doi 10.4436/jass.95004

JASs Reports

Journal of Anthropological Sciences
Vol. 95 (2017), pp. 203-217

Biomechanics of microliths manufacture: a preliminary approach to Neanderthal's motor constrains in the frame of embodied cognition

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Summary - *The systems of perception and action of the brain appear as important constraining factors in human evolution under current models of embodied cognition. In this view, the emergence of certain items in the archeological record is not necessarily subsequent to the emergence of a 'symbolic' mind, but instead to the appearance of the sensory-motor systems enabling that behavior. One of the products normally absent in pre- Homo sapiens species is the standardized microlith, whose production seems very demanding for the hand due to their small size and need for fine craft. In the present study, we provide preliminary empirical evidence that the biomechanical requirements of microliths manufacture made this industry difficult to achieve by Neanderthals. The biomechanical parameters of the human hand in the manufacture of microliths are here explored in two individuals with different degrees of expertise. The figures obtained in this manner are subsequently contrasted and extrapolated to Neanderthal's hand anthropometric data, as obtained from the available literature. Results indicate that Neanderthals would exhibit lower efficiency than modern humans as a consequence of their smaller hands and shorter arms, resulting in a smaller area to distribute forces and an increased mechanical stress in the microlith manufacturing processes. This might be a plausibly contributing factor for precluding microlith production in Neanderthals on noticeable scales, in consonance with the archeological record.*

Keywords - *Neanderthal, Human evolution, Microlith industry, Hand biomechanics.*

Introduction

In the study of the origin and evolution of human artistic behavior, the systems of perception and action of the brain have been proposed as important constraining factors (Martín-Loeches, 2013, 2014, 2017). This perspective is entrenched in current models of *embodied cognition* (Barsalou, 2008; Carota *et al*., 2012), in which the human mind and thinking processes are not viewed as necessarily based upon the use of symbolic representations of the world. Instead, sensorimotor experiences assembled along the continuous dynamic interplay of the body with the outer world are the basis of human knowledge, with different degrees of abstraction. In this view, the emergence of art is not necessarily subsequent to the emergence of a 'symbolic' mind, but instead to the appearance of the sensory-motor systems enabling this behavior (developed in deep in Martín-Loeches, 2017). Given the large similarities between human and nonhuman primates' visual systems, it is proposed that a main limiting factor precluding the emergence of art in other species –including Neanderthals- might relate to differences in the motor domain, namely in the ability to finely, precisely and accurately use their hands. Other recent concurrent proposals also spot a differential capacity in hands use by Neanderthals, forcing this species to employ their teeth and mouth as a 'third hand' (developed in Bruner & Lozano, 2014, 2015, and related Forum's discussion). Moreover, it has recently been emphasized that the evolution of the motor systems has been a main determinant in the evolution of human cognition (Mendoza & Merchant, 2014).

Due to the condition that the Neanderthal is an extinct species, a way to analyze the hand use capabilities of this species has been through the inference of biomechanical capabilities from hand bone remains. There are significant differences between the hands of Neanderthals and *Homo sapiens*, even if they are the most comparable within the *Homo* genus. The Neanderthal hand was much stronger, exhibiting larger muscles and broader fingertips (Maki & Trinkaus, 2011; Niewoehner *et al.*, 2003). There were observable disparities in the shape and orientation of capitate-metacarpal articulations, in relative lengths of distal and proximal phalanges, and in flexor mechanics over metacarpo- and inter-phalangeal joints (Marzke & Marzke, 2000; Niewoehner, 2001). Neanderthals exhibited reduced flexion-extension capacities at the interphalangeal joints as well as lower force capacities and force vectors at the distal phalanges, yielding less mechanical advantage for gripping at the fingertips and, hence, less precise control when manipulating small objects (Trinkaus & Villemeur, 1991). On the other hand, the derived structure of the *Homo sapiens*' hand reflects functional adaptations related to more frequent precision grip usage, finer finger movements, and oblique grips, as required for engraving and incising (Niewoehner, 2001). Accordingly, biomechanical constraints (on a par with coupled neural motor systems, as developed in Martín-Loeches, 2017; see also the discussion section) might be a main factor limiting the presence of art in other than *Homo sapiens* species, including Neanderthals (though not necessarily precluding it; e.g., Rodríguez-Vidal *et al.*, 2014).

