardised data collection and publication.

Keywords: bow, experimental archeology, hafting, hand-thrown projectile, projectile point, spear-thrower, use-wear analysis.

Whether made of stone or bone, sharp or piercing, with or without barbs, projectile armatures have long attracted considerable attention from archaeologists, primarily, of course, prehistorians specializing in hunter-gatherer societies. Palaeolithic and Mesolithic sites have yielded large quantities of objects interpreted as projectile armatures given their shape and size or based on comparisons with ethnographic points (arrows, spears, javelins, harpoons, etc.). From the outset of the European Upper Palaeolithic, projectiles came to form a substantial portion of archaeological

assemblages. The significant spatio-temporal variability of these ubiquitous elements has resulted in multiple hypotheses and interpretations for their use, especially given that their presence on archaeological sites reflects a particular activity – hunting – which is fundamental to the survival of populations that do not rely on agriculture or animal husbandry. This is especially the case for groups who live in cold environments that afford only limited possibilities of gathering. Finally, as all technical objects equally bear a symbolic dimension, projectile points, the

quintessential 'arrowhead' for instance, are among the few prehistoric objects to evoke a particularly powerful response in the contemporary imagination.

For no short amount of time, projectile points were primarily approached in terms of typology, with the aim of classing objects and exploring their potential as chrono-cultural markers. Subsequently, and especially from the 1980s onwards, the development of lithic technology and its bone equivalent made it possible to investigate how these points were made. In tandem with the study of their manufacture, additional questions emerged as to how exactly these objects were used, quickly leading to the development of projectile experiments.

Over the last forty years, reconstructing prehistoric projectiles and the manner in which they were launched (bow, spear-thrower and, of course, by hand) have become active research topics. This trend was first initiated by specialists of the Palaeolithic and Mesolithic, followed progressively by researchers working on the Neolithic, with those working in protohistory and historic periods being less concerned. Particularly developed by Anglo-American researchers at the end of the 1970s and beginning of the 1980s, projectile experiments became more widespread and diversified towards the end of the 1980s and into the 1990s. While slightly neglected at the turn of the 21st century, the ensuing decade would see a dynamic renewal and internationalization of projectile research. There now exist over 160 publications and academic studies focused, at least in part, on experiments concerning the use of prehistoric projectiles. This contribution is an updated and adapted translation of an initial manuscript written in 2015 and published in 2020 (Pétillon and Cattelain 2020). This

introduction to projectile experiments, while incomplete and biased in favour of the Western European Upper Palaeolithic, presents the main avenues of research, associated methodologies and results. Only the analysis of the projectile points themselves is considered, leaving out experimental studies of projectile impacts on bone (such as Morel 1993; Smith *et al.* 2007; Letourneux and Pétillon 2008; Castel 2008; Gaudzinski-Windheuser 2016; Smith *et al.* 2020), use-wear on spear-throwers (Cattelain 1991), or issues touching upon the use of spear-throwers and the bow (i.e. bow and spear-thrower mechanics, techniques of use, effective range, etc.).

Archaeological questions and the development of experimentation

Projectile experiments can be defined as the testing of replica prehistoric armatures in controlled conditions, with results systematically recorded using a pre-defined protocol. These are not, strictly speaking, experiments in prehistoric hunting. First off, if we accept the existence of armed conflicts in prehistory, then projectiles can just as well represent weapons rather than hunting gear. Moreover, hunting involves multiple aspects that are overlooked in projectile experiments; namely, tracking, driving, the use of hides, approaching or even trapping prey, all essential steps which, for the hunter, are equally if not more important than the shot itself (Testart 1984). Prehistoric weaponry should therefore not be conflated with broader issues linked to prehistoric subsistence strategies despite obvious links between the two (Pétillon 2006. 85-86).

Projectile experiments fix more modest objectives designed to respond to one or several issues concerning the interpretations of a series of archaeological

projectile points. Questions at the origin of these experiments can be broadly summarised as follows: were the objects in question used as projectile armatures? If so, how were they fixed to the projectile (hafting arrangement, adhesive or binding type, possible use of a foreshaft)? How well did they perform (efficiency, reliability, etc.)? Finally and with particular importance for the Palaeolithic, were they mounted on hand-thrown projectiles or launched with a spear-thrower or bow?

Experimental projectile tests are likely to bring if not definitive conclusions, at least clues and potential answers to these questions. This necessarily requires an experimental reference collection of impact traces, with the objective of experimental tests being to produce a series of micro- and macroscopic traces on the experimental points that are diagnostic of their use as projectile armatures or typical of a hafting arrangement or a particular delivery method. However, as in any experimental approach, in order to produce reliable interpretations of archaeological material, particular attention must be paid to the development of the experimental protocol.

Reconstructing projectile delivery systems: experimental protocols

Any experiment necessarily begins with the elaboration of a *prehistoric delivery system* comprising the combination of five elements: (1) a *shooter*, (2) *propulsion device* (i.e. an instrument that launches the projectile, such as a spear-thrower or bow, or neither when thrown by hand), (3) *projectile*, in other words, an object capable of being shot over a certain distance resulting in damage to a target, (4) a *firing trajectory* connecting the shooter and the target, and finally (5) a *target*.

Each of these elements is subject to multiple variations: the propulsion device

can, for example, take the form of a spear-thrower (flexible or rigid, male or female), a bow (short or long, straight or reflex), or be completely absent. Moreover, a variation in one element often leads to changes in one or more of the others – a change in propulsion device can, for example, imply modifications in the size and weight of the projectiles as well as the nature of the target. However, in most prehistoric contexts where perishable organic materials other than bone are not conserved, only part of the propulsion system is likely to be recovered: a part of the projectile (stone or osseous point, possible osseous foreshaft), part of the target (skeleton of the prey) and possibly part of the propulsion device (the distal portion of a spear-thrower made of antler, lithic elements interpreted as spear-thrower weights, and more rarely, osseous bow or spear-thrower handles). Direct associations between propulsion devices and projectiles are very rarely encountered outside of burial contexts. Bows, projectile shafts, or even adhesives and ligatures used for hafting have only occasionally been recovered from contexts with exceptional preservation conditions. In Europe, most of these finds come from lake or peatland contexts in Scandinavia, Germany, France or Switzerland, and date to the Mesolithic or Neolithic (e.g., Gramsch 2000; Ramseyer 2000; Junkmanns 2001; Cattelain 2006; Bocquet 2011; Larsson *et al.* 2017). The nature (type of material, wood species, morphometry, fissibility, point of equilibrium, mass, density, straightness, etc.) of the shafts associated with the armatures, although of fundamental importance, therefore remains impossible to discern (Cattelain 1994. 19; Maerky 2021. 281-286).

This being the case, an important aspect of prehistoric projectile systems still

remains practically unknown, and it is of course impossible to test all the theoretically possible variants: during experimentation it is feasible to vary only one or two parameters systematically and under controlled conditions (for example the type of propulsion device or the hafting arrangement), otherwise the results will not be statistically valid and exploitable.

