

INSTRUCTION, DIGITAL PRESSURE AND BIMANUAL CONTROL IN STONE-TOOL SKILL

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ABSTRACT

To examine the relationship between stone-tool instruction, practical competence and pressure distribution across the hammer and core hands. A six-maker investigation of Oldowan chopper production measured force and pressure at 200 Hz and found lower thumb loading than digit II and/or III. A comparison of 23 novices and nine experts associated expertise with lower hammer-hand pressure-time integrals. Core-hand investigations identified greater pressure during platform preparation than detachment and substantial fifth-digit participation. Teaching experiments involved 184, 30 and 71 participants and differed in instructional content and production outcomes. None of the investigations examined here establishes a teaching effect on pressure recorded simultaneously from both hands. Technical competence and manual exposure are distinct outcomes of stone-tool learning. Demonstrating an acquired pressure change requires an instructional comparison, synchronized hand recordings and an assessment without immediate guidance. An ergonomic benefit additionally requires an explicit favourable exposure outcome and adequate flake-production performance. Archaeological flake dimensions alone cannot identify the learner's bilateral pressure history.

Keywords: stone knapping; digital pressure; bimanual coordination; motor learning; biological anthropology; teaching.

INTRODUCTION

Stone knapping links a socially acquired technical skill to the mechanics of a two-handed action. The hammer hand accelerates and directs a striking object; the core hand controls the orientation and support of the stone receiving the blow. A successful flake preserves the consequences of fracture, while the contacts that maintained the grip leave a less direct record. Skill acquisition therefore concerns both the production of an intended removal and the bodily actions through which that removal becomes possible (Pargeter et al., 2019; Bril et al., 2015).

The relationship between skill and movement cannot be reduced to imitation of a single posture. Functional investigations show that different joint contributions can satisfy the same tool-material interaction (Parry et al., 2014). Stone-tool ergonomics also encompasses different operations: manufacture, cutting and pounding do not impose interchangeable demands on the hand (Key and Lycett, 2023). A learner may improve flake production while changing preparation time, shifting contact toward another digit or increasing the effort of the supporting hand. Counting successful flakes alone does not distinguish these possibilities.

This review examines three questions. Which aspects of manual exposure differ with task and experience? What do stone-tool teaching experiments establish about practical competence? What measurements distinguish a retained change in hand use from an ergonomic benefit? The anthropological question is whether a learning relationship transmits a production goal, a particular bodily technique, or both. The kinesiological question is how to measure the consequences for each hand without treating external pressure as a direct measure of internal tissue stress.

MOTOR COORDINATION DURING MANUFACTURE

CONTROL OF THE STRIKING TRAJECTORY

Rein et al. examined covariation among striking-arm movements using uncontrolled-manifold analysis (Rein et al., 2013). The distinction is between variation that preserves the hammer trajectory and variation that changes it. Their subsequent movement-pattern investigation comprised nine experienced and nine novice makers and identified substantial differences between individuals (Rein et al., 2014). Similarity within social groups was partial rather than complete. These findings permit successful task control and diverse movement patterns to coexist: stability of the tool trajectory does not require identical joint motion across makers.

The importance of task constraints is also apparent in wrist restriction. Williams et al. tested eight participants and found that unrestricted action allowed greater accuracy and hammer velocity than braced action (Williams et al., 2014). The comparison concerns the mechanical consequences of restricting movement, not a teaching intervention. It therefore supports attention to available joint motion without demonstrating that an instructor's preferred wrist posture is necessary for competence.

CRAFT EXPERTISE AND BODILY VARIATION

Kinematic investigations of Indian stone-working craftsmen place technical movement within sustained practice and material work (Biryukova et al., 2015). These makers developed their actions through long work histories, unlike participants receiving brief laboratory instruction. Movement descriptions nevertheless do not identify how a particular lesson altered contact pressure. Simulated stone-tool use further associates external task performance with hand morphology and muscle mechanics (Rolian et al., 2011). Anatomical differences can permit different gripping solutions; resemblance to a demonstrator is therefore an incomplete measure of learning.