A corollary of this perspective is that the motor constraints presumed in other species might as well explain the absence of samples of fine work other than fine art in the archeological record. In this regard, *microliths*, small flakes and bladelets typically as small as 30 mm in length or less (Clark, 1985) could be mentioned. Although microliths can be found as far back as 300–250 Kya BP, or even earlier, this is notoriously occasional. According to McBrearty (2012), the pattern was actually established and standardized by *Homo sapiens*, being very common (though not ubiquitous) in our species particularly starting 40 Kya ago, although it had already been prominent as early as around 70 Kya ago in places like Howiesons Poort (Wurz & Lombard, 2007) or Pinnacle Point (Brown *et al.*, 2012), both in South Africa. As an example, samples in SADBS stratum at Pinnacle Point Site -dated around 71 Kya- exhibit mean length values of 27 mm, 9 mm width, and about 3 mm thickness. Microlith production seems indeed very demanding for the hand due to their size and need for fine craft. This, together with biomechanical constraints apparently limiting the manipulation of small objects by Neanderthals, as discussed above, could help to understand their lack of this type of technology more parsimoniously than cognitive difficulties in understanding the complexity of the tools assembled with them, as typically claimed (e.g., Brown *et al.*, 2012).

The objective of this investigation is to provide preliminary empirical evidence that the biomechanical requirements of standardized microliths manufacture made this industry difficult to achieve by Neanderthals. This would convey evidence of motor constraints in the Neanderthal limiting microlith production -at least in observable scales-, adding to or even replacing interpretations based on cognitive constraints. For these purposes, the biomechanical parameters of the human hand in the manufacture of microliths are here explored in two individuals with different degrees of expertise. The figures obtained in this manner will be subsequently contrasted and extrapolated to Neanderthal's hand anthropometric data, as obtained from available literature, in order to assess whether microlith industry would have implied significantly higher levels of difficulty and effort to Neanderthals as compared to modern humans.

Materials and methods

Participants

This experiment implied the analysis of the movements of two men during the manufacturing process of microliths from different cores. Both participants are archeologists, have extensive experience in lithic knapping and are part of two recognized research groups in archeology. Participant 1 was 49 years old, with a knapping experience level as an expert, and an experience time of 30 years. Participant 2 was 35 years old, with an intermediate knapping experience level and experience time of 16 years. In both cases the dominant hand was the right one. In a preliminary phase, data collection of clinical history was made, collecting information such as anthropometric data, upper limb joint mobility and length, among others.

Procedure

Tasks. The two knappers were instructed to manufacture a series of backed microliths (characterizing intentional, standardized microliths in the archeological record; e.g., Barrière *et al*., 1969; Ríos-Garaizar *et al*., 2014) of around 30 mm in their largest length and with trapezoidal and triangular shapes. The sequence started from the reduction of an untouched flint core, and finished with the production of small blades, its fragmentation, and the extraction of the microliths by abrupt retouching. Although the whole sequence was recorded and analyzed, our main interest here focused in these final stages of flaking, extraction and retouching.

Video recording - The capture of videos during microliths configuration in the two participants was performed using two digital cameras: a high speed video camera (Panasonic HC-W850) and a standard digital camera (Canon SX230), located in the frontal and sagittal plane participant, respectively. For the biomechanical analysis of the collected images, the SportsCAD Video Motion Analysis software (Seaside Software, Inc) was used, according to the protocol described by Nordin and Frankel (2012) centered on bony prominences of the participant. This procedure allows having a comprehensive observation of the movements and gestures for analysis of the involved segments and their positioning in the manual clamp (finger, palm, wrist, elbow and shoulder), as well as the degree of joint mobility in stages, the frequency of use of each manual clamp and the kinetic chains and bodily location of the center of gravity.

Data analysis

Biomechanical analysis. The analyses focused on the flaking, extraction and retouching stages, as mentioned. To facilitate the analyses, the process is divided into *momentum* and *propulsion* phases, in the case of the dominant (right, in both cases) hand, and *attachment* phase for the non-dominant (left) hand.

The dominant hand is characterized by being the hand holding the hammerstone or punch element that is involved in the momentum and propulsion phases. The momentum phase, or elevation of the striking element, is defined as the movement performed by the upper member from the starting point until reaching elbow flexion enough to start the propulsion phase. The propulsion phase, or dropping the hammerstone, is defined as the movement that makes the upper body, from the peak of elbow flexion to the impact of the striker with the core or flake hold by the non-dominant hand.

The non-dominant hand holds the core during the attachment phase in which the core or flake stabilization to resist direct impact of the hammerstone or punch takes place, in order to produce edge and configure the microlith.

Calculation of mechanical stress in microliths manufacturing. Subsequently, a biomechanical classification of the most frequent manual grips is performed during the flaking, extraction and retouching phases, together with the calculation of mechanical stress, in order to quantify its demands on body and hand for further comparison to Neanderthal parameters. In biomechanics, it is stated that the human body structures are subjected to external and internal loads or forces to generate a mechanical stress in the tissues, whose unit of measure, according to the international system, is expressed in Newtons per square meter [N/m2] or Pascal [Pa], also symbolized as sigma (s) (Dufour & Pillu, 2006; Giancoli, 2004). However, to calculate the mechanical stress experienced by the body structures in the configuration of microliths, it is necessary to extend this definition to the observation of kinetic attributes and to the level-of-effort extraction that this activity may require in modern humans (and possibly in Neanderthals). Accordingly, in this paper mechanical stress *(E_m)* is defined as the force applied by the hammerstone or punch (F) divided by the area of contact with the hand to form the manual clamp (A), multiplied by the *kinetic chain* factor (e_{cc}) that quantifies the level of fatigue, not only of the hand but also of the upper limb (see below). Thereafter, the mechanical stress can be calculated as:

1. $E_m=e_{cc}\cdot(F/A)$

The e_{cc} factor is defined as the ratio between the time of maximum fatigue as measured considering all manual grips involved (t_{fmax}), and the fatigue time of the grip under study (t_f) (see Equation 2). The e_{cc} factor is inversely proportional to the time t_f for which the participant is able to maintain the same position or repetitive gesture without taking a break. The factor therefore indicates the level of effort that the body structure is subjected to before reaching the point of muscle fatigue, and demonstrates that the nature of the clamp (clamp or fixation) greatly influences the mechanical stress (Trew & Everett, 2005). The kinetic chain factor or e_{cc} is actually representing a principle of motion which states that body structures behave as continuous circuits in different directions and spatial planes during a gesture, through which the forces propagate in an ordered sequence of movements that will be essential in the biomechanical analysis (Nordin & Frankel, 2012).

2. $e_{cc}=(t_{fmax}/t_f)$

When the clamp is an *open kinetic chain* (OKC), as in the case of fixation grip, muscle action generates oscillatory movements using a limited number of muscle groups that are contracted in the momentum phase, and then, elongated in the propulsion phase, allowing muscle groups resumption of reserved energy without reaching the point of fatigue easily (Martín-Urrialde & Mesa-Jiménez, 2007).

When the manual grip is a *closed kinetic chain* (CKC), as in the case of manual fixation clamp, muscle action generates stability and supports the use of multiple muscle groups. This type of kinetic chain involves multiple joints and body segments, which will hold the position for long periods of time. In physiological terms, one CKC involves sustaining muscle contraction, decreasing energy supply and metabolic reserves, this leading to a strong increase in fatigue (Martín-Urrialde & Mesa-Jiménez, 2007; Willmore *et al.*, 2007). In Figure 1, a diagram illustrating and summarizing the whole process of measurement and analysis is shown.

Extrapolation of mechanical stress in the Neanderthal. After computing the mechanical stress of the most frequent manual grips in the manufacturing of microliths, it is possible to extrapolate the analyses to Neanderthal's parameters. This departs from the assumption that Neanderthals would perform similar manual grips and would use the same or similar tools in the manufacture of microliths as those used by our sample of subjects. To achieve these purposes, a

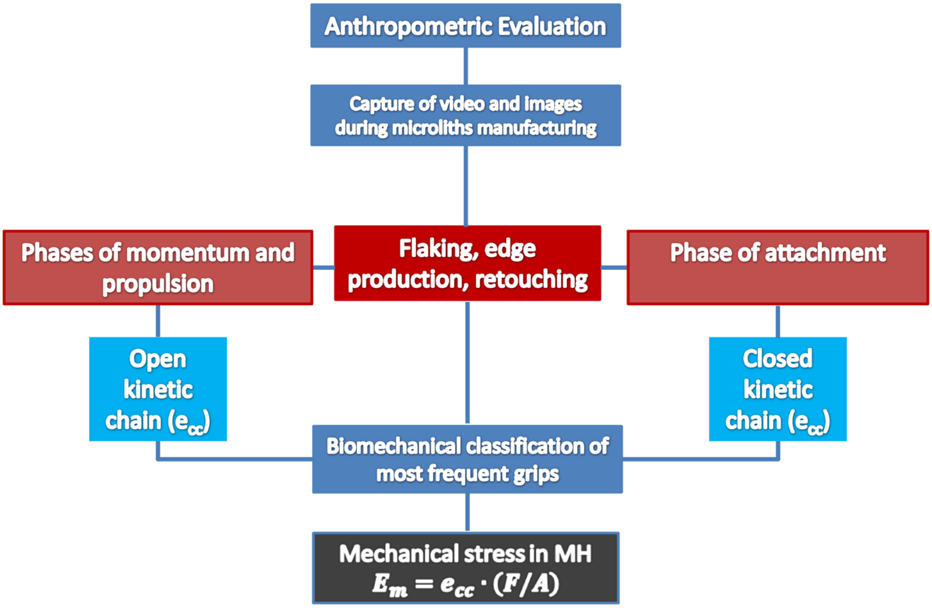


Fig. 1 - Stages in the biomechanical analysis in the manufacturing of microliths. MH: Modern Human; ecc: kinetic chain factor; Em : mechanical stress. The colour version of this figure is available at the JASs website.

review of the available literature on the anthropometry of the Neanderthal hand is needed. Making use of specific data published to date and applying the same criteria as with modern humans, biomechanical analysis of the process of manufacturing microliths is feasible for Neanderthals. In this regard, the data of Neanderthal's hand is made using the reports in Lorenzo (1999), Maki & Trinkaus (2011), Mersey (2013) and Trinkaus (1985). In cases of incomplete data, the measures where complemented from linear interpolation using existing information and relating it to the averaged human hand, considering the average relative deviation estimated in the aforementioned literature. All the information obtained was established and analyzed statistically with the Excel software. To achieve a conclusive analysis of the impact of the grip's contact area on the produced mechanical stress, a 100% is assigned to the grip with the highest stress level in order to obtain the relative stress values for the other hand grips. It is important to note that the initial estimates were made with a relative ratio deviation of ±8.5%, and then the results should be taken within their respective error range.