Confronted with this problem, experimenters have adopted solutions that broadly reflect two trends (Iovita *et al.* 2016). The first, sometimes referred to as "in vivo experimentation" or "replicative experimentation," focuses on ensuring that experimental conditions reproduce as accurately as possible how prehistoric weapons were likely used in a given archaeological context. As such, experimental armatures are fashioned from materials identical to those from the studied archaeological assemblage; their size and form encapsulate the variability of the archaeological pieces; the target consist of a whole, freshly slaughtered animal (to best replicate actual hunting conditions) of a species identical to the dominant prey in the sites studied; the delivery system is modelled after known prehistoric examples (e.g., Mesolithic or Neolithic type bows), etc. Parameters undetectable in the archaeological record; for example, shooting distances or shaft dimensions, are compensated for via indirect evidence that at least allow them to be fixed at plausible ranges. Comparative ethnography also provides important contextual information on the use of bows and spear-throwers amongst traditional hunters (e.g. Cattelain 1994, 1997). Propulsion systems used by sub-contemporary hunter-gatherer populations living in highly diverse environments provide important information concerning the range of possibilities and hence more accurate

reconstructions (Cattelain 2000). The body of experimental projectile data accumulated over several decades also represents a considerable amount of experience and reflection. Numerous studies have systematically explored varying one parameter and its knock-on effects for the whole delivery system; for example, the ballistic properties of particular projectiles, problems balancing shafts and the influence of the fletching (for these issues see Knecht 1997a. 13-16; Whittaker 2010; Coppe *et al.* 2019; Maerky 2021). Finally, the contribution of prehistoric archery and spear-throwing competitions held regularly in Western Europe and North America since the 1980s are worth mentioning. Although not conducted under scientifically controlled conditions, these competitions have nevertheless allowed the participants to become expert marksmen, as well as accruing substantial know-how and practical experience concerning hafting techniques and the manufacture of projectiles (e.g. Bellier and Cattelain 1989; Stodiek 1993; Whittaker *et al.* 2017).

The fundamental interest of replicative experiments is to produce reference collections that are succinctly adapted to the archaeological context at hand and optimize the subsequent use of experimental data in the analysis of archaeological material. As we will see below, the most interesting interpretive evidence is often specific to a particular form of projectile point and precise mode of use, meaning that it can only be discerned in the framework of a well-designed experiment.

However, replicative experiments of course have their limits. First, experimental conditions never fully reproduce those of prehistoric hunting. It has equally been noted on multiple occasions that tests using

an animal carcass, even when complete and fresh, does not perfectly simulate a live target, which for both ethical and methodological reasons is unfeasible. Moreover, certain parameters remain difficult to control, such as temperature and humidity, which in extreme conditions, can influence projectile performance. For example, the extreme cold renders lithic and osseous material more brittle (Ellis 1997: 58; Gyria and Khlopachev 2018). Finally and above all, the desire to reproduce “realistic” shooting conditions brings with it substantial variability; each projectile and each shot are unique, which can complicate the interpretation of results and comparisons between experiments.

This latter problem effectively gave rise to the development of second type of experimentation sometimes referred to as “controlled experimentation” that has met considerable and growing success. These experiments aim to control all potential variables as accurately as possible. In the most successfully designed experiments, the protocol succinctly reproduces conditions of a ballistics laboratory – a mechanical delivery system (e.g. calibrated cross-bow, compressed air propulsion system) allowing projectiles to be launched at a fixed velocity, using standardized hafts, identical projectile points or even identical test pieces, or an animal target replaced by a more homogeneous artificial material, often blocks of ballistic gelatin or clay in recent experiments (e.g. Bebbler *et al.* 2020; Mika *et al.* 2020).

The advantages and disadvantages of this type of experimentation echo those of replicative projectile experiments. Again, the overall goal is to isolate each parameter and then vary it according to a precise, quantified scale (e.g. shooting velocity,

impact angle), which theoretically allows observed variations to be recorded and reliably linked to a particular factor. This type of experiment is therefore particularly well adapted to testing specific parameters, for example, the composition of an adhesive or the presence or absence of a binding with “all other conditions held constant” in order to measure the influence of these variations on the overall system (e.g., Gaillard *et al.* 2016). The second advantage of controlled experiments is that, at least in theory, they afford better inter-experiment comparisons. However, the act of ‘fixing’ the number of parameters brings with it an additional risk – creating experimental conditions that diverge considerably from real world situations and hence reference collections whose applicability for interpreting archaeological material is problematic.

As in other fields, this seemingly conflictual situation actually reflects the complementarity between the two types of experimentation. The challenge today is for these two approaches to function reflexively via frequent feedback, in order to produce a mutually validated framework of analysis.

Identifying Projectiles: impact traces

More often than not, the primary motivation for developing an experimental shooting program is to test whether or not a series of bone or stone points found mixed together with thousands of other artefacts in a given archaeological layer were in fact used as arrowheads or spearpoints, a question relevant to even the earliest phases of prehistory. As the scientific literature on the subject is both numerous and riddled with controversy and that the goal of this contribution is

not a synthesis of the dozens of available reference collections, we concentrate on a series of methodological issues.

The first concerns what could be described as 'the illusion of efficiency'. In certain publications reporting the results of projectile experiments, particularly the earliest examples, the fact that the points 'performed very well' (i.e. they were efficient in penetrating or were robust, etc.) was sometimes advanced as an argument for their use as projectile armatures. While of course these conditions are necessary – it is difficult to imagine prehistoric groups manufacturing defective armatures – they are not sufficient evidence of projectiles: numerous bone points and equally large numbers of flint pieces, as long as they are sharp and/or pointed, have a form that is fairly well adapted to a potential use as a projectile armature but were not used as such. Demonstrating that an object 'performs' well as a projectile does not validate such an interpretation in the absence of diagnostic impact traces.

However, from a use-wear perspective, projectile points are a very specific case (Rots and Plisson 2014). Unlike tools used to scrape wood, clean hides, etc., projectile points were not subjected to repeated and prolonged contact with the worked material. The same is true even for points reused for several shots, the contact between the point and the target is too short for the formation of specific use-wear pattern. Moreover, this contact is generated in extremely variable conditions according to the context. The form and hafting arrangement of the point, the form (morphometry), mass and velocity of the projectile, impact angle, contact material (hide, bone, and or flesh as well as plant and mineral materials for errant shots) are all susceptible to influence the formation of

impact traces and hence their substantial variability.

On the other hand, for damage to be considered diagnostic of use as a projectile point, other potential causes must be ruled out. Armatures can potentially be broken prior to use (breakage during shaping, especially for stone points) or after use (trampling or post-depositional damage). The analysis of this type of alteration must also be carried out in order not to be confused with traces of use (Iovita *et al.* 2014). Projectile elements can also serve additional functions (stone points as knives, piercers, etc.). Above all, uses other than as projectiles can produce relatively similar damage to that resulting from an impact, including fractures (e.g; certain fractures on stone tools used in butchery activities, and tongued fractures on bone tools used for percussion or pressure). Consequently, both experience with and a reference collection of the traces produced by these activities is necessary. Certain of these 'additional activities' can also be linked to hunting activities other than projectile use. Several studies have sought to establish whether traces exhibited on hand-held weapons (i.e. thrusting spears) can be distinguished from those on hand-thrown projectiles (i.e. throwing spears; see Clarkson 2016; Iovita *et al.* 2016; Milks *et al.* 2016, 2019; Coppe *et al.* 2019 for recent discussions concerning the appearance of the earliest projectiles, which remains a relatively underdocumented subject).

