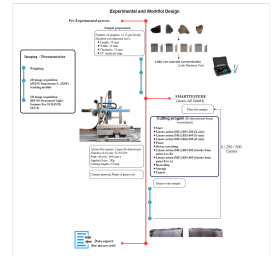




Mar 19, 2025

The Dichotomy of Human Decision-Making: The Impact of Lithic Raw Material Properties on Stone Tool Efficiency.

DOI

<https://dx.doi.org/10.17504/protocols.io.bp2l6djg1vqe/v1>David Nora^{1,2}, Joao Marreiros³, Walter Gneisinger³, Telmo Pereira⁴, Antonella Perdergnana⁵¹Institute of Archaeology of the Hebrew University of Jerusalem, Humendy Lab;²ICArHEB (Interdisciplinary Center for Archaeology and the Evolution of Human Behaviour);³TraCer. MONREPOS, RGZM; ⁴Universidade Autónoma de Lisboa;⁵South Tyrol Archeological Museum, Bozen, Italy. 17 6 Institute of Evolutionary Medicine (IEM) – University of Zurich (UZH), Switzerland. 18 7 Institute for Mummy Studies, Eurac Research, Bozen, Italy.

TraCerMonreposLEIZA



David Nora

hebrew university

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<https://dx.doi.org/10.17504/protocols.io.bp2l6djg1vqe/v1>

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Protocol status: Working

We use this protocol and it's working

Created: March 04, 2025

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Protocol Integer ID: 123772

Keywords: Experimental Archaeology, Controlled Experiments, Lithic Raw Materials, Stone Tool Edge Efficiency, Effectiveness, Durability, Human Decision-Making, stone tool efficiency, including hardness, impact of lithic raw material property, lithic raw material property, different lithic raw material, significant differences in the efficiency, mechanical performance, physical properties of various raw material, distinct raw material, edge efficiency, various raw material, raw material, different types of raw material, efficiency, quartzite, durability, physical property, grain size, edge wear, ratio between effectiveness, tool

Funders Acknowledgements:

Seed Fund'21 of ICArEHB

Grant ID: UIDP/04211/2020

European Research Council - TransCause-Investigating Pleistocene population dynamics in the Southern Caucasus

Grant ID: 948015

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Abstract

This protocol reports a controlled experiment to test the mechanical performance, focusing on the efficiency (ratio between effectiveness and durability) of four distinct raw materials (quartzite, dacite, flint, and obsidian). Our study addresses the null hypothesis: *"Edge efficiency does not vary according to the different lithic raw materials."* Efficiency is assessed by the combination of penetration depth (proxy to measure effectiveness) and edge wear (proxy to measure durability). These two proxies were measured, and the results correlated to the physical properties of various raw materials, including hardness and grain size. Our results show significant differences in the efficiency between the different types of raw materials.

This experiment was performed sequentially in 3 stages, and each sample was recorded at stage 0 (before the experiment), stage 1 (125 cycles), stage 2 (125 cycles), and stage 3 (500 cycles after the experiment was complete).

Guidelines

All the guidelines are present in the following steps.

Materials

 1 Gutasar Block

 1 Dacite Block

 1 Flint Block

 1 Quartzite Block

Protocol materials

 Acetone $\geq 99.5\%$ Carl Roth Catalog #5025.6

 Plurafac LF 901 BTC Europe GmbH, Rheinpromenade 1, D-40789 Monheim Catalog #-

Safety warnings

 No warnings

Samples Preparation

1 Selection and Preparation of Lithic raw materials samples

Selection of Lithic Raw Materials:

 1 Gutanasar Obsidian Block  [40.36904821375954, 44.6891532701293](#)

 1 Dacite Block  [40°12'31.5"N 44°12'00.2"E](#)

 1 Flint Block  [55° 56' 45.07" N, 12° 46' 4.27" E](#)

 1 Quartzite Block  [50.41546454547622, 7.485007315560989](#)

End of step 1.

2 Sample preparation:

The goal of step 2 is to ensure uniformity in morphology and length of the edges, all specimens were saw-cut with a length of 30 mm, a width of 25 mm, a thickness of 10 mm, and a 45° unifacial edge (representative of the active edge, see Conford (1986, pp.34)) by a diamond band saw. Each piece was assigned a unique ID and a bar code.

2.1 Blank preparation:

After block selection, we used a lapidary rock saw to create a parallelepiped morphology of 60 mm (length), 25 mm (width), and 10 mm (thickness).

 3 Gutanasar parallelepiped blank morphology

 3 Dacite parallelepiped blank morphology

 3 Flint parallelepiped blank morphology

 3 Quartzite parallelepiped blank morphology

Note: Add an ID to each blank / Weight each sample.

Equipment

Goliath 450

NAME

Lapidary rock saw

TYPE

Steinschleifmaschinen & Lapidary tools Ltd.