Results

Biomechanical analysis of microliths manufacture

Participant 1. Figure 2 shows the types of grip used most frequently during the momentum and propulsion phases, which highlights the *three fingers grip*. In this type of clamp, where the tips of the first three fingers hold the hammer stone, the shoulder and elbow joints are flexed stabilizing the arm while the wrist of the dominant hand performs a slight flexion in order to accumulate the energy and transfer it to the center of gravity in the momentum phase. This subject takes a position in which the center of gravity moves down, generating greater stability and accuracy in both the trunk and the upper limbs, essential for fine hand movements involved at this stage.

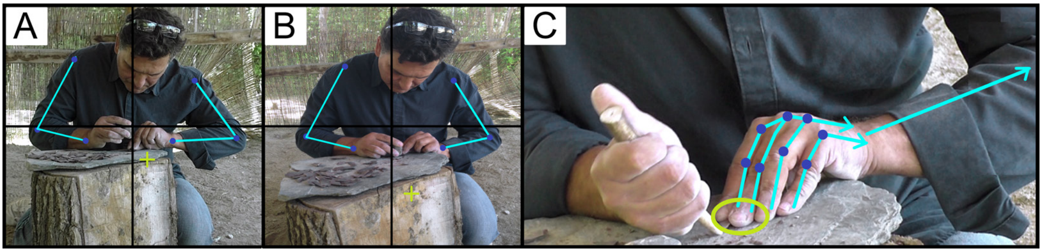


Fig. 2 - Characterization of the stages involved in manufacturing microliths, extraction and retouching steps, Participant 1. A: Phase of momentum during extraction. B: Phase of propulsion during extraction. C: Fixation with non-dominant hand (attachment phase) during retouching. The center of gravity is represented by a yellow cross. The colour version of this figure is available at the JASs website.

During the propulsion phase (Fig. 2B), it can be seen that the efficiency of the three-finger grip depends on the integrity of the first three fingers causing the intervention of the thumb's longest flexor and the superficial flexor of the index finger to fasten the hammer stone, together with the little finger. The lateral face of the little finger avoids any possible displacement of the hammer stone inwards and proximally. Support is given by the forearm in pronation (the right arm of the subject, Figure 2B); this functional position corresponds to a natural balance between opposing muscle groups and interosseous structures, and therefore with minimal muscle wasting.

During the fixation or attachment phase (Fig. 2C), the arm of the non-dominant hand is predominantly bent in the shoulder joint, elbow and wrist. The synergistic and stabilizing action of the flexor muscles in the fingers is provided by the extensor muscles of the wrist; during the extension of the wrist, fingers flexed automatically. This operational position is defined as slight wrist extension from 40° to 45° and slight radial adduction of about 15°. Also in this position, flexor possess maximum efficiency, since the flexor tendons are relatively shorter than in the alignment position of the wrist, generating a greater force when the wrist is flexed (Kapandji, 2007). It has to be noted that the arm of the non-dominant hand meets the principle of *closed kinetic chain* (CKC). The support delivered by the forearm provides stability and prevents the core from moving during impact. This internal stability is the result of joint congruence, the postural control of the entire muscle-chain of upper limbs, and the action of co-contraction of the stabilizer muscles of elbow and wrist involved during supporting and fixation of the core, setting the non-dominant hand as a substantial element for making microliths.

<u>Participant 2.</u> In the momentum phase it can be observed that the characteristics of the gesture are similar to those in Participant 1. In this case, Participant 2 adopts the position shown in Figure 3A, in which the supporting base both increases and lowers the center of gravity by distributing body weight in all four limbs, which provides better stability and accuracy in trunk and upper limbs, initially advantageous for these manual fine movements. However, although the posture increases the stability of the upper limbs, it is observed a moment of force from the spine in the lumbar section, which results in missing the force line on the trunk and not enough contraction in the abdominal muscles, altering the kinetic chain of the upper limb and subsequently a loss of stability and strength.