DIGITAL PRESSURE ACROSS TECHNOLOGICAL OPERATIONS

HAMMER-HAND CONTACTS

In Oldowan bifacial-chopper production, Williams et al. measured normal force and pressure at 200 Hz in six experienced makers. Thumb peak force, pressure, impulse and pressure-time integral were lower than the corresponding values for digit II and/or III in every participant (Williams et al., 2012). The thumb's visible involvement in gripping did not establish its relative loading. Digit-specific measurements are needed to identify which contacts carry the recorded demand.

Williams-Hatala et al. compared 23 novices and nine experts producing flakes with direct hard-hammer percussion. Experts had lower cumulative pressure and pressure-time integrals, with loading emphasizing digits I and II (Williams-Hatala et al., 2021). This is an experience-group association. Practice duration, anatomy, selection into expertise and instructional history can differ between groups, so the contrast does not identify a causal effect of instruction. Cumulative pressure across recorded contacts also remains distinct from whole-hand normal force.

CORE SUPPORT, PREPARATION AND THE FIFTH DIGIT

Key and Dunmore measured core-hand pressure in nine experienced makers during Oldowan flake and Acheulean handaxe production. Platform preparation required greater pressure than flake detachment, while pressure variation was not significantly associated with flaking success (Key and Dunmore, 2018). A record confined to the strike would therefore omit a demanding part of the production sequence.

Key, Dunmore and Marzke measured the non-dominant hand of nine experts across four production behaviours and identified frequent, substantial fifth-digit loading (Key et al., 2019). Monitoring only the thumb and index finger would miss this ulnar contribution. The two nine-person investigations are discussed by operation and measured contact; their participants are not combined because sample independence has not been established here.

FLAKE DIMENSIONS AND GRIPPING STRATEGY

Key et al. identified positive associations between flake dimensions and dominant-hand pressure, together with pronounced individual differences in gripping strategy (Key et al., 2017). Some makers varied pressure with flake size and mass, whereas others maintained relatively high pressure. Flake morphology can therefore constrain interpretation of hand loading under the tested conditions. The same dimensions do not uniquely identify pressure throughout preparation,

impact and repositioning, nor do they reveal the supporting hand's contribution. Inferring a teaching history from an archaeological flake requires assumptions beyond the observed morphology–pressure association.

MUSCULAR ACTIVATION AND IMPACT-FORCE MEASUREMENT

Macchi et al. recorded joint angles and muscular activity in one expert using passive-hammer, bipolar-on-anvil and freehand techniques (Macchi et al., 2021). The contrasts describe the same maker performing different percussion methods. They demonstrate that technique changes coordination and muscular demand, while providing no estimate of variability across makers. A large number of strikes does not change that participant count.

Eteson et al. examined 25 participants: 16 without experience, four with theoretical knowledge and five with practical knapping experience. Eight sEMG channels captured cutting and nut-cracking (Eteson et al., 2024). Figure 1 displays their phase-specific associations between experience and relative muscle-recruitment PC1. Negative coefficients indicate lower activation scores with greater experience; the scores are not muscle forces.