In order to produce a reliable use-wear analysis, the comparative reference collection needs to be sufficiently large. This is particularly the case for experimental reference collections, where, as a general rule, the number of projectiles fired needs to be on the order of several dozen (in a majority of published experiments,

they range from 10 to 60). Only a reference collection of this magnitude can sufficiently encapsulate the variability and relative frequency of use-induced traces. This is equally the case for the archaeological material to be analysed, where what is essential is the idea of *recurrence*. In other words, the designation of series of typologically identical pieces (e.g. a group of backed points) as projectile points cannot be based uniquely on the presence of a single characteristic piece or a handful of isolated impact traces. It is, however, difficult to fix an exact sample size and despite considerable debate, the degree of variability is such that there is currently no consensus as to what percentage of impact fractures ought be found in an assemblage of projectiles. In this respect, it is necessary to weed out the noise resulting from the complex pre- and post-depositional history of the archaeological assemblage in order to confer meaning to the results. In other words, the debate is far from over.

To conclude this brief review of methodological issues, it should be emphasized that the formation of impact damage is also influenced by the shape and size of the armature; whether or not a specific character is diagnostic of an impact varies therefore according to the type of point considered. For example, the experiments by Fischer and colleagues (1984) using Bromme points, which are fairly large tanged points, demonstrated only secondary removals of at least 6 mm in length to be diagnostic of their use as projectiles, with this threshold reduced to 1 mm for the thinner, transverse arrowheads.

With these reservations in mind, it becomes apparent that devising a catalog of universally valid diagnostic impact fractures for all types of projectiles and

under all experimental conditions is impossible. Accordingly, the acronym DIF (*diagnostic impact fractures*), which is regularly encountered in the scientific literature devoted to prehistoric projectiles, where it is sometimes used rather casually, appears highly misleading and increasingly the subject of criticism (Rots and Plisson 2014; Hutchings 2016; Coppe and Rots 2017). It is, however, possible to outline the broad categories of impact traces that should first be taken into account when investigating projectile use (see Coppe and Rots 2017 for a critical review and relevant references). On stone projectile armatures, impact damage takes the form of fracture that above all initiates from the distal extremity of the piece. Diagnostic impact fractures are frequently described as step terminating bending breaks with specific traits according to the circumstances: very long bending breaks, bending breaks with different terminations (stepped, hinged, burinating), the presence of one or multiple secondary removals, etc. Impact fractures are not, however, limited to the distal extremity and can equally occur on other edges of the piece, especially when hafted laterally, in the form of chipping and scarring (Geneste and Plisson 1990; Gauvrit Roux 2019, etc.). In addition to fractures, microscopic evidence of impact, MLIT or *microscopic linear impact traces*, have also been reported (Rots and Plisson 2014; Sano and Oba 2014, 2015; Gauvrit Roux 2019). All of these types of impact damage, and not simply distal fractures need to be taken into account when exploring the potential use of an object as a projectile tip.

Over the last ten years, Wallner lines have equally been used to identify projectile fractures in prehistoric lithic assemblages. The geometry of these lines on the fracture surface allows a

propagation velocity to be calculated for the fracture wave that distinguishes projectile damage from other tool uses (Hutchings 2011; Sahle *et al.* 2013). This approach requires very fine-grained raw materials such as obsidian (Rots and Plisson 2014; Iovita *et al.* 2016). The reliability of this method for identifying projectile armatures has however been criticized due to the overlap between fracture velocities resulting from manufacturing techniques, particularly soft-hammer percussion, and impact damage (Douze *et al.* 2018).

Impact damage on osseous points has received less attention compared to their stone counterparts (see Pétilion *et al.* 2016 for a review). This evidence primarily consists of distal crushing and mesial or distal fractures of various morphologies (longitudinal splits, saw-tooth fractures and, most frequently, bending or beveled fractures). In archaeological examples, the development of these fractures is highly variable and comparisons with experimental data suggest that the most extreme cases result from missed shots striking a hard obstacle (stone, rock etc.). Currently, there is limited data for tip damage on osseous weapon points compared to that found on tools of similar morphologies (beveled items used as intermediary tools, awls, etc.). Consequently, it is difficult to reliably identify diagnostic fractures linked to their use as projectiles, meaning that the published reference collections report damage that is only *compatible* with such a use. The analysis of microscopic use-wear on osseous projectile points, while currently limited, represents a promising avenue of research.

Identifying hafting arrangements

Beyond the simple identification of projectile armatures, the manner in which

they were fixed to the shaft equally poses questions, particularly in the case of certain lithic elements. In fact, while hafted at the tip of the shaft (equally referred to as axially or distally hafted) might seem obvious for certain forms, such as shouldered or tanged points, the situation is far from clear for others. For backed pieces (Gravette points, for examples), objects with two pointed extremities (such as Azilian bipoints) and of course Upper Palaeolithic bladelets and Mesolithic microliths, a lateral hafting arrangement (on the edges of the shaft) or, in some cases, a apico-lateral arrangement (oblique to the shaft head, with the proximal portion protruding) is equally possible (Plisson 2005; Yaroshevich *et al.* 2010; Chesnaux 2014; Gauvrit Roux 2019). These differences obviously bear important consequences for our conception of prehistoric projectile types.

Projectile experiments can help address these questions. For example, by systematically testing multiple hafting arrangements (e.g. lateral versus apical) and comparing damage produced in each case with that exhibited on archaeological examples, it may be possible to advance a hypothesis about how the latter were arranged. The analysis of the lengths of proximal fragments and fracture orientations on Gravettian micropoints from the site of Rabier suggested that, based on comparisons with experimental fracture data from bow launched points, they were hafted “distally with a ligature” (Soriano 1998). Similarly, Philibert (2002) highlighted differences in the location and form of fractures on Mesolithic microliths depending on whether they were hafted distally as points or laterally as barbs. More recently, experiments by Chesnaux (2014) involving similar projectile elements demonstrated that the proportions of

different types of burin-like or transverse damage in a collection of archaeological microliths can shed light on an apical, lateral or apico-lateral hafting arrangement. Experimental data equally revealed the reconstruction of certain hafting arrangements for shouldered points from Mediterranean Spain not to be functional (Muñoz Ibañez *et al.* 2017) or, conversely, identified strict functional requirements for the profile of the initial bladelet in a hafting arrangement comprising multiple backed bladelets hafted contiguously on an osseous point (Pétillon *et al.* 2011).

In cases where there is little doubt that stone elements armed the point of the weapon, experiments can also provide additional information concerning hafting techniques. Research carried out by the TFPS project (*Technologie Fonctionnelle des Pointes de projectiles Solutréennes*) on Solutrean shouldered points has, for example, shown fractures on archaeological pieces at the level of the stem or several millimetres above the shoulder can only result from a hafting system where the ligature binds the entirety of the stem to the shaft (Plisson and Geneste 1989).

Less experimentation has focused on how osseous weapon elements were hafted, possibly because the form of the base in a majority of point types is already fairly indicative of how they were fixed on the projectile (e.g. simple beveled point fixed to a similar bevel at the extremity of the shaft, a double beveled point inserted in a V-shaped notch, a massive based point fixed in a socket, or a forked-based point embedded in a symmetrical fork at the end of the projectile, Pétillon 2006, Pétillon *et al.* 2011). Oblique or transverse striations frequently present at the base of these points and interpreted as designed to help fix them to the shaft also provide evidence

for the presence of an adhesive and or a ligature and even the extent to which the ligature enveloped the piece. (Allain and Rigaud 1986, 1989). Only Aurignacian split-based bone points have been the subject of a detailed analysis of potential hafting arrangements due to the considerable controversy they have solicited over the decades. Experiments by Knecht (1993, 1997b) revealed that the only solid manner to fix the point to a shaft was a male hafting arrangement where the base is fit into a slot and fixed in place with a ligature with a wedge subsequently inserted into the split via a space left in the ligature.