During the propulsion phase in the dominant hand (Fig. 3B), the efficiency of this three-finger grip depends on one long flexor of the thumb, the superficial index flexor and the little-finger to hold the hammer stone. The predominant support point is the elbow joint, which is limited by a fourth body weight loading it and the subsequent ground reaction force that limits the momentum and propulsion phases. Despite extrinsic factors of this stage (weight of the hammer or punch and

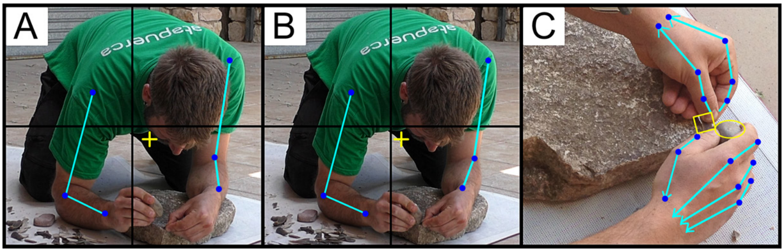


Fig. 3 - Characterization of the stages involved in manufacturing microliths, extraction and retouching steps, Participant 2. A: Phase of momentum during extraction. B: Phase of propulsion during extraction. C: Fixation with non-dominant hand (attachment phase) during retouching. The center of gravity is represented by a yellow cross. The colour version of this figure is available at the JASs website.

of the core stone, the gravity, and the reaction force exerted by the anvil over the core stone), in this posture the height of the anvil becomes a constraint for the execution since it generates even greater decline in the center of gravity. As a consequence, the kinetic chain in upper limbs is out of line relative to load transference and, hence, the involved muscles are insufficient and an overload may occur.

During the fixation phase (Fig. 3C), the arm of the non-dominant hand is flexed at the shoulder joint, elbow and wrist. A synergistic stabilizing action of the flexor muscles of the fingers is given by the extensor muscles of the wrist, so that during the extension of the wrist fingers are flexed automatically. In this manual grip, *finger and thumb tip,* this synergistic action is not adequately met since the wrist is flexed; the flexor tendons are relatively longer than in the alignment position. This condition produces less force in the wrist and decreases efficiency, relative to extending the wrist. Again, the arm of the non-dominant hand complies with the principle of closed kinetic chain (CKC).

In the posture used by this participant, the dominant hand generates its muscular action with two additional factors limiting the muscular efficiency (see Figure 3). First, a quarter of the body weight at the elbow becomes a burden that must be supported by the joint, fatiguing the muscles in the arm at the same time. Second, the muscle *brachioradialis*, which has its attachment with both humerus and radio, will have to meet two actions both as a stabilizer of the elbow joint and as a forearm pronator, generating fatigue earlier than in the position adopted by the Participant 1. Indeed, this position has three limiting factors that sharply influence its internal stabilization and convey a significant increase in fatigue when compared to Participant 1.

1) In addition to doing the manufacturing work, the upper member must endure a fourth of the body weight, resulting in compression or joint at tendon structures in the elbow, affecting the muscular action of the hand and forearm.
2) The wide support base results in a greater torque in spine at the lumbar area, leading to strain in this area.
3) The postural control is impaired due to lack of abdominal muscles contraction, essential to the efficiency of the kinetic chain in the upper limb. This alteration produces a significant increase in fatigue.

Figure 4 displays examples of (trapezoidal microliths produced by the two participants during the present study.

Classification of manual grips in microliths manufacture

Subsequent to the analysis of the different manual grips used by the two participants, a list recording biomechanical properties is extracted comprising *composition*, *position of the segments*,

Fig. 4 - Examples of the microliths crafted by the two knappers in the study. The two leftmost examples (1 & 2) belong to Participant 1; the two rightmost (3 & 4) belong to Participant 2. The colour version of this figure is available at the JASs website.

and *movements* of the manual grip, according to the classification system introduced by Marzke (1997). It is found that each participant takes different manual grips, changing the position of the segments and the composition of the grip. The results are shown in Table 1 for Participant 1 and in Table 2 for Participant 2. Each table contains the most frequent manual grips of each participant for both hands in the stages of flaking and extraction/retouching.

Manual grips classification by mechanical stress level in modern humans

With the aim of summarizing the most relevant results, Table 3 collects the mechanical stress analysis data of the most frequent manual grips throughout the experiment, that is, in both participants for all stages and both hands.

It is remarkable that the non-dominant hand supports higher stress than the dominant one during the manufacture of microliths since it is affected by two factors:

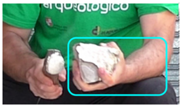
1) This hand has the primary function of stabilizing the core stone allowing an efficient stroke; the upper member obeys the principle of closed kinetic chain (CKC) (Dufour & Pillu, 2006), implying greater fatigue in less time (as explained above).
2) Due to the smaller contact area (e.g. the index-thumb grip), the generated stress has a smaller surface to distribute forces applied by the hammer-stone.

It is also important to note that the level of mechanical stress withstood by the dominant hand is related with the mass of the hammer and the contact area by the factor e_{cc}. This is the expected behavior of the principle of open kinetic chain (OCC). Overall, the human hand holds a significant mechanical stress, especially in those manual grips that imply smaller contact area with the material; however, as aforementioned, the mechanical stress of the execution not only depends on the contact area, it also depends on the mass of the core and

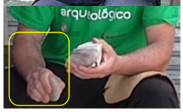
Tab. 1. Most frequent manual grips used by Participant 1 during flaking, extraction and retouching stages of microlith manufacture (dominant and non-dominant hand). IP: interphalangeal; MCP: metacarpo-phalangeal. The colour version of this figure is available at the JASs website.