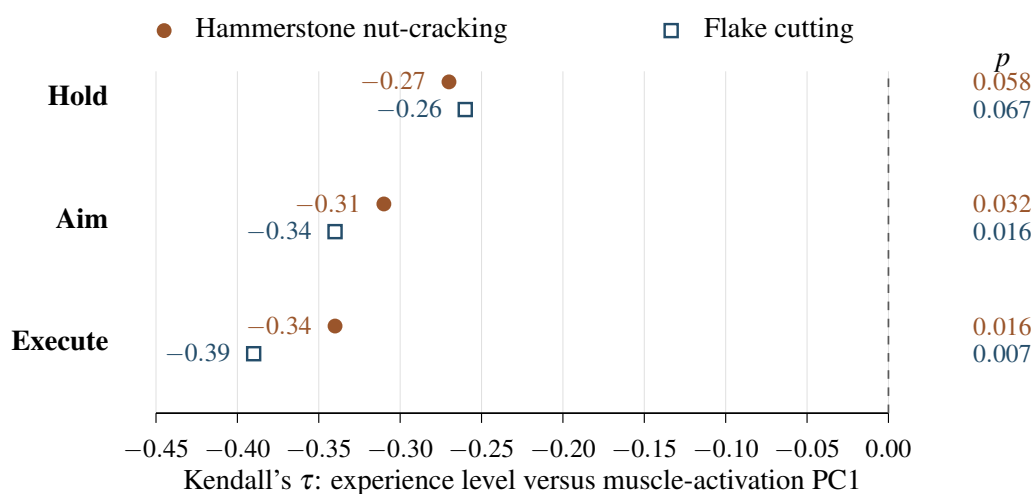


FIGURE 1. EXPERIENCE–ACTIVATION ASSOCIATIONS DURING TOOL USE. COEFFICIENTS AND p VALUES CONCERN 25 PARTICIPANTS ACROSS THREE PHASES. PC1 DENOTES RELATIVE MUSCLE RECRUITMENT. CONFIDENCE INTERVALS ARE UNAVAILABLE FOR THESE COEFFICIENTS; THE PLOT DOES NOT SHOW A MANUFACTURE OR TEACHING EFFECT.

Barroso-Medina et al. calibrated a sensorized hammerstone against a force plate. Sixteen trials containing 160 strikes were used for a linear fit, and two trials were withheld for validation. The withheld trials yielded a root mean square error of 38.7 N, approximately 5.6% (Barroso-Medina et al., 2024). The fit's adjusted r^2 was 0.92, with a fitting error of 36.3 N. A further six trials contained 60 strikes during anvil-supported glass knapping. These are instrument-validation observations, not independent participants in a learning comparison. The device measures percussive force in the tested arrangement; it does not supply pressure distributions at both hand–object interfaces or internal joint stresses.

INSTRUCTION, PRACTICAL COMPETENCE AND LEARNING RELATIONSHIPS

COMMUNICATION DURING EARLY ACQUISITION

Morgan et al. studied 184 adults in transmission chains across five learning conditions. Teaching, particularly with language, improved assessed transmission of toolmaking relative to conditions providing less instructional support (Morgan et al., 2015). Lombao et al. compared imitation-emulation, gestural teaching and verbal teaching in 30 non-experts learning a specified reduction method; teaching favoured early acquisition (Lombao et al., 2017). Neither comparison measured the pressure histories of both hands.

Cataldo et al. assigned 71 participants to no instruction ($n = 10$), gesture ($n = 27$), speech ($n = 23$), or gesture plus speech ($n = 11$). Instruction lasted five minutes and flintknapping lasted up to 20 minutes. The groups differed in viable-flake count ($\chi^2 = 10.2$, $df = 3$, $p = 0.017$), viable-flake proportion ($\chi^2 = 13.5$, $df = 3$, $p = 0.0036$), cutting edge ($\chi^2 = 19.5$, $df = 3$, $p < 0.001$) and flake quality ($\chi^2 = 21.9$, $df = 3$, $p < 0.001$) (Cataldo et al., 2018). Speech performed worse than gesture and combined instruction; gesture and combined instruction did not differ significantly. The latter comparison does not establish equivalence. Across these teaching investigations, communication condition, content and task differ, preventing a universal ranking of verbal instruction above demonstration.

The distinction between production and bodily exposure is consequential. Demonstrating platform orientation, specifying an intended removal and correcting core support address different aspects of the task. Neural investigations of stone-tool manufacture likewise require interpretation within their instructional conditions (Putt et al., 2017). Learning about fracture, producing a flake and reducing recorded pressure must be assessed separately before their relationship can be determined.

DISCOVERY, SUSTAINED PRACTICE AND APPRENTICESHIP

Snyder et al. found that 25 technique-naïve participants independently developed early knapping techniques and produced and used tools (Snyder et al., 2022). The appearance of an elementary technique therefore does not itself establish copying of procedural knowledge. It remains compatible with teaching effects on reliability, practice duration or manual exposure. Pargeter et al. distinguish knowledge of an intended removal from the practical ability to execute demanding removals (Pargeter et al., 2020). Correct description and successful execution are separate indications of competence.