Identifying propulsion systems: spear-throwers and bows

Considerable ink has been spilt concerning the exact timing of the appearance of the spear-thrower and bow, as these two innovations are generally considered of fundamental importance in the evolution of hunter-gatherer subsistence strategies (e.g. Lombard 2019; Sano *et al.* 2019). This question has been explored for both the European Palaeolithic, the prehistory of North America and, more recently, in the archaeological record of southern Africa. The problem lies in the fact that these two weapon elements are most often manufactured from perishable materials, meaning that direct archaeological evidence is rare and therefore does not necessarily reflect the geographic and chronological distribution of these weapon systems in the past. In terms of unambiguous evidence from the European Palaeolithic, spear-thrower fragments are known with certainty from the beginning of the Middle to the end of the Late Magdalenian, or the period roughly between 19 and 14 cal ka BP (Cattelain 2005), and perhaps earlier, during the

Upper Solutrean (Cattelain 1989), while the earliest direct evidence for the use of a bow (arrow shafts from the Ahrenburgian site of Stellmoor in Germany: Rust 1943) dates to between roughly 11,800 and 11,200 cal BP (Fischer and Tauber 1986). A potentially earlier emergence of bow and arrow technology has, however, been discussed. In the absence of direct evidence, the study of potential projectile points, sometimes involving significantly earlier material (for example Streletskayan points dated to around 36,000 to 38,000; Bradley *et al.* 1995, Cattelain 2006) that are morphometrically very similar to arrow-tips from more recent periods, potentially provides indirect evidence for bow-and-arrow technologies.

Numerous works have set out to develop morphometric criteria based on comparisons with ethnographic material in order to distinguish spearpoints (on average larger, heavier and launched with a spear-thrower) from arrowheads, which are on average smaller, lighter and shot with a bow. The use of such indices remains, however, controversial, notably due to the high degree of overlap between these two categories, with the debate on the subject continuing for several decades with no real consensus in sight (see Clarkson 2016 for a critical review).

Multiple projectile experiments have aimed to determine if it is possible to identify the propulsion mode based on the impact damage on armatures, with the results remaining limited. In fact, the only means of carrying out a comparative use-wear analysis of bow, spear-thrower, and hand-thrown projectiles requires a substantial body of experimental projectile points delivered using these three methods under controlled conditions; however, this is rarely the case. Fischer *et al.* (1984) had previously shown that, amongst the experimental Bromme points used in their

study, the most well-developed fractures were exhibited on hand-thrown spear points rather than arrow-tips. Cattelain and Perpère's (1993) experiments with Gravette points also demonstrated not only that those launched with a spear-thrower more frequently exhibited fractures than those shot with a bow but also that certain fracture morphologies ("tongued" or "stepped") were better represented amongst the spear-thrown examples while the average size of the fractures was greater on those shot with a bow. The studied archaeological assemblage, the Gravette points from Abri Pataud, exhibited intermediate traits between the two experimental reference collections, making it impossible to reliably identify the delivery method.

Equally treating Gravette and micro-Gravette points, Coppe and Rots (2017) suggested that the location of certain fracture types can be influenced by the propulsion method; on arrow points, scars initiated from a previous fracture surface mostly concerned the distal part, while identical scars are found primarily on the mesial-proximal portion of dart points. Experiments carried out by the TFPS research group using Solutrean shouldered points equally demonstrated that certain well-developed bending breaks (transverse bending breaks that broke along the width of the piece) were more frequent on spear-points (Rots and Plisson 2014. 158-159). Finally, in terms of osseous armatures, experiments with Magdalenian forked-based points revealed that proximal breaks, in other words on the fork itself, occurred uniquely when a spear-thrower was used (Pétillon 2006). The fact that these types were equally present in high numbers of forked-based points from the Magdalenian of Isturitz was consistent with the hypothesis of these points arming spears.

A trend is evident amongst all these experiments; spear-thrower launched and perhaps hand-thrown projectiles on average produce more damage to the points than those shot with a bow. This difference is likely connected to the higher kinetic energy of spears which is itself due to the greater mass of these weapons compared to arrows as well as their ballistic properties (i.e. a more sinuous trajectory for the latter). Projectile size also undoubtedly plays a role; wobbling at the moment of impact, a long, thick shaft, as in the case of a spear, behaves like a lever that exerts significant bending stress on the projectile element planted in the target. Additional experimentation is, however, needed to confirm and add greater precision to these general trends.

Similarly, observations of experimental split-based antler points showed that the degree of damage was in part due to the force transferred to the projectiles, which is itself determined by the bow force of the calibrated crossbow (Doyon and Katz-Knecht 2014). Other experiments with lithic projectile points under controlled conditions demonstrated that an increase in projectile velocity, and hence the kinetic energy, results in larger impact fractures (Iovita *et al.* 2014, Sano and Oba 2014, 2015; Sano *et al.* 2016). On the other hand, Coppe and colleagues (2019) have shown that the kinetic energy evident in these experiments failed to accurately replicate those they were designed to simulate (e.g. hand-thrown, bow, spear-thrower), limiting the relevance of these results for the interpretation of archaeological material.

Moreover, the example of the Gravette points from Abri Pataud described above once again reveals how the application of experimental results to archaeological material is often complicated and rarely results in clear-cut conclusions. The

complex formational history of archaeological assemblages, including the mixture of pieces broken during manufacture, abandoned after use, or broken by trampling, produces a more nuanced vision of use-wear evidence than the comparatively simple one produced under experimental conditions.

Projectile performance: efficiency, reliability, and management

Projectile experiments have also produced a wealth of information concerning the performance of different armature types, including their penetrative capacity (generally estimated as the penetration depth in the target body) or durability (resistance to impact, potential for repairing damaged elements).

Projectile experiments notably confirmed an idea previously suggested by comparison to ethnographic data (Ellis 1997); when it comes to osseous or wood versus stone projectile tips, the main advantage of the latter lies in their greater cutting capacity which inflicts more damage on the target. In tests using small-to-medium sized ungulates, arrows and spears armed with stone points whose trajectory is not altered by striking a bone generally penetrate to an average depth of around 20 cm, if not more (Cattelain and Perpère 1993; Stodiek 1993; Shea *et al.* 2002, Wood and Fitzhugh 2018). In comparison, average penetration depths for osseous points tested in the same conditions ranged between 12 and 20 cm (Stodiek 1993; Pétilion 2006; Foletti 2012). Experiments have also shown that fixing bladelets along the edge of antler spear points launched with a spear-thrower practically doubles the average penetration depth (from approximately 15 to 28 cm, Pétilion *et al.* 2011).

This advantage of stone tipped weapons has nevertheless been called into question by a series of recent experiments demonstrating projectiles armed with simple wooded points to perform equally well in terms of penetration depth compared to stone-tipped projectiles (Waguespack *et al.* 2009; Loendorf *et al.* 2015). Additional experiments have however nuanced this evidence, demonstrating that lithic points produce more substantial and larger wounds compared to bone points despite penetrating to equal depths (Wilkins *et al.* 2014; Salem and Churchill 2016). The use of ballistic gel targets requires caution concerning these recent results, and legitimate questions can be posed as to the whether this choice adequately reflects actual hunting conditions, in that ballistic gel does not simulate the resistance of the tegument (e.g. skin and fur), the main obstacle encountered by the projectile (Morel 1993).