STAGE	HAND	MANUAL CLAMP	COMPOSITION SEGMENTS	POSITION SEGMENTS	HAND MOVEMENT	MANUAL CLAMP IMAGE
FLAKING	Dominant	3 finger clip (strength & precision pinch)	Thumb / yolks 2^{nd} and 3^{rd} finger	2^{nd}, 3^{rd} , & thumb: MCP bending 4^{th} & 5^{th}: MCP flexion, IP extension	Ulnar deviation Radial deviation Wrist flexion	
	Non dominant	Full hand clamp - pronation (clamp force)	Thumb / 4 fingers - Palm Core weight on thigh	Thumb: Opposition to the 2^{nd} finger 2^{nd} – 5^{th}: IP, MCP and bending 3^{rd} & 5^{th} fingers: flexion IP and MCP	Fixing and Repositioning	
EDGE PRODUCTION/ RETOUCHING	Dominant	Needlenose pliers index (Caliper precision and strength)	Thumb / 4^{th} finger	Thumb - 2^{nd} finger MCP flexion and extension IP flexion 3^{rd}- 5^{th} fingers flexion MCP, Proximal IP – Distal IP flexion	Pronation Wrist flexion	
	Non dominant	Clamp finger and thumb tip (Precision grip)	Thumb / 2^{nd} finger Carpal Support	Thumb: IP, MCP extension 2^{nd} finger: MCP flexion, IP extension 3^{rd}- 5^{th} fingers: MCP - IP bending	Fixation and repositioning	
		Thumb tip clip (Precision grip)	Thumb / 4 fingers Support on anvil	Thumb: MCP extension, IP flexural strength at peak 2^{nd} finger: MCP extension, IP bending 3^{rd} - 5^{th} fingers: IP MCP extension	Fixation	

Tab. 2. Most frequently manual grips used by the participant 2 during flaking, extraction and retouching stages of microlith manufacture (dominant and non-dominant hand). IP: interphalangeal; MCP: metacarpo-phalangeal. The colour version of this figure is available at the JASs website.

STAGE	HAND	MANUAL CLAMP	COMPOSITION SEGMENTS	POSITION SEGMENTS	HAND MOVEMENT	MANUAL CLAMP IMAGE
FLAKING	Dominant	5-finger gripper with buds (Precision Tweezers Force)	Tips of thumb and 4 fingers	Thumb: Opposition to the 2^{nd} finger and extension 2^{nd-5th}: Extension	Ulnar deviation Radial deviation	
	Non dominant	5-finger gripper -supinación (Precision Tweezers Force)	Thumb / 4 fingers, Palm Hammerstone weight over palm area	Thumb: Abduction, MCP and bending IP 4^{th} -5^{th}: abduction, MCP and bending IP	Fixation and repositioning	
EDGE PRODUCTION/ RETOUCHING	Dominant	3-finger gripper with buds (Precision Tweezers Force)	Thumb / 2^{nd} - 3^{rd} fingers	Thumb: Opposition to the 2^{nd} - 3^{rd} finger, MCP - IP bending	Wrist flexion	
	Non dominant	Tip clamp forefinger and thumb, supination (Precision grip)	Thumb / 2^{nd} finger No carpal support	Thumb: IP & MCP extension 2^{nd} finger flexion MCP, Proximal IP flexion, Distal IP extension 3^{rd}- 5^{th} finger: MCP - IP bending	Fixation	

Tab. 3. Most frequent manual grips in modern humans during microliths manufacture (dominant and non-dominant hand) and mechanical stress data. The colour version of this figure is available at the JASs website.

STAGE	HAND	CLAMP TYPE	CONTACT AREA - (CM²)	CORE MASS (KG)	FACTOR E_{cc}	E_M (PA)	RELATIVE STRESS	STRESS LEVEL	MANUAL CLAMP IMAGE
FLAKING	Dominant	3-finger gripper	17.93	0.08	1.15	504.5	69%	High	
FLAKING	Dominant	5-finger gripper with buds	29.29	0.1	1.00	334.6	46%	Medium	
FLAKING	Non dominant	Full hand clamp - pronation	72.39	0.23	1.53	476.6	65%	Medium	
EDGE PRODUCTION/ RETOUCHING	Dominant	Needlenose pliers index	18.83	0.03	2.94	459.2	63%	Medium	
EDGE PRODUCTION/ RETOUCHING	Dominant	3-finger gripper with buds	25.24	0.05	1.60	309.8	42%	Medium	
EDGE PRODUCTION/ RETOUCHING	Non dominant	Clip-tipped forefinger and thumb, supination	12.66	0.01	3.57	276.5	38%	Medium	
EDGE PRODUCTION/ RETOUCHING	Non dominant	Clamp finger and thumb tip	33.35	0.01	4.17	294.8	40%	Medium	
EDGE PRODUCTION/ RETOUCHING	Non dominant	Thumb tip clip	8.75	0.01	6.52	730.4	100%	High	