In the longer training investigation of Pargeter et al. (2019), 26 initially naïve participants received up to 90 hours of training over several months (Pargeter et al., 2019). Learning duration and individual variation thus matter when comparing expertise with short instruction. Rein et al. (2014) examined master-apprentice and other social relationships but found only partial similarity in movement patterns (Rein et al., 2014). The craft context of Indian stone-working adds evidence of skilled action within sustained material practice (Biryukova et al., 2015).

For anthropological interpretation, the relevant learning relationship includes who demonstrates, what action is demonstrated, how correction occurs, which materials are available and how often the learner practises. A reduction sequence can remain recognizable within a tradition while anatomically different makers use different grips. Similarity between teacher and learner is meaningful only in relation to the taught operation and the criteria used to judge its completion. Modern instruction experiments establish effects within their teaching conditions; they do not directly identify prehistoric apprenticeship relationships.

BIMANUAL ASSESSMENT OF ACQUIRED SKILL

CONTACT PRESSURE, DURATION AND RECORDED FORCE

The hammer and core hands contact different objects over different areas. Equal and opposite forces at hammer-core impact do not imply equal pressures at the hands: object acceleration, rotation and additional supports alter the contact requirements. Synchronized recording must retain separate digit measurements for each hand, including the core-hand fifth digit and any covered palm contacts. Preparation, striking and repositioning require distinct temporal definitions because preparation can exceed detachment in recorded pressure (Key and Dunmore, 2018; Key et al., 2019).

Let $h \in \{H, C\}$ identify the hammer or core hand, d identify a digit, and $\Omega_{h,d}$ denote a fixed sensor region of area $A_{h,d}$. For valid local pressure $p_h(x, t)$, the area-averaged pressure is

$$\bar{p}_{h,d}(t) = \frac{1}{A_{h,d}} \int_{\Omega_{h,d}} p_h(x, t) dA. \quad (1)$$

This average includes calibrated non-contact sensels as zeros. Averaging only sensels in contact defines a different quantity. Sensor position, contact-area convention, calibration range, saturation and missing channels must accompany the measurement. A disconnected sensel is missing, not a zero-pressure contact. Multiple regions on one digit require area-weighted aggregation.

For a phase q with boundaries $t_{0,q}$ and $t_{1,q}$,

$$Q_{h,d,q} = \int_{t_{0,q}}^{t_{1,q}} \bar{p}_{h,d}(t) dt, \quad T_q = t_{1,q} - t_{0,q}. \quad (2)$$

The pressure-time integral Q has units of kPa·s when pressure is in kilopascals and time in seconds. It measures accumulated contact pressure over time; it is neither mechanical energy nor internal tissue stress. Phase duration and mean pressure distinguish a longer action from a more highly pressurized action. Synchronized video can identify the phase boundaries, with timing uncertainty stated explicitly.

A digit's share of the five recorded integrals is

$$s_{h,d,q} = \frac{Q_{h,d,q}}{\sum_{j=1}^5 Q_{h,j,q}}, \quad \sum_{d=1}^5 s_{h,d,q} = 1. \quad (3)$$

The denominator must be positive and all required digit channels must be valid. This share describes recorded pressure-time signals, not the fraction of whole-hand force. Absolute integrals and sensor coverage remain necessary because the same share can accompany different total exposure.

Normal force over the covered region is instead

$$N_{h,d}^{\text{rec}}(t) = \int_{\Omega_{h,d}} p_h(x, t) \, dA. \quad (4)$$

Pressure-area unit conversion yields newtons. Unmeasured palm contacts and shear forces remain outside this quantity. Eqs. (1)–(4) specify standard measurement definitions; they do not establish a physiological threshold or a validated injury indicator. Surface electromyography measures electrical activation and requires separate electrode-placement, normalization and processing procedures.

RETENTION, TRANSFER AND TASK ACHIEVEMENT

An instruction-associated exposure change requires a defined teaching contrast, a characterized production task and pressure measurements after immediate guidance has been removed. Recording both hands identifies compensation or redistribution even when only one hand changes. A delayed assessment without cues tests retention. Performance on another core, hammer or task tests transfer and answers a different question.