While lithic weapon elements afford greater cutting power, they are less resistant to impact. Taking into account the high degree of variability between experiments in terms of point type, hafting and launching mode, as well as the nature of the target, it is reasonable to estimate that between 40 and 80% of apically or apico-laterally hafted lithic armatures fracture on the first impact and are generally unrepairable (Fischer *et al.* 1984; Ellis 1997; Soriano 1998; Shott 2002; Cheshier and Kelly 2006; Loendorf *et al.* 2018). This observation is, however, case sensitive: certain, perhaps larger stone projectiles, such as Levallois points (Shea *et al.* 2001, 2002), may be more resistant to breakage, while Holocene stone points from southern Patagonia also portray significant variations in terms of durability between types (Cardillo *et al.* 2021). Certain

point forms also afford more opportunities for resharpening, thus prolonging their use-lives. This would be the case with Elko and Folsom points whose manufacturing and management sequence has been the subject of multiple experimental analyses by North American prehistorians (e.g. Flenniken and Raymond 1986; Towner and Warburton 1990; Shott 2020). These reservations do not, however, alter the general trend of the greater fragility and hence shorter use-lives of stone projectiles. Experimentally, laterally hafted lithic weapon elements – backed bladelets or microlithic ‘barbs’ – fracture less frequently due to the fact that they are less exposed to violent impacts, although they often dislodge at the moment of impact and are lost in the target (Pétillon *et al.* 2011; Gauvrit Roux 2019). It has been suggested on several occasions that this increased fragility of stone-tipped projectiles, whether in terms of breakage rates or the loss of laterally hafted elements, could be intentional. By dislodging in the body of the target, the stone weapon tip shatters into sharp fragments that spread in the prey’s body causing additional damage. This hypothesis is based on relatively rare ethnographic evidence (Ellis 1997. 51-52) and, as it has never been tested experimentally, remains a matter of speculation.

The picture is quite different for osseous weapon points (Pétillon *et al.* 2016). Most experiments have highlighted their substantial degree of resistance to impact independent of the hafting mode or delivery system. The point remained intact after being fired into more relatively flexible obstacles (sediments), small-sized animals or even parts of larger animals (the softer portions, certain vertebrae, thinner bones such as ribs or the sternum). The ability of osseous points to pierce and break

thin bones such as ribs and occasionally vertebrae without suffering any perceptible macroscopic damage has been reported on multiple occasions. Only impacts with thicker, more rigid obstacles (stone, frozen ground) or with larger bones (scapula, coxal, long bones) of medium-to-large sized ungulates produced more frequent damage. When fractures did result, they occurred most often near the distal extremity and occasioned only limited loss in overall length, which was easily repairable by resharpening. More substantial damage likely to render the point irreparable (e.g. longitudinal splitting, basal fractures) also occurred but was significantly less frequent and often resulted from abnormally violent impacts.

Several experimenters have also reported that this resistance is particularly greater for antler points compared to bone points that tend to break more frequently (Guthrie 1983; Bergman 1987; Knecht 1997b). Although this aspect does, however, require additional systematic testing, it is nevertheless consistent with the mechanical properties of these two bone tissues: the more elastic antler better resists mechanical constraints compared to bone and it is unlikely to be a coincidence that prehistoric groups often preferred it for the manufacture of projectile elements (Albrecht 1977; Currey 1979; MacGregor and Currey 1983). In terms of ivory points, detailed experiments remain rare but available data (some unpublished) does indicate a similarly high degree of resistance to impacts.

Some have argued that this increased durability of osseous points could be particularly advantageous for hunting in open landscapes where the tendency to lose projectiles is diminished compared to closed contexts and where the potential for their re-use is higher. The considerable

time invested in their manufacture compared to their stone counterparts is offset by a longer use-life (Cattelain 1995). In the same respect, in functional terms, composite projectiles from different phases of the Upper Palaeolithic that combine an antler point armed with laterally hafted stone elements (i.e. bladelets) would represent the optimisation of the different raw materials available to prehistoric hunter-gatherers – the highly impact resistant antler and the cutting power of flint (Pétillon *et al.* 2011).

Summary and perspectives

Several decades of research carried out by specialists working in various archaeological contexts have demonstrated the clear interest of an experimental approach to understanding the function of prehistoric projectiles. Despite their complexity and difficulties associated with the execution of experimental protocols designed to handle multiple parameters, combined with what are often difficult to interpret use-wear signatures, research in this discipline continues to grow, motivated by the central role of projectiles in the study of numerous prehistoric societies, principally of course, hunter-gatherers.

In addition to the need for additional case studies, our review of projectile experiments highlighted several important avenues for future research, which are especially important as no general list of ‘diagnostic impact traces’ can substitute for experiments specially-adapted to each archaeological context. First is the need for increased communication and collaboration between controlled and replicative experiments, which are still too often carried out by individual researchers working with separate methodologies as part of distinct projects despite recent

research showing the fruitfulness of integrating and combining the two approaches to resolve the same archaeological question (Chesnaux 2014; Gaillard *et al.* 2016; Wood and Fitzhugh 2018). Second is the development of large scale meta-analyses, which are currently few in number. This shortcoming notably reflects difficulties in directly comparing experiments, a problem that is only resolvable by harmonising elements of research (e.g; fracture terminology, standardisation of what and how data is present in publications: Coppe and Rots 2017). Here we have suggested several potential directions future meta-analyses could take in order to move beyond a simple increase in case studies and uncover genuine transcultural trends based on the rich body of research generated by what is today a long tradition of experimenters.

Acknowledgements: The authors warmly thank Monica Mărgărit and Adina Boroneanț for inviting us to contribute to this volume. We are also grateful to Sylvie Beyries for accepting that a previous version published in the volume she edited (<https://eac.ac/books/9782813003003>) serves as a basis for this contribution. Damien Flas, Brad Gravina, Caroline Renard and Nicolas Zwyns are thanked for their help and advice on lithic points; all errors and omissions of course remain our own. Lastly, we are grateful to Brad Gravina for the English translation of the text, and to the editors and reviewers for improving the manuscript.

References

Albrecht, G. 1977. Testing of materials as used for bone points in the Upper Palaeolithic. In Camps-Fabrer H. (ed.), *Méthodologie appliquée à l'industrie de l'os préhistorique*. CNRS Éditions, Paris: 119–124.

Allain, J., Rigaud, A. 1986. Décor et fonction: quelques exemples tirés du Magdalénien. *L'Anthropologie* 90: 713–738.

Allain, J., Rigaud, A. 1989. Colles et mastics au Magdalénien. In Olive, M., Taborin, Y. (eds.), *Nature et fonction des foyers préhistoriques, colloque de Nemours, 1987*. APRAIF (Musée de Préhistoire d'Ile-de-France, mémoire 2), Nemours: 221–223.

Bebber, M.R., Wilson, M., Kramer, A., Meindl, R.S., Buchanan, B., Eren, M.I. 2020. The non-invention of the ceramic arrowhead in world archaeology. *Journal of Archaeological Science: Reports* 31: 102283.

Bellier, C., Cattelain, P. 1989. Troisième championnat international rhénan de tir au propulseur. *Bulletin de la Société préhistorique française* 86-6 : 166–167.

Bergman, C.A. 1987. Hafting and use of bone and antler points from Ksar Akil, Lebanon. In Stordeur D. (ed.), *La Main et l'outil. Manches et emmanchements préhistoriques, actes du colloque de Lyon, 1984*. CNRS Éditions, Paris: 117–126.