the nature of the clip (i.e. support or fixation). For Grip 1 (three-finger grip), for example, mechanical stress is high since the mass of the core is high compared with Grip 8 (index tip and thumb), which is the clamp with the highest mechanical stress given its lower contact area and despite the low mass of the core. With regard to the nature of the clip, it can be said that in a fixation clamp the kinetic chain factor e_{cc} is high, increasing the mechanical stress level according to Equation (2), due to the continued tension in the involved muscles and the small contact area to distribute the load.

Biomechanical analysis of Neanderthal hand applied to microliths manufacture

It is possible to extend the mechanical stress (*Em*) observation to other individuals, such as the Neanderthal, by relating the identification of manual grips and biomechanical structures with morphological attributes. Based on anthropometric data given in Table 4, it is possible to calculate the level of mechanical stress withstood by the Neanderthal hand when executing manual grips similar to those used by the participants described in this paper. As a comparative study, the results of the extrapolation of the mechanical stress from the modern human hand to the Neanderthal hand are shown in Table 5. The mass of the core-stone and the hammer-stone were measured in the laboratory through precision scales.

Neanderthals would withstand greater mechanical stress, because the average anthropometric measurements of their hand are lower than the corresponding ones in the modern human hand, that is, they have shorter fingers and palm. This condition would generate an increased mechanical stress for a certain mass of manipulated material and for a certain force applied both to support and fixation grips. Nevertheless, the hands are not the unique structures burdened during the manufacturing process. The arms are part of the body structures that distribute the mechanical stress. Neanderthals had shorter arms (Grotte, 2011), which further diminishes the surface in which stress is distributed, compared to current human.

Overall, based on observations of the modern human hand and considering the morphological characteristics of the Neanderthal hand registered in archaeological evidence, it is possible to conclude that Neanderthals could execute the manual grips in tool making, but not with the efficiency of modern humans, because of their small hands that would result in a smaller area to distribute forces and therefore a greater mechanical stress on manual grips. By presenting a mechanical stress ratio of 2.5: 1 compared to modern humans (see Tab. 5), Neanderthals possibly were not able to withstand the mechanical stress required by manual grips, being the process of manufacturing microliths inefficient and too demanding for them, due to their biomechanical conditions and the small size of this industry.

Tab. 4. Anthropometric data of the Neanderthal hand.

SEGMENT	THUMB	FINGERS			
		2ND	3RD	4TH	5TH
MTC	44.1a	74.8b	69.0b	50.8d	54.3d
PPH	29.5b	39.6 d	35.1b	38.1 d	29.6d
MPH	-	27.7d	28.3c	27.7d	15.0d
DPH	24.8d	20.7d	22.9b	18.5 d	16.8b
Media distal width	12.6d	10.7d	12.9d	10.0d	9.5d

All measurements are in mm. A (-) indicates that the measure does not apply to the thumb phalanx. Average measurements of Neanderthal hand bones from the following collections of Neanderthal fossils: Data correspond to (a) Amud 1 La Chapelle-aux-Saints 1, Feldhofer 1, La Ferrassie 1 and 2, Kebara 2, Kiik-Koba 1, Regourdou 1, Shanidar 4, and Tabun 1 (Trinkaus & Maki, 2011) ; (b) Moula - Guercy (Mersey, 2013); (c) La Chapelle - aux-Saints, The Ferrassie 1, Regourdou 1 2 Krapina 201.1 Kebara Shanidar 3, 4, 6, Tabun 1 (Lorenzo, 1999); (d) calculations by linear interpolation of data in Moula - Guercy (Mersey, 2013), applied to the lengths in the image of the Neanderthal hand Shanidar 4 (Trinkaus 1985). MTC: metacarpal. PPH: proximal phalanx. MPH: middle phalanx. DPH: distal phalanx. A relative ratio deviation of +8.5% applies to the data.

Discussion

In this paper, an experimental approach that involves a biomechanical analysis of the movements of the human hand is used with the aim of defining the biomechanical demands and the manual grips involved in microliths manufacture. Through this analysis it has been possible to characterize the process of manufacturing microliths in two experts and the biomechanical requirements applied to the modern human hand. Based on these preliminary observations and considering the morphological characteristics of the Neanderthal hand registered in the archaeological record (see Tab. 4), it is possible to extend the biomechanical analysis of microlith manufacturing to the Neanderthal hand (see Tab. 5), in order to determine its degree of ability and biomechanical constrains to produce microliths.