An acquired change can increase, decrease or redistribute contact pressure. Calling it an ergonomic benefit requires a favourable outcome defined before analysis and an acceptable level of technical achievement. The latter can include intended-flake success, cutting-edge production or a specified removal geometry. A lower hammer-hand mean accompanied by longer preparation, poorer removals or higher core-hand exposure does not establish an overall benefit. Pressure reduction alone also does not establish reduced injury incidence.

DISCUSSION

The evidence distinguishes three relations that should remain separate: experience with manual loading, instruction with production, and instruction with retained bilateral exposure. The first two have direct observations in the investigations examined here; the third does not. Expertise comparisons identify how selected groups perform, whereas teaching comparisons identify consequences of particular instructional conditions. Joining their directional findings does not supply a causal pressure effect that neither comparison measured.

A direct learning comparison must distinguish instruction about the striking platform from additional instruction about grip and support. Assessments before instruction, immediately after instruction and after a delay separate initial differences, immediate guidance and retained change. Random assignment at learner level addresses differences preceding instruction. Where instruction is assigned by class or instructor, the analysis must preserve that allocation structure. Learners, cores and instructors can generate dependencies; repeated strikes remain nested observations rather than additional participants.

Exposure and technical performance require joint interpretation. Analysing only successful removals can select different attempts in different teaching conditions. Platform preparation and support can themselves change after instruction, so adjusting for them without specifying the intended causal contrast can obscure the total instructional effect. The contrast between assigned teaching conditions should be distinguished from descriptions that hold a technological phase or task feature constant. Effect estimates, uncertainty and missing-channel frequency are more informative than a significance statement alone. The present evidence does not justify a numerical sample-size target or a pressure threshold for injury prevention.

The anthropological interpretation also depends on the duration and organization of learning. Brief communication trials and months of practice represent different opportunities to acquire competence. A stable production goal does not require a stable grip across makers, and a shared grip does not establish equal pressure. Learning relationships should therefore be described through demonstrators, correction practices, materials and accumulated practice rather than broad cultural labels alone.

Several limitations constrain the review. Selection and reference following were purposive, access to complete text was uneven, and no independent duplicate appraisal was undertaken. Small expert groups, different definitions of experience and different sensor coverage limit comparisons. Partly shared movement records and undetermined relationships among other samples prevent counting every article as independent corroboration. The 2011–June 2025 date restriction excludes earlier foundational work. Heterogeneous pressure, kinematic, sEMG and production outcomes cannot be pooled into one exposure estimate.

Finally, modern experiments do not uniquely connect an archaeological flake to a teacher, learner or bilateral loading history. The flake-dimension associations identified by Key et al. (2017) support conditional interpretations of gripping demand. Individual pressure strategies, unobserved supporting-hand contacts and preparation duration prevent a unique inverse inference. Anthropological explanation is strongest when the technological operation, observed bodily action and learning relationship remain explicitly connected.

CONCLUSIONS

Stone-tool competence includes control of fracture and coordination of distinct hand roles. Digital-pressure investigations show task-dependent loading, lower hammer-hand pressure-time integrals in experts and substantial core-hand fifth-digit participation. Teaching experiments demonstrate production differences under specified communication conditions. Establishing an acquired bilateral exposure change requires measuring the instructional contrast, both hand records and performance without immediate guidance. Demonstrating an ergonomic benefit additionally requires adequate technical achievement and a favourable exposure outcome; injury prevention and prehistoric teaching relationships require separate evidence.

DECLARATIONS

CONFLICT OF INTEREST

The authors declare that there are no conflicts of interest related to this study.

DATA AVAILABILITY

Not applicable.