Bocquet, A. 2011. *Les oubliés du Lac de Paladru. Ils dormaient depuis 2000 ans à Charavines en Dauphiné*. Fontaine de Siloé, Paris.

Bradley, B.A., Anikovich, M., Girea, E. 1995. Early Upper Palaeolithic in the Russian Plain: Streletskayan flaked stone artefacts and technology. *Antiquity* 69: 989–998.

Cardillo, M., Charlin, J., Cheme Arriaga, L., Donadei Corada, J.P., Moreno, E., González-José, R., Shott, M.J. 2021. Functional efficiency and life history of Late Holocene lithic points from southern Patagonia: An experimental estimation using survival curves models. *Journal of Archaeological Science: Reports* 38: 103023.

Castel, J.-C. 2008. Identification des impacts de projectiles sur le squelette des grands ongulés. *Annales de Paléontologie* 94: 103–118.

Cattelain, P. 1989. Un crochet de propulseur solutréen de la grotte de Combe-Saunière 1 (Dordogne). *Bulletin de la Société préhistorique française* 86 (7): 213–216.

Cattelain, P. 1991. Les propulseurs : utilisation et traces d'utilisation. In *Archéologie expérimentale, tome 2 - La terre, actes du colloque international « Expérimentation en archéologie : bilan et perspectives »*, Beaune: 74–81.

Cattelain, P. 1994. La chasse au Paléolithique supérieur. Arc ou propulseur, ou les deux ? *Archéo-Situla* 21-24: 5–26.

Cattelain, P. 1995. Armatures de projectiles en pierre ou en matière dure animale : un choix lié à l'environnement ? In Otte, M. (ed.), *Nature et culture, actes du colloque international de Liège, 13-17 décembre 1993*. Service de Préhistoire - Université de Liège (ERAUL, 68), Liège: 181–185.

Cattelain, P. 1997. Hunting during the Upper Paleolithic: bow, spearthrower, or both? In Knecht, H. (ed.), *Projectile technology*. Plenum press, New York: 213–240.

Cattelain, P. 2000. L'apport de la comparaison ethnographique à la connaissance et aux tentatives de reconstitution des propulseurs paléolithiques. In Bellier, C., Cattelain, P., Otte, M. (eds.), *La Chasse dans la Préhistoire, Colloque international de Treignes, octobre 1990*, *Anthropologie et Préhistoire* 111, *Artefacts* 8, ERAUL 51: 60–69.

Cattelain, P. 2005. Propulseurs magdaléniens : marqueurs culturels régionaux ? In Dujardin, V. (ed.), *Industrie osseuse et parures du Solutréen au Magdalénien en Europe*. Société préhistorique française (mémoire 39), Paris: 301–317.

Cattelain, P. 2006. Apparition et évolution de l'arc et des pointes de flèches

dans la Préhistoire européenne (Paléo-, Mésolithique, Néolithique). In Bellintani, P., Cavulli, F. (eds.), *Catene operative dell'arco preistorico: incontro di Archeologia Sperimentale, Fiavè - S. Lorenzo in Banale, 30/31 agosto - 1 settembre 2002*. Provincia autonoma di Trento, Trento: 45–66.

Cattelain, P., Perpère, M. 1993. Tir expérimental de sagaies et de flèches emmanchées de pointes de la Gravette. *Archéo-Situla* 17-20: 5–28.

Cheshier, J., Kelly, R.L. 2006. Projectile point shape and durability: The effect of thickness:length. *American Antiquity* 71: 353–363.

Chesnaux, L. 2014. *Réflexion sur le microlithisme en France au cours du premier Mésolithique 10^e-8^e millénaires avant J.-C. Approches technologique, expérimentale et fonctionnelle*. PhD thesis, Université Paris I Panthéon-Sorbonne, Paris.

Clarkson, C. 2016. Testing archaeological approaches to determining past projectile delivery systems using ethnographic and experimental data. In Iovita, R., Sano, K. (eds.), *Multidisciplinary Approaches to the Study of Stone Age Weaponry*. Springer (Vertebrate Paleobiology and Paleoanthropology), Dordrecht: 189–201.

Coppe, J., Rots, V. 2017. Focus on the target. The importance of a transparent fracture terminology for understanding projectile points and projecting modes. *Journal of Archaeological Science: Reports* 12: 1–15.

Coppe, J., Lepers, C., Clarenne, V., Delaunoy, E., Pirlot, M., Rots V. 2019. Ballistic study tackles kinetic energy values of Palaeolithic weaponry. *Archaeometry* 61(4): 933–956.

Currey, J.D. 1979. Mechanical properties of bone tissues with greatly differing functions. *Journal of Biomechanics* 12: 313–319.

- Douze, K., Delagnes, A., Rots, V., Gravina, B. 2018. A reply to Sahle and Braun's reply to 'The pattern of emergence of a Middle Stone Age tradition at Gademotta and Kulkuletti (Ethiopia) through convergent tool and point technologies' [J. Hum. Evol. 91 (2016) 93–121]. *Journal of Human Evolution* 125: 207–214.
- Doyon, L., Katz-Knecht, H. 2014. The effects of use and resharpening on morphometric variability of Aurignacian antler projectile points. *Mitteilungen der Gesellschaft für Urgeschichte* 23: 83–101.
- Ellis, C.J. 1997. Factors influencing the use of stone projectile tips: An ethnographic perspective. In Knecht, H. (ed.), *Projectile Technology*. Plenum press, New York: 37–74.
- Fischer, A., Tauber, H. 1986. New C-14 datings of Late Palaeolithic cultures from northwestern Europe. *Journal of Danish Archaeology* 5: 7–13.
- Fischer, A., Vemming-Hansen, P., Rasmussen, P. 1984. Macro and micro wear traces on lithic projectile points: experimental results and prehistoric examples. *Journal of Danish archaeology* 3: 19–46.
- Flenniken, J.J., Raymond, A.W. 1986. Morphological projectile point typology: replication experimentation and technological analysis. *American Antiquity* 51(3): 603–614.
- Foletti, G. 2012. *Doubles pointes en matières dures animales et armatures de projectiles à la fin du Néolithique moyen : étude fonctionnelle et tentative d'interprétation à partir du site de Marin-Les Piécettes (NE, Suisse)*. MA thesis, Université de Neuchâtel.
- Gaillard, Y., Chesnaux, L., Girard, M., Burr, A., Darque-Ceretti, E., Felder, E., Mazuy, A., Regert, M. 2016. Assessing hafting adhesive efficiency in the experimental shooting of projectile points: a new device for instrumented and ballistic experiments. *Archaeometry* 58 (3): 465–483.
- Gaudzinski-Windheuser, S. 2016. Hunting lesions in Pleistocene and early Holocene European bone assemblages and their implications for our knowledge on the use and timing of lithic projectile technology. In Iovita, R., Sano, K. (eds.), *Multidisciplinary Approaches to the Study of Stone Age Weaponry*. Springer (Vertebrate Paleobiology and Paleoanthropology), Dordrecht: 77–100.
- Gauvrit Roux E. 2019. *Comportements techniques au Magdalénien moyen ancien. Approche techno-fonctionnelle de l'industrie lithique de deux gisements du Centre Ouest de la France : la Marche (Vienne) et la Garenne (Indre)*. PhD thesis, Université Côte d'Azur.
- Geneste, J.-M., Plisson, H. 1990. Technologie fonctionnelle des pointes à cran solutréennes : l'apport des nouvelles données de la grotte de Combe-Saunière. In Kozłowski, J.K. (ed.), *Feuilles de pierre. Les industries à pointes foliacées du Paléolithique supérieur européen, actes du colloque de Cracovie, 1989*. Service de Préhistoire - Université de Liège, Liège: 293–332.
- Gramsch, B. 2000. Mesolithic bone points: hunting weapons or fishing equipment. In Bellier, C., Cattelain, P. (eds.), *La chasse dans la Préhistoire, actes du colloque international de Treignes, 3-7 octobre 1990*. SRBAP / Université de Liège - Service de Préhistoire / Cedarc, Bruxelles: 109–113.
- Guthrie, R.D. 1983. Osseous projectile points: biological considerations affecting raw material selection and design among Paleolithic and Paleoindian people. In Clutton-Brock, J., Gribson, C. (eds.), *Animals and archaeology, I: hunters and their prey*. BAR International Series 165, Oxford: 273–294.