It has been possible to show here that, in the manufacture of microliths, efficiency of manual grips depends directly on both the posture that is adopted and the upper limb positioning when performing each manual grip. In

Tab. 5. Comparison of mechanical stress of manual grips between the modern human (MH) and Neanderthal (ND) estimated hand.

STAGE	HAND	CLAMP TYPE	ND CONTACT AREA (CM²)	CORE MASS (KG)	E_M (PA) ND	E_M (PA) MH	ND INTENSITY RELATIVE TO MH	STRESS LEVEL ND
FLAKING	Dominant	3-finger gripper	9.9	0.08	911	504.5	181%	High
		5-finger gripper with buds	14.1	0.1	697	334.6	208%	High
	Non dominant	Full hand clamp - pronation	116.2	0.23	297	476.6	62%	Medium
EDGE PRODUCTION/ RETOUCHING	Dominant	Needlenose pliers index	73.0	0.03	118	459.2	26%	Low
		3-finger gripper with buds	12.2	0.05	644	309.8	208%	High
	Non dominant	Clip-tipped forefinger and thumb, supination	6.4	0.01	547	276.5	198%	High
		Clamp finger and thumb tip	6.4	0.01	638	294.8	216%	High
		Thumb tip clip	3.7	0.01	1709	730.4	234%	High

addition, applying the principle of kinetic chain, it has been possible to analyze the biomechanical requirements of the manual grips, in relation to the nature of the grip (support or fixation), and quantify them by calculating the e_{cc} factor. This complements the conventional definition of mechanical stress, which only takes into account the mass of the hammer or the core involved in the process and the contact area with the hand.

From our analysis it can be settled that Neanderthals would exhibit lower efficiency than modern humans in the execution of manual grips for manufacturing microliths. This is mainly a consequence of their smaller hands, resulting in a smaller area to distribute forces and an increased mechanical stress in the microlith manufacturing processes. Our data are in consonance with reports by Trinkaus & Villemeur (1991) or Niewoehner (2001), in the sense of reduced accurate control in Neanderthals when manipulating small objects or the presence of derived features in *Homo sapiens*' hand facilitating fine work. Our present data represent empirical evidence supportive of this depiction. Culley

(2006) reached similar conclusions in an unpublished study that analyzed the biomechanics of art production. Most postures that appeared unique to Paleolithic image-making in Culley's (2006) study were found to be directly facilitated by features specific of the *Homo sapiens* hand.

In order to be cautious, nonetheless, it must be considered that the capacity of Neanderthals for fine works such as microliths or art production is not necessarily refuted here. Rather, what our results indicate is that it was highly demanding for them. This in turn would plausibly be a contributing factor for precluding or limiting image and microlith production in Neanderthals, at least on noticeable scales, in consonance with the archeological record.

Although our conclusion does not necessarily presume neurocognitive differences between Neanderthal and modern humans, it can be speculated that differences in this regard might have been present. Neurocognition is deeply rooted in bodily experience, being the body a complex and dynamic interface whose systems of perception and motor-control interact with each other and with the internal and external world. These interactions, in turn, influence brain structure and neural function (Longo, 2015; Maravita *et al.*, 2002; Maravita & Iriki, 2004). In recent theories of cognition, such as the embodied cognition (Barsalou, 2008; Carota *et al.*, 2012; Caligiore & Fischer, 2013) or the enacting cognition models (Bruner & Lozano, 2014; Malafouris, 2013), cognition is deeply embedded within the material world; objects such as tools are an integrating part of the neural-cognitive circuits, modulating the way these circuits develop and are stablished. It may be suggested therefore that disparities in the cognitive and neural domains might have also existed between Neanderthals and modern humans regarding fine motor control abilities, in accordance with differences at the biomechanical domain. In Martín-Loeches (2017) arguments are provided for possible core differences in the corticospinal system, rooted in M1 or primary motor cortical areas. Association, premotor cortical areas might also be implied, particularly regions such as PMV, in charge of controlling manual grips (Davare, 2011; Santello *et al.*, 2013).

The study of the biomechanics of an extinct species is not without its limitations, particularly when applied to a concrete function such as microliths manufacture. Most of the analyses performed involve a number of assumptions, and are based on two samples of modern human behavior and information from the archeological record that is necessarily limited and incomplete. In this regard, our approach must be considered preliminary, granting further explorations with wider samples. In addition, it cannot be discarded that Neanderthals could have approached microliths manufacture through alternative biomechanical programs compensating their hand limitations, though this seems improbable. In our opinion, the data obtained here are representative enough as to how the human species affords microliths manufacture, being therefore informative to the field and contributing to reckon possible intervening factors arising along human evolution.

Acknowledgements

FYP & MML are funded by grant PSI2013-43107-P from the, Ministerio de Economía y Competitividad –MINECO, Programa Estatal de Investigación Científica y Técnica de Excelencia, Spain. MT-B received a fellowship from the Cátedra Atapuerca (Atapuerca Foundation and Duques de Soria Foundation).

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Editor, Giovanni Destro Bisol