BRAND

-

SKU

https://www.steinschleifmaschinen.at/index.php?main_page=product_info&cPath=1_17&products_id=184

LINK

-

SPECIFICATIONS



2.2 Leeb Reboung Hardness test:

Leeb Hardness Test (LHT). LHT method is built on the dynamic impact principle: An impact body's rebound velocity ($V_{rebound}$) is recorded and reported relative to its downward, or impact velocity (V_{impact}). The impact body rebounds faster from harder surfaces than softer ones. The magnitude of $V_{rebound}$ depends on the elasticity of the surface and any energy loss by plastic deformation. For more please check the following literature:

Citation

A. G. Corkum · Y. Asiri · H. El Naggar · D. Kinakin (2018)
. The Leeb Hardness Test for Rock: An Updated Methodology and UCS Correlation.
Rock Mechanics and Rock Engineering.

[10.1007/s00603-017-1372-2](https://doi.org/10.1007/s00603-017-1372-2)

LINK

Citation

Sasan Ghorbani · Seyed Hadi Hoseinie · Ebrahim Ghasemi · Taghi Sherizadeh · Christina Wanhainen

(2022). A new rock hardness classification system based on portable dynamic testing. Bulletin of Engineering Geology and the Environment.

[10.1007/s10064-022-02690-3](https://doi.org/10.1007/s10064-022-02690-3)

[LINK](#)

The equipment used to measure the rebound hardness

Equipment

Equotip 550

NAME

Portable hardness tester

TYPE

Proceq

BRAND

-

SKU

<https://www.proceq.com/products/list/Category/equotip-portable-hardness-testing/>

[LINK](#)

Leeb C probe

SPECIFICATIONS



- a) Calibration of the LHT device.
 - b) Since the blank samples did not fulfill the industrial requirements for minimum sample size and weight, coupling paste (proceq) was used between the sample and the base (granite base of known hardness).
 - c) Couple the blank (#2.1) with the granite slab and measure. (Repeat the measure procedure 10 times)
- For each blank (#2.1) the instrument Leeb hardness tester device was used vertically (Yaşar & Erdoğan, 2004).
- d) Export to a .csv file for further statistical analysis and a .pdf report (see SOM4) for each sample, including the Leeb instrument reference and all additional information.



General view of the LHT devive with a probe C.

2.3 **Standardization of the blank edge**

Blanks from (#2.1) were clipped to a diamond saw machine to create an edge angle of 45 degrees.

Equipment	
310 CP	NAME
Diamond band saw	TYPE
Exact	BRAND
-	SKU
https://www.exakt.de/en/products/thin-section/industry.html	
	



2.4 After all blanks (#2.1) pass through the step 2.3, they return to the Goliath 450 to standardise the length to 30 mm.

2.5 **Coordinate system by ceramic beads.**

Three ceramic beads were added to the surface of each blank to facilitate comparison between experiment cycles. For more information, please see the following citation.

Citation

Ivan Calandra & Lisa Schunk & Alice Rodriguez & Walter Gneisinger & Antonella Pedernana & Eduardo Paixao & Telmo Pereira & Radu Iovita & Joao Marreiros (2019). Back to the edge: relative coordinate system for use-wear analysis. Archaeological and Anthropological Sciences.

<https://doi.org/10.1007/s12520-019-00801-y>

LINK



General photo of the Obsidian blank with the beads coordinates.

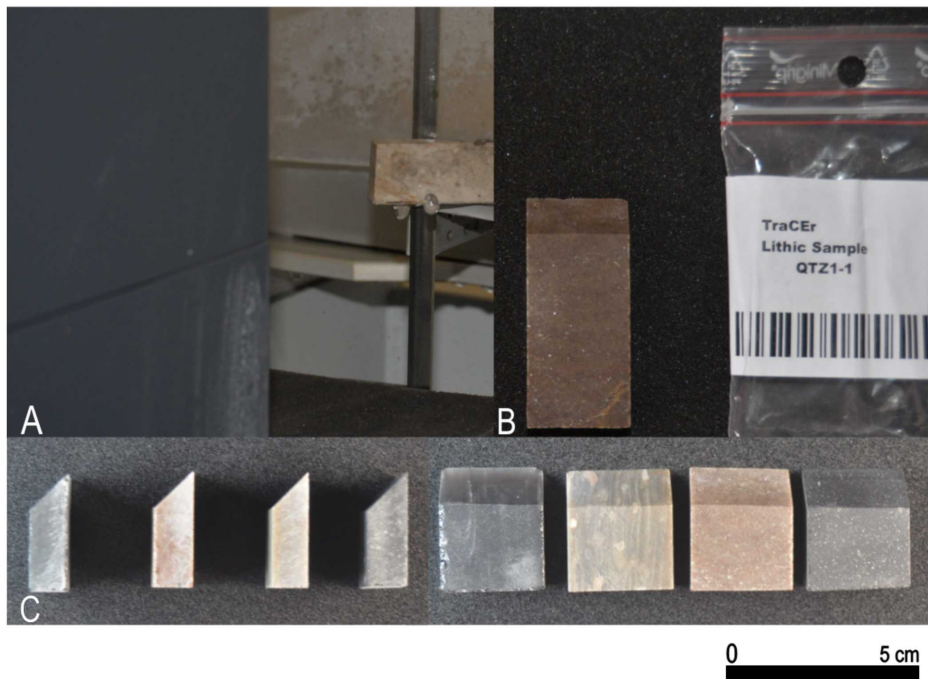
2.6 Goal of the step 2:

3 Gutanasar blank length 30 mm, a width 25 mm, thickness 10 mm, and a 45° edge

3 Dacite blank length of 30 mm, a width of 25 mm, a thickness of 10 mm, and a 45° edge

3 Flint blank length of 30 mm, a width of 25 mm, a thickness of 10 mm, and a 45° edge

3 Quartzite blank length of 30 mm, a width of 25 mm, a thickness of 10 mm, and a 45° edge



Preparation of lithic samples. (A) Standardised cutting of blocks into dimensions (30 mm x 25 mm x 10 mm) with a 45° edge. (B) Processed samples labelled and packed. (C) Array of prepared lithic samples from all raw materials.

End of step 2.

3 **Cleaning**

In this experiment, we applied the standard cleaning procedure of lithic samples practiced on the Tracer lab, Monrepos, LEIZA. (shared with protocols

Protocol

NAME

An experimental approach on dynamic Occlusal Fingerprint Analysis to simulate use-wear development and localisation on stone tools

CREATED BY

Hannah Rausch

Preview



After sample preparation (#2), the saw-cut blank samples are cleaned to remove any residues that accumulated during preparation:

1. Blank samples are rinsed with tap water.
2. Tool samples are individually packed in plastic bags filled with demineralised water and a surfactant:

🧴 100 mL Cleaning solution

🧴 1 Mass / % volume

🧴 Plurafac LF 901 BTC Europe GmbH, Rheinpromenade 1, D-40789
Monheim Catalog #-

3. The bags are suspended in a preheated ultrasonic bath for 5 minutes at 100 KHz.

Equipment

Heated ultrasonic bath

NAME

Sonorex Digitec DT255H

BRAND

62083

SKU



🕒 00:05:00

🌡️ 40 °C

4. Lastly, each blank edge was treated with acetone applied with cotton swabs, and left to dry at room temperature.

🧴 Acetone ≥99.5 % Carl Roth Catalog #5025.6

End of step 3.

4 Contact Material

As a passive sample we used a slab of pine wood (*Pinus sylvestris*) with the following dimensions:

➦ 20 mm Length

↔ 165 mm Width

↔ 20 mm Thickness

Note

Pine wood (*Pinus sylvestris*) plank was obtained from the Bauhaus commercial bricolage centre in Germany. European Pinewood has an average density of 550 kg/m³ and a moisture content of 12 to 15%.

The contact material was used to perform all bi-directional movements.



Pine wood (*Pinus sylvestris*) plank.

Sample documentation

- 5 The documentation protocol was performed the same way for each stage of the experimental design: cleaning of the sample, weighing, 3D scanning, and digital microscope imaging.

Imaging / Documentation



Weighting



**2D image acquisition
(ZEISS Smartzoom 5,
(EDF) stacking module)**



**3D image acquisition
(HP 3D Structured
Light Scanner Pro S3
DAVID SLS-3)**

Documentation protocol

5.1 General Photo

Digital photos of the tool samples and the experiment workflow are taken to acquire general documentation images.



Equipment

D610

NAME

Digital camera

TYPE

Nikon

BRAND

-

SKU

Objective:

SPECIFICATIONS

AF-S NIKKOR 24-85 mm 1:3,5-4,5G ED VR

Automatic focus setting

5.2 2D imaging of the sample's edge

This is a standard procedure in the Tracer Laboratory to ensure data acquisition for future studies, several other projects share the same protocol, such as:

Protocol

NAME

An experimental approach on dynamic Occlusal Fingerprint Analysis to simulate use-wear development and localisation on stone tools

CREATED BY

Hannah Rausch

Preview

Overview images of the edge are acquired for each side (dorsal, ventral) of the tool samples using a digital microscope Smartzoom5. The following steps are followed:

- The sample is calibrated with the coordinate beads using the 1.6x/0.1 objective.

- A 3D image of the edge is acquired with the 1.6x objective using the tile-stitching and z-stack functions.
- Settings: the ringlight brightness is identical for all images and the exposure is adjusted as needed. The blending function is activated to acquire smoother borders between the tiles.
- An EDF image of the edge is acquired and exported as CZI and PNG files.