- Gyria, E., Khlopachev, G.A. 2018. Experimental data on the splitting and knapping of mammoth tusks and reindeer antlers. In Christensen, M., Goutas, N. (eds.), « À coup d'éclats ! » *La fracturation des matières osseuses en Préhistoire : discussion autour d'une modalité d'exploitation en apparence simple et pourtant mal connue*. Société préhistorique française (Séances, 13), Paris: 325–340.
- Hutchings, W.K. 2011. Measuring use-related fracture velocity in lithic armatures to identify spears, javelins, darts, and arrows, *Journal of Archaeological Science* 38: 1737–1746.
- Hutchings, W.K. 2016. When is a point a projectile? Morphology, impact fractures, scientific rigor, and the limits of inference. In Iovita, R., Sano, K. (eds.), *Multidisciplinary Approaches to the Study of Stone Age Weaponry*. Springer (Vertebrate Paleobiology and Paleoanthropology), Dordrecht: 3–12.
- Iovita, R., Schönekeß, H., Gaudzinski-Windheuser, S., Jäger F. 2014. Projectile impact fractures and launching mechanisms: results of a controlled ballistic experiment using replica Levallois points. *Journal of Archaeological Science* 48: 73–83.
- Iovita, R., Schönekeß, H., Gaudzinski-Windheuser, S., Jäger F. 2016. Identifying weapon delivery systems using macrofracture analysis and fracture propagation velocity: a controlled experiment. In Iovita, R., Sano, K. (eds.), *Multidisciplinary Approaches to the Study of Stone Age Weaponry*. Springer (Vertebrate Paleobiology and Paleoanthropology), Dordrecht: 13–27.
- Junkmanns, J. 2001. *Arc et flèche. Fabrication et utilisation au Néolithique*. Musée Schwab, Bienne.
- Knecht, H. 1993. Early Upper Palaeolithic approaches to bone and antler projectile technology. In Peterkin, G.L., Bricker, H.M., Mellars, P. (eds.), *Hunting and animal exploitation in the Later Palaeolithic and Mesolithic of Eurasia*. APAAA (4), Washington, DC: 33–47.
- Knecht, H. 1997a. The history and development of projectile technology research. In Knecht, H. (ed.), *Projectile technology*. Plenum press, New York: 3–35.
- Knecht, H. 1997b. Projectile points of bone, antler and stone: experimental explorations of manufacture and use. In Knecht H. (ed.), *Projectile technology*. Plenum press, New York: 191–212.
- Larsson, L., Sjöström, A., Heron, C. 2017. The Rönneholm arrow: a find of a wooden arrow-tip with microliths in the bog Rönneholms Mosse, central Scania, southern Sweden. *Lund Archaeological Review* 22: 7–20.
- Letourneux, C., Pétilion, J.-M. 2008. Hunting lesions caused by osseous projectile points: experimental results and archaeological implications. *Journal of Archaeological Science* 35(10): 2849–2862.
- Loendorf, C., Oliver, T.J., Tiedens, S., Plumlee, R.S., Woodson, M.K., Simon L. 2015. Flaked-stone projectile point serration: a controlled experimental study of blade margin design. *Journal of Archaeological Science: Reports* 3: 437–443.
- Loendorf, C., Blikre, L., Bryce, W.D., Oliver, T.J., Denoyer, A., Wermers, G. 2018. Raw material impact strength and flaked stone projectile point performance. *Journal of Archaeological Science* 90: 50–61.
- Lombard M. 2019. On the minds of bow hunters. In Overmann, K.A., Coolidge, F.L. (eds.), *Squeezing minds from stones: cognitive archaeology and the evolution of the human mind*. Oxford Scholarship Online.
- MacGregor, A.G., Currey, J.D. 1983. Mechanical properties as conditioning factors in the bone and antler industry of the 3rd to the 13th century AD. *Journal of Archaeological Science* 10: 71–77.

- Maerky, G. 2021. *Tendances et variabilités des systèmes d'emmanchements parmi les chasseurs maritimes subactuels d'Alaska méridional (Aléoute, Alutiik) et de Patagonie australe (Kaweskar, Yaghan) : un aperçu d'après les collections ethnographiques*. Thèse de doctorat Université Paris 1 Panthéon-Sorbonne, Paris.
- Mika, A., Flood, K., Norris, J.D., Wilson, M., Key, A., Buchanan, B., Redmond, B., Pargeter, J., Bebbler, M.R., Eren, M.I. 2020. Miniaturization optimized weapon killing power during the social stress of late precontact North America (AD 600-1600). *PLoS ONE* 15(3): e0230348.
- Milks, A., Champion, S., Cowper, E., Pope, M., Carr, D. 2016. Early spears as thrusting weapons: Isolating force and impact velocities in human performance trials. *Journal of Archaeological Science: Reports* 10: 191-203.
- Milks, A., Parker, D., Pope, M. 2019. External ballistics of Pleistocene hand-thrown spears: experimental performance data and implications for human evolution. *Scientific Reports* 9: 820.
- Morel, P. 1993. Impacts de projectiles sur le gibier: quelques éléments d'une approche expérimentale. In Anderson, P.C., Beyries, S., Otte, M., Plisson, H. (eds.), *Traces et fonction. Les gestes retrouvés, actes du colloque international de Liège, 8-10 décembre 1990*. Service de Préhistoire - Université de Liège (ERAUL, 50), Liège: 55-57.
- Muñoz Ibáñez, F.J., Marín De Espinosa Sánchez, J.A., Márquez Mora, B., Martín Lerma, I., Síntes, Peláez J. 2017. The Solutrean shouldered point with abrupt retouch: hafting and propulsion systems. In Alonso, R., Canales, D., Baena, J. (eds.), *Playing with the time. Experimental archeology and the study of the past*. Servicio de Publicaciones de la Universidad Autonoma de Madrid, Madrid: 47-52.
- Pétillon, J.-M. 2006. *Des Magdaléniens en armes. Technologie des armatures de projectile en bois de Cervidé du Magdalénien supérieur de la grotte d'Isturitz (Pyrénées-Atlantiques)*. CEDARC (Artefacts 10), Treignes.
- Pétillon, J.-M., Cattelain, P. 2020. Le tir expérimental de projectiles préhistoriques : aperçu de trente ans de recherches. In Beyries S. (ed.), *Expérimentation en archéologie de la préhistoire*. Éditions des archives contemporaines (Sciences archéologiques), Paris: 61-77.
- Pétillon, J.-M., Plisson, H., Cattelain, P. 2016. Thirty years of experimental research on the breakage patterns of Stone Age osseous points. Overview, methodological problems and current perspectives. In Iovita, R., Sano, K. (eds.), *Multidisciplinary approaches to the study of Stone Age weaponry*. Springer (Vertebrate Paleobiology and Paleoanthropology Series), Dordrecht: 47-63.
- Pétillon, J.-M., Bignon, O., Bodu, P., Cattelain, P., Debout, G., Langlais, M., Laroulandie, V., Plisson, H., Valentin, B. 2011. Hard core and cutting edge: experimental manufacture and use of Magdalenian composite projectile tips. *Journal of Archaeological Science* 38(6): 1266-1283.
- Philibert, S. 2002. *Les derniers « Sauvages ». Territoires économiques et systèmes techno-fonctionnels mésolithiques*. BAR International Series 1069, Oxford.
- Plisson, H. 2005. Examen tracéologique des pointes aziliennes du Bois-Ragot. In Chollet, A., Dujardin, V. (eds.), *La Grotte du Bois-Ragot à Gouex (Vienne), Magdalénien et Azilien : essais sur les hommes et leur environnement*. Société préhistorique française (mémoire 38): 182-189.
- Plisson, H., Geneste, J.-M. 1989. Analyse technologique des pointes à cran solutréennes du Placard (Charente), du Fourneau du Diable, du Pech de la