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REFERENCES

1. Barroso-Medina C, Lin SC, Tocheri MW, Sreenivasa M. Design and development of a sensorized hammerstone for accurate force measurement in stone knapping experiments. *PLoS ONE*. 2024;19(9):e0310520.
2. Biryukova EV, Bril B, Frolov AA, Koulikov MA. Movement kinematics as an index of the level of motor skill: The case of Indian craftsmen stone knapping. *Motor Control*. 2015;19(1):34-59.
3. Bril B, Parry R, Dietrich G. How similar are nut-cracking and stone-flaking? A functional approach to percussive technology. *Philosophical Transactions of the Royal Society B: Biological Sciences*. 2015;370(1682):20140355.
4. Cataldo DM, Migliano AB, Vinicius L. Speech, stone tool-making and the evolution of language. *PLoS ONE*. 2018;13(1):e0191071.
5. Eteson B, Affinito S, Moos ET, Karakostas FA. "How handy was early hominin 'know-how'?" An experimental approach exploring efficient early stone tool use. *American Journal of Biological Anthropology*. 2024;185(3):e25019.
6. Key AJM, Dunmore CJ. Manual restrictions on Palaeolithic technological behaviours. *PeerJ*. 2018;6:e5399.
7. Key A, Lycett SJ. The ergonomics of stone tool use and production. In: *The Oxford Handbook of Cognitive Archaeology*. Oxford University Press; 2023. p. 771-796.
8. Key A, Dunmore CJ, Hatala KG, Williams-Hatala EM. Flake morphology as a record of manual pressure during stone tool production. *Journal of Archaeological Science: Reports*. 2017;12:43-53.
9. Key AJM, Dunmore CJ, Marzke MW. The unexpected importance of the fifth digit during stone tool production. *Scientific Reports*. 2019;9:16724.
10. Lombao D, Guardiola M, Mosquera M. Teaching to make stone tools: New experimental evidence supporting a technological hypothesis for the origins of language. *Scientific Reports*. 2017;7:14394.
11. Macchi R, Daver G, Brenet M, Prat S, Hugheville L, Harmand S, Lewis J, Domalain M. Biomechanical demands of percussive techniques in the context of early stone toolmaking. *Journal of the Royal Society Interface*. 2021;18(178):20201044.

12. Morgan TJH, Uomini NT, Rendell LE, Chouinard-Thuly L, Street SE, Lewis HM, et al. Experimental evidence for the co-evolution of hominin tool-making teaching and language. *Nature Communications*. 2015;6:6029.
13. Pargeter J, Khreisheh N, Stout D. Understanding stone tool-making skill acquisition: Experimental methods and evolutionary implications. *Journal of Human Evolution*. 2019;133:146-166.
14. Pargeter J, Khreisheh N, Shea JJ, Stout D. Knowledge vs. know-how? Dissecting the foundations of stone knapping skill. *Journal of Human Evolution*. 2020;145:102807.
15. Parry R, Dietrich G, Bril B. Tool use ability depends on understanding of functional dynamics and not specific joint contribution profiles. *Frontiers in Psychology*. 2014;5:306.
16. Putt SS, Wijeakumar S, Franciscus RG, Spencer JP. The functional brain networks that underlie Early Stone Age tool manufacture. *Nature Human Behaviour*. 2017;1:0102.
17. Rein R, Bril B, Nonaka T. Coordination strategies used in stone knapping. *American Journal of Physical Anthropology*. 2013;150(4):539-550.
18. Rein R, Nonaka T, Bril B. Movement pattern variability in stone knapping: Implications for the development of percussive traditions. *PLoS ONE*. 2014;9(11):e113567.
19. Rolian C, Lieberman DE, Zermeno JP. Hand biomechanics during simulated stone tool use. *Journal of Human Evolution*. 2011;61(1):26-41.
20. Snyder WD, Reeves JS, Tennie C. Early knapping techniques do not necessitate cultural transmission. *Science Advances*. 2022;8(27):eabo2894.
21. Williams EM, Gordon AD, Richmond BG. Hand pressure distribution during Oldowan stone tool production. *Journal of Human Evolution*. 2012;62(4):520-532.
22. Williams EM, Gordon AD, Richmond BG. Biomechanical strategies for accuracy and force generation during stone tool production. *Journal of Human Evolution*. 2014;72:52-63.
23. Williams-Hatala EM, Hatala KG, Key A, Dunmore CJ, Kasper M, Gordon M, Kivell TL. Kinetics of stone tool production among novice and expert tool makers. *American Journal of Physical Anthropology*. 2021;174(4):714-727.