Equipment

Smartzoom5

NAME

Digital microscope

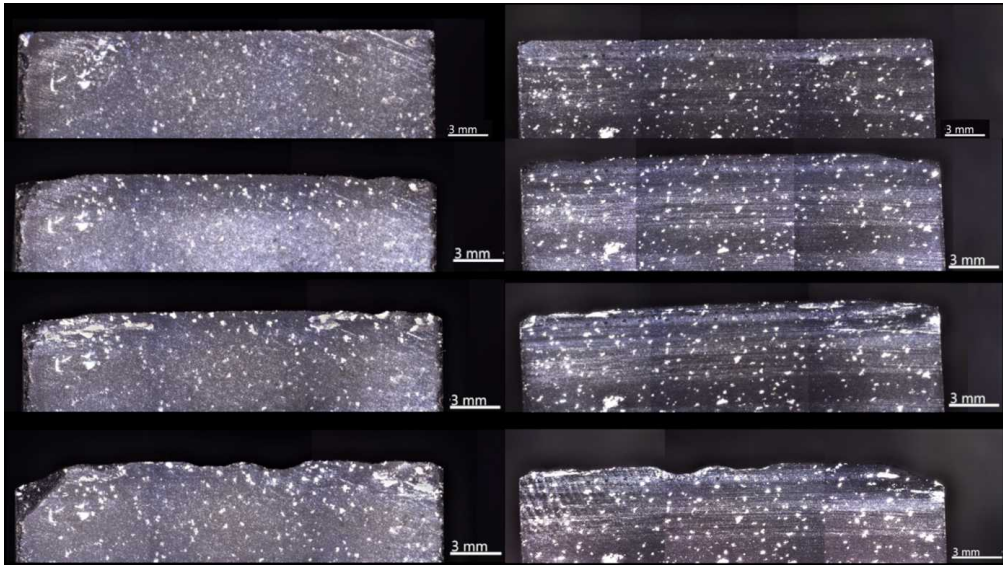
TYPE

Zeiss

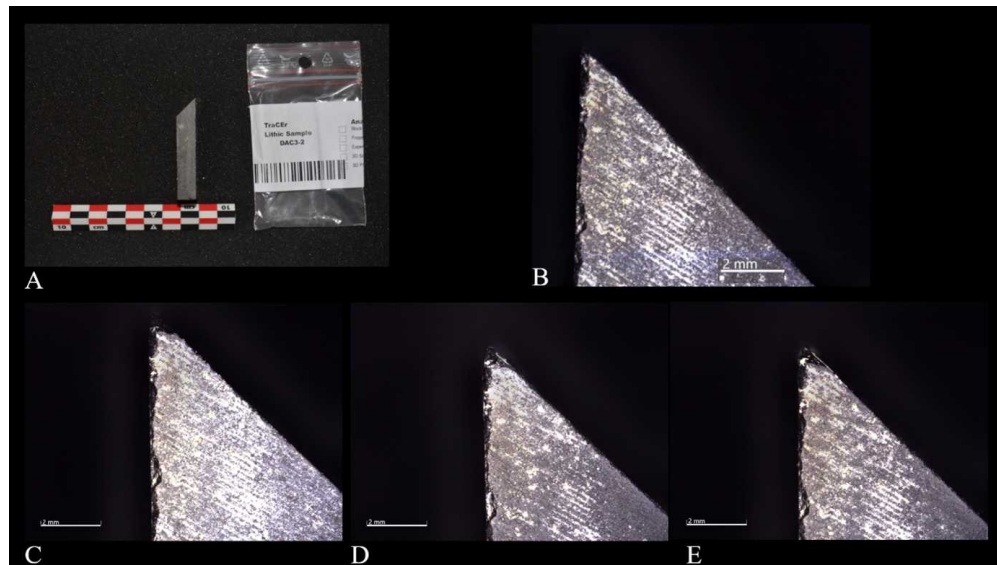
BRAND

<https://www.zeiss.de/mikroskopie/produkte/imaging-> SKU

1.6x objective; EDF-stitching images SPECIFICATIONS



ZEISS Smart zoom DAC3-2_left_back_view_Right_front_view_top_to_bottom_cycle_0_125_250_500



ZEISS Smart zoom DAC3-2_Profile view, A – Sample_ ID; B – cycle 0; C – cycle 125; D - cycle 250; E – cycle 500

5.3 3D Surface morphology documentation

All three-dimensional acquisition was done with the following equipment and followed these steps:

A). Turning on the system

Before use, the 3D structured light scanner must be warmed up one hour in advance.

B). Calibration

The scanner was calibrated with the appropriate calibration plate. The software would do an automatic accuracy check.

C). Placing the sample

Each sample was placed in the middle of the turntable, and all samples were scanned upright.

1. The tool samples are scanned with the automatic measuring function and the turntable, which takes scans while rotating 360°. Depending on the final point cloud, we did 8 to 10 stops in this setting.
2. The scans are merged at the working computer using the DAVID-4-PRO software and exported as STL files.

Equipment

HP 3D Structured Light Scanner Pro S3 DAVID SLS-3

NAME

Structured Light Scanner

TYPE

HP

BRAND

SLS-3

SKU

<https://support.hp.com/us-en/product/details/hp-3d-structured-light-scanner/model/14169439>

LINK

FOV: up to 120 mm / Resolution: up to 0.06 mm

SPECIFICATIONS



Software

DAVID-4-PRO

NAME

HP

DEVELOPER

<https://support.hp.com/us-en/drivers/hp-3d-structured-light-scanner/model/14169439>