Boissière et de Combe-Saunière (Dordogne). *Paléo* 1: 65–105.

Ramseyer, D. 2000. Les armes de chasse néolithiques des stations lacustres et palustres suisses. In Bellier, C., Cattelain, P. (eds.), *La chasse dans la Préhistoire, actes du colloque international de Treignes, 3-7 octobre 1990*. SRBAP / Université de Liège - Service de Préhistoire / Cedararc, Bruxelles: 130–142.

Rots, V., Plisson, H. 2014. Projectiles and the abuse of the use-wear method in a search for impact. *Journal of Archaeological Science* 48: 154–165.

Rust, A. 1943. *Die Alt- und Mittelsteinzeitlichen Funde von Stellmoor*. Karl-Wachholtz Verlag, Neumünster.

Sahle, Y., Hutchings, W.K., Braun, D.R., Sealy, J.C., Morgan, L.E., Negash, A., Atnafu, B. 2013. Earliest stone-tipped projectiles from the Ethiopian Rift date to >279,000 years ago. *PLOS ONE* 10(4): e0126064.

Salem, P.E., Churchill, S.E. 2016. Penetration, tissue damage, and lethality of wood- versus lithic-tipped projectiles. In Iovita, R., Sano, K. (eds.), *Multidisciplinary approaches to the study of Stone Age weaponry*. Springer (Vertebrate Paleobiology and Paleoanthropology Series), Dordrecht: 203–212.

Sano, K., Oba, M. 2014. Projectile experimentation for identifying hunting methods with replicas of Upper Palaeolithic weaponry from Japan. In Marreiros, J., Bicho, N., Gibaja, J.F. (eds.), *International Conference on Use-Wear Analysis. Use-Wear 2012*. Cambridge Scholars Publishing, Cambridge: 466–478.

Sano, K., Oba, M. 2015. Backed point experiments for identifying mechanically-delivered armatures. *Journal of Archaeological Science* 63: 13–23.

Sano, K., Denda, Y., Oba, M. 2016. Experiments in fracture patterns and

impact velocity with replica hunting weapons from Japan. In Iovita, R., Sano, K. (eds.), *Multidisciplinary approaches to the study of Stone Age weaponry*. Springer (Vertebrate Paleobiology and Paleoanthropology Series), Dordrecht: 29–46.

Sano, K., Arrighi, S., Stani, C., Aureli, D., Boschini, F., Fiore, I., Spagnolo, V., Ricci, S., Crezzini, J., Boscato, P., Gala, M., Tagliacozzo, A., Birarda, G., Vaccari, L., Ronchitelli, A., Moroni, A., Benazzi, S. 2019. The earliest evidence for mechanically delivered projectile weapons in Europe. *Nature Ecology and Evolution* 3(10): 1409–1414.

Shea, J.J., Davis, Z.J., Brown, K.S. 2001. Experimental tests of Middle Palaeolithic spear points using a calibrated crossbow. *Journal of Archaeological Science* 28: 807–816.

Shea, J.J., Brown, K.S., Davis, Z.J. 2002. Controlled experiments with Middle Palaeolithic spear points: Levallois points. In Mathieu, J.R. (ed.), *Experimental archaeology: replicating past objects, behaviours, and processes*. BAR International Series 1035, Oxford: 55–72.

Shott, M.J. 2002. Weibull estimation on use life distribution in experimental spear-point data. *Lithic Technology* 27(2): 93–109.

Shott, M.J. 2020. Allometry and resharpening in experimental Folsom-point replicas: analysis using inter-landmark distances. *Journal of Archaeological Method and Theory* 27: 360–380.

Smith, M.J., Brickley, M.B., Leach, S.L. 2007. Experimental evidence for lithic projectile injuries: improving identification of an under-recognised phenomenon. *Journal of archaeological science* 34: 540–553.

Smith, G.M., Noack, E.S., Behrens, N.M., Ruebens, K., Street, M., Iovita, R., Gaudzinski-Windheuser, S. 2020. When lithics hit bones: evaluating the potential of a multifaceted experimental protocol to

Recreating artefacts and ancient skills: from experiment to interpretation

illuminate Middle Palaeolithic weapon technology. *Journal of Paleolithic Archeology* 3: 126–156.

Soriano, S. 1998. Les microgravettes du Périgordien de Rabier à Lanquais (Dordogne). Analyse technologique fonctionnelle. *Gallia Préhistoire* 40: 75–94.

Stodiek, U. 1993. *Zur Technologie der jungpaläolithischen Speerschleuder: eine Studie auf der Basis archäologischer, ethnologischer und experimenteller Erkenntnisse*. Archaeologia Venatoria (Tübinger Monographien zur Urgeschichte 9), Tübingen.

Testart, A. 1984. La classification des méthodes de chasse. *Techniques et culture* 3: 119–128.

Towner, R.H., Warburton, M. 1990. Projectile point rejuvenation: a technological analysis. *Journal of field archaeology* 17(3): 311–321.

Waguespack, N., Surovell, T.A., Denoyer, A., Dallow, A., Savage, A., Hyneman, J., Tapster, D. 2009. Making a point: wood- versus stone-tipped projectiles. *Antiquity* 83: 786–800.

Whittaker, J. 2010. Weapon trials: the atlatl and experiments in hunting technology. In Ferguson, J.R. (ed.),

Designing experimental research in archaeology. University Press of Colorado: 195–224.

Whittaker, J., Pettigrew, D.B., Grohsmeyer, R.J. 2017. Atlatl dart velocity: accurate measurements and implications for Paleoindian and Archaic archaeology. *PaleoAmerica* 3(2): 161–181.

Wilkins, J., Schoville, B.J., Brown, K.S. 2014. An experimental investigation of the functional hypothesis and evolutionary advantage of stone-tipped spears. *PLoS ONE* 9: e104514.

Wood, J., Fitzhugh, B. 2018. Wound ballistics: the prey specific implications of penetrating trauma injuries from osseous, flaked stone, and composite inset microblade projectiles during the Pleistocene/Holocene transition, Alaska U.S.A. *Journal of Archaeological Science* 91: 104–117.

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. *Journal of Archaeological Science* 37: 368–388.