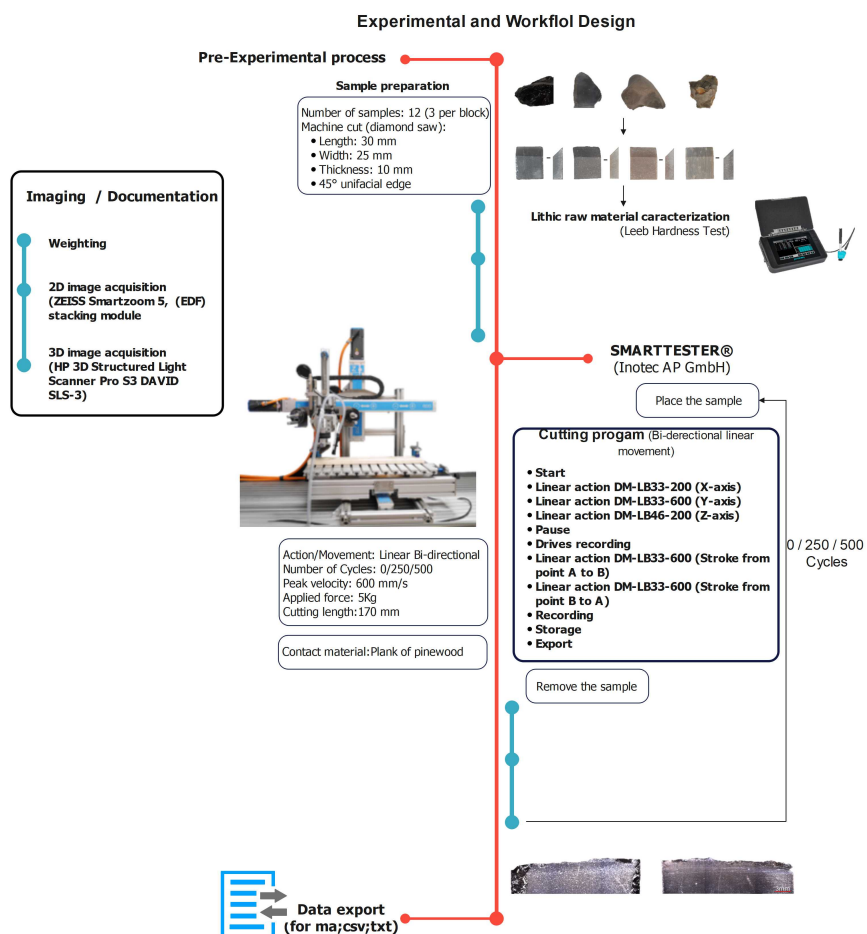
SOURCE LINK

Edge efficiency Experiment

6

General variables settings:

-  3 Gutanasar
-  3 Flint
-  3 Dacite
-  3 Quartzite



Experimental workflow

6.1 Experiment setup



Sample Attachment and Measurement:

1. Attach the samples (plank and lithic) to the machine, ensuring proper alignment.
2. Measure the sample (3 cm).
3. Set a safety zone on the Z-axis (50 cm).
4. Establish the point of contact with the contact material (130 cm).
5. Define the maximum penetration depth (14 cm).

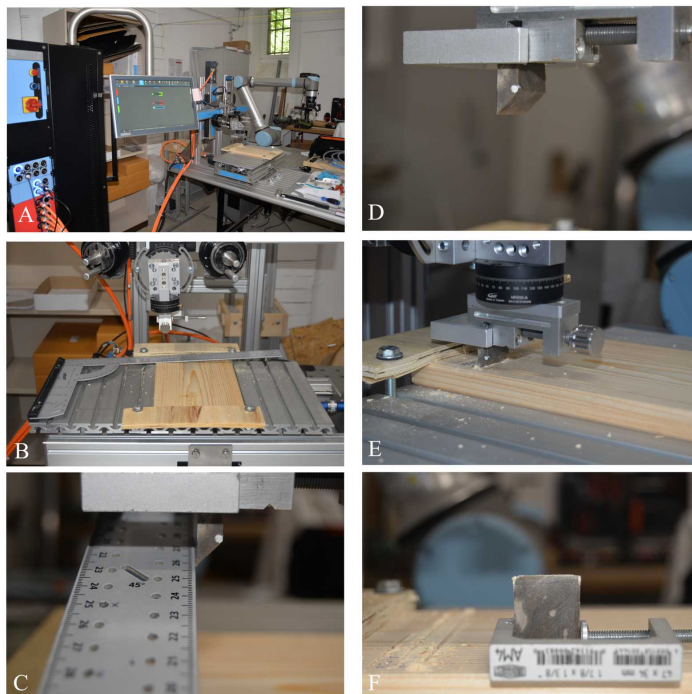
Alignment: Ensure all samples are precisely aligned with the contact material's surface to achieve a clean and straight cut at the start of the experiment.

Running Stages: Each sample undergoes three running stages:

0-250 strokes

251-500 strokes

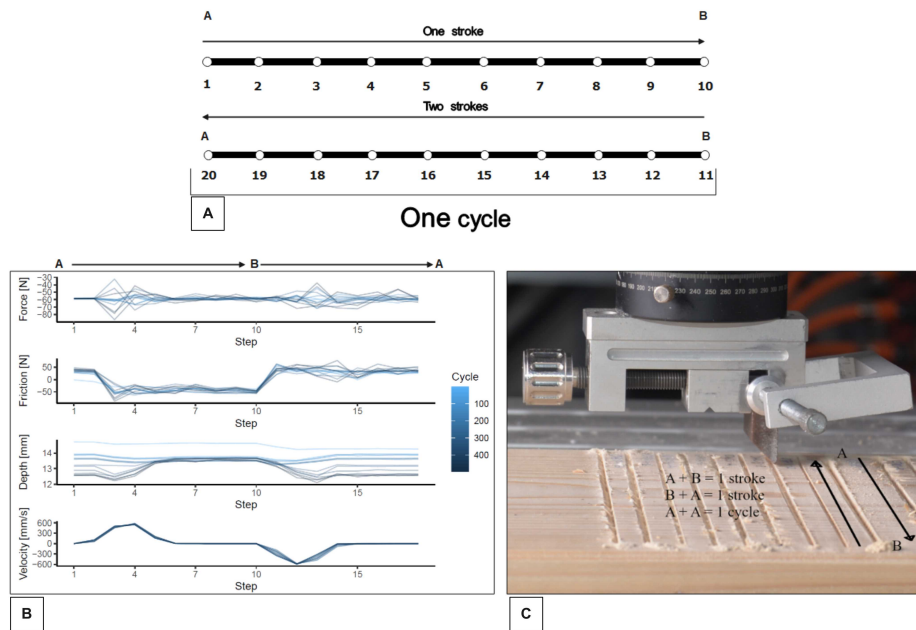
501-1000 strokes



Experiment setup

Stroke and Cycle Definition:

A single stroke is one complete linear bidirectional movement from point A to point B. Drive measurements are recorded in cycles, where one cycle equals the path length from point A to point A.



Stroke and Cycle Definition

Data Recording and Export:

Up to 20 points are recorded per cycle path.

All recorded points are exported to a .txt file, containing measurements for each selected sensor.

Repeat Imaging Step

7 Repeat  go to step #5

Each lithic sample is removed and documented at every experiment's stop.



Data processing

8 **Point cloud and Mesh treatment**

For point cloud and mesh treatment we use the following software and workflow:



Software

GOM Inspect

NAME

Hotfix 2, Rev. 111729, build 2018-08-22

OS

GOM

DEVELOPER

<https://www.gom.com/de-de/produkte/gom-inspect-suite>

SOURCE LINK

GOM Inspect Workflow

Mesh Treatment

1. Import the stage 0 .stl file (alternative: ply) import STL as target element type: mesh
→ ok
2. Eliminate Mesh Errors
 - a. RMC (right mouse click) Select all points of Element
 - b. Operations → Mesh → Other → Eliminate Mesh Errors → Apply
3. Align 3D model
 - a. RMC on the Left back of the screen X, Y, Z icon to establish Matrix
 - b. RMC Select all points of Element
 - c. Operations → Alignment → Manual Alignment → Set Matrix (Settings1)
 - d. Change Rotation values until your object is aligned
 - e. Change Translation to set your object to the 0/0/0 (zero) point2 → Ok
4. Cut 3D model
 - a. RMC → Select/Deselect Trough Surface (Ctrl+Shift+Space) → Close the select area LMC
 - b. Delete select 3D area (Ctrl+Del)
5. Export Mesh as a .stl file. (File → Export → .stl).
6. Close Project.

Aligned Cut

1. Cut 3D Models aligned

a. Import the stage 0 (zero) .stl file aligned cut (add Part)

b. RMC Select all points of Element → Operations → CAD → Actual Mesh to CAD

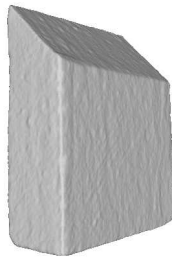
2. Import mesh stg250_rawdata .stl file (second 3D model)

a. Operations → Alignment → Initial Alignment → Prealignment3 (At this stage both 3D models are overlap).

b. Cut the mesh at the same line as the stage 0 (zero) → RMC → Select/Deselect Trough Surface (Ctrl+Shift+Space) → Close the select area LMC

3. Export Mesh as a .stl file. (File → Export → .stl)

4. Repeat the aligned cut for the other 3D models.



FLT10-stg0

Measuring Efficiency

9 In this experiment, to address the lithic raw material efficiency, we suggest the following equation: $Efficiency = effectiveness/durability$.

Effectiveness (the degree to which something is effective/done, is represented by penetration depth (PD).

Durability (the degree at which deterioration occurs or volume loss) is represented by edge wear (Ew).

9.1 **Durability data acquisition**

Durability is the sum of material loss from the edge measured on each sample after and before use.

CloudCompare (C2M)

CloudCompare is a software application that processes three-dimensional point clouds and triangle meshes. The C2M (cloud to mesh) tool was employed in the present study to assess the surface deviation between triangular meshes. The comparisons were conducted for all lithic samples using combinations of 0 to 125 cycles, 125 to 250 cycles, and 250 to 500 cycles.

CloudCompare workflow:

1. Import the two .stl files (before and after)
2. Align 3D models
 - a. Select the two meshes.
 - b. Registration and Match Bounding-box centers
 - c. Registration and Align (points pair picking)
 - d. Registration and Fine registration (ICP)
3. Compare the two meshes
 - a. Select the two meshes
 - b. Compute Cloud/Mesh distance
 - c. Compute
 - d. Select only the "registered" mesh
 - e. In Properties/SF display params/Display ranges
 - i. Set displayed values to 0.2 mm (3D Scanner accuracy and baby powder layer)
 - ii. Make the Color Scale visible
 - iii. In the Parameters bar, unselect "show NaN/ out of range values in grey"
4. Get comparison data
 - a. Select only the "registered" mesh
 - b. Show Histogram
 - c. Export Histogram to a .CSV file
 - d. Export Histogram to image to .png

Combinations: Stage 1(0-125 cycles); Stage 2 (126-250 cycles), Stage 3 (251-500 cycles) and Stage 1 with Stage 3 (0-500 cycles)



Citation

David Nora (2021)

. The role of lithic raw materials on tool performance and use: The efficiency and durability on stone tools edge.

Universidade do Algarve, Faculdade de Ciencias Humanas e Sociais..

<http://hdl.handle.net/10400.1/17581>

LINK

Software

CloudCompare

NAME

v2.13.alpha [macOS 64-bit] Compiled with Qt 5.15.2 License: GNU GPL

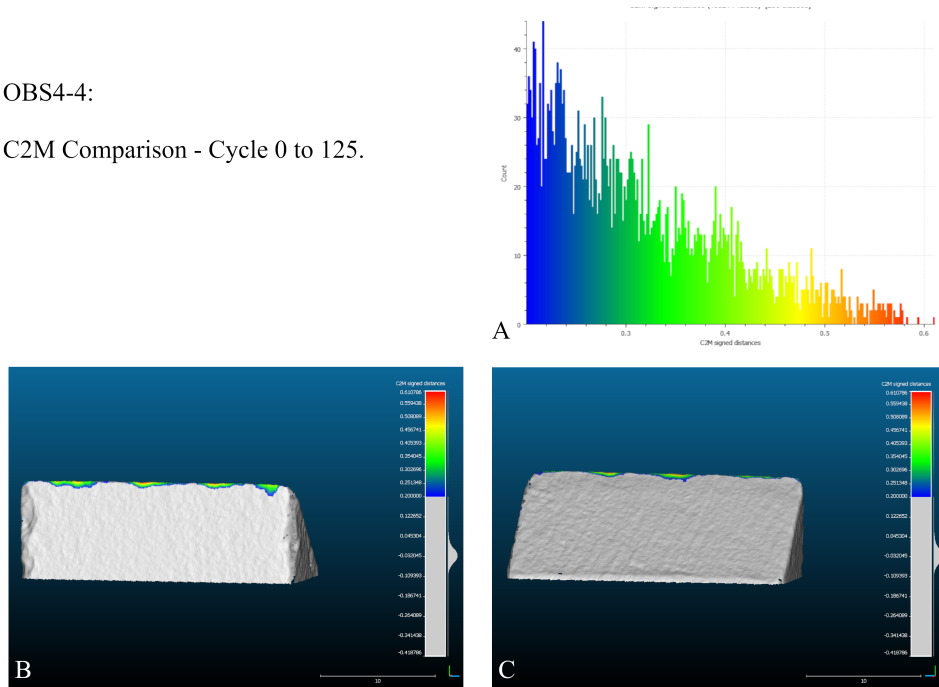
DEVELOPER

<https://www.danielgm.net/cc/>

SOURCE LINK

OBS4-4:

C2M Comparison - Cycle 0 to 125.



Example of the C2M workflow.

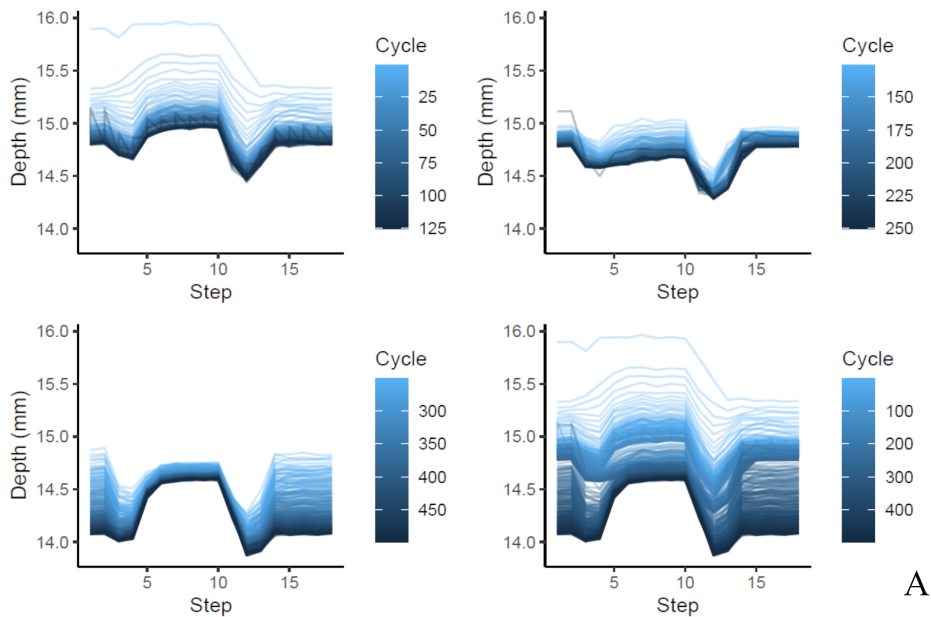
9.2 Effectiveness data acquisition

Effectiveness (penetration depth) is measured by the depth sensor, which is not an absolute figure but the measured penetration depth minus blade attrition for each cycle. From each stroke, the Smarttester takes twenty measures. Those same measures are then recorded and saved to be imported for quantification and visualisation for every stroke and then grouped for the representation of each lithic raw material.

SMARTTESTER® data analysis

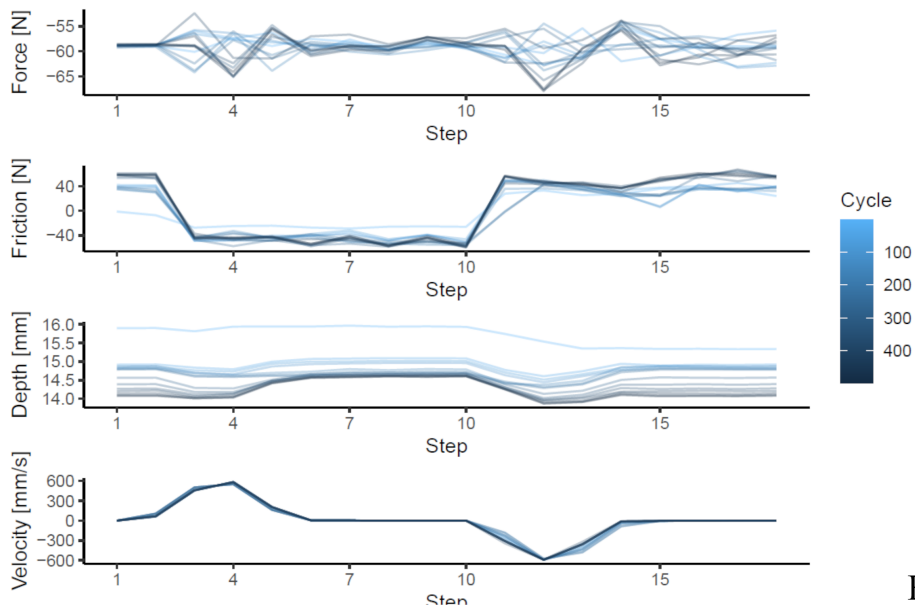
All CSV files with experimental data (step #6) are combined into one CSV file. The sensor data recorded throughout the experiment is then analysed in R. The analysis includes descriptive statistics and plotting the variables velocity, force, penetration depth, and friction data. All packages used are cited in the R script (see #10).

QZT1-1



A

QZT1-1



B

Example of the variables plotted

Data analysis

- 10 The data acquired within the experiment (#6) and from the data processing (#9) were analysed in R to test the null hypothesis that "*Edge efficiency does not vary according to*



the different lithic raw materials."

The following group of analyses is proposed:

Analysis for LHT) This script reads and plots the data from the Leeb Rebound hardness. Hardness was measured on each rock using the device Equotip 550 Leeb Impact device C (HLC).

Analysis of 3D) This script reads and plots the data from the 3D volume loss, which was calculated using CloudCompare cloud-to-mesh distance tool.

Relationship Analysis) This script analyses the relationship between the different variables.

For more in-depth info please check:

<https://github.com/jmmarreiros/noraetalstonedura2025>.

Software

R Studio Desktop

NAME

The R Studio, Inc.

DEVELOPER

<https://www.rstudio.com/products/RStudio/>

SOURCE LINK

Results

- 11 Available in open access on Zenodo:
<https://doi.org/10.5281/zenodo.14012777>



Citations

Step 2.2

A. G. Corkum · Y. Asiri · H. El Naggat · D. Kinakin. The Leeb Hardness Test for Rock: An Updated Methodology and UCS Correlation

[10.1007/s00603-017-1372-2](https://doi.org/10.1007/s00603-017-1372-2)

Step 2.2

Sasan Ghorbani · Seyed Hadi Hoseinie · Ebrahim Ghasemi · Taghi Sherizadeh · Christina Wanhainen. A new rock hardness classification system based on portable dynamic testing.

[10.1007/s10064-022-02690-3](https://doi.org/10.1007/s10064-022-02690-3)

Step 2.5

Ivan Calandra & Lisa Schunk & Alice Rodriguez & Walter Gneisinger & Antonella Pedergrana & Eduardo Paixao & Telmo Pereira & Radu Iovita & Joao Marreiros. Back to the edge: relative coordinate system for use-wear analysis

<https://doi.org/10.1007/s12520-019-00801-y>

Step 9.1

David Nora. The role of lithic raw materials on tool performance and use: The efficiency and durability on stone tools edge.

<http://hdl.handle.net/10400.1/17581>