C. R. Palevol 17 (2018) 388–398

Contents lists available at ScienceDirect

Comptes Rendus Palevol

www.sciencedirect.com

Human Palaeontology and Prehistory

Consider the third dimension: A new approach for measuring the symmetry of the middle Paleolithic points of the Mirak Site

La troisième dimension à prendre en considération : une nouvelle approche pour mesurer la symétrie dans les pointes du Paléolithique moyen du site de Mirak

Nasim Feizi[a], Hamed Vahdati Nasab[a,*], Thomas Wynn[b]

[a] *Department of Archaeology, Tarbiat Modares University, Tehran, Iran*
[b] *Department of Anthropology, University of Colorado, Colorado Springs, USA*

ARTICLE INFO

Article history:
Received 3 June 2017
Accepted after revision 23 November 2017
Available online 8 March 2018

Presented by Marcel Otte

Keywords:
Index of symmetry
The deviation of symmetry
3D comparison
Middle paleolithic
Points
Iran

Mots clés :
Indice de symétrie
Déviation de la symétrie
Comparaison 3D
Paléolithique moyen
Pointes
Iran

ABSTRACT

There is evidence that recognizes the importance of symmetry in the study of the evolution of hominid cognition. The development of stone tools parallels the evolution of human cognition. The last three decades have used quantitative methods that the most important of which is Symmetry Index. This paper proposes a new methodology for measuring the deviation of symmetry using 3D comparison. It focuses on the stone points of the largest Middle Paleolithic open-site in Iran, Mirak. Our results show that the index of deviation of symmetry (IDS) assesses all of the points as symmetrical tools, while this number drops to 133 pieces using 3D comparison. In addition, paired samples t-test suggests a positive correlation between the increasing proportion of preparation removals and the decrease in deviation of symmetry on the two sides of the tools. Thus, it is likely that symmetry is affected by the morphology characteristics.

RÉSUMÉ

Il y a une preuve qui reconnaît l'importance de la symétrie dans l'étude de l'évolution de la cognition des hominidés. Le développement des outils en pierre suit un chemin parallèle à celui de l'évolution de la cognition humaine. Les trois dernières décennies ont utilisé des méthodes quantitatives, parmi lesquelles l'indice de symétrie est la plus importante. Cet article propose une nouvelle méthodologie pour mesurer la déviation de la symétrie utilisant la comparaison 3D. Elle se focalise sur les pointes en pierre du plus grand site à ciel ouvert d'Iran, Mirak. Nos résultats montrent que l'indice de déviation de la symétrie (IDS) estime que toutes les pointes sont des outils symétriques, alors que leur nombre tombe

---

* Corresponding author.
E-mail address: vahdati@modares.ac.ir (H. Vahdati Nasab).

https://doi.org/10.1016/j.crpv.2017.11.004

à 133 lorsqu'on utilise la comparaison 3D. En outre, un test-*t* par échantillons appariés évoque une corrélation positive entre la proportion croissante d'enlèvements en cours de préparation et la décroissance de déviation de la symétrie des deux côtés des outils. Il est donc probable que la symétrie est affectée par les caractéristiques de la morphologie.

1. Introduction

The Middle Paleolithic is an important period in several respects that include the rise of *Homo sapiens* (Coolidge et al., 2007), the first possible encounter between early *Homo sapiens* and Neanderthals in Levant (Shea, 2013), the cognitive evolution of *Homo* (Ambrose, 2001), and the different uses of common tools such as points by *Homo sapiens* (throwing) and Neanderthals (thrusting) (Wynn and Coolidge, 2012). In this respect, points as effective hunting weapons are important tools for understanding the similarities and differences between cognitive and behavioral capacity and subsistence patterns in these two hominids. Thus the study of the morphological characteristic of points could be an effective approach. One of the most important components of both morphological and cognitive aspects in these tools is symmetry. The fact that symmetry is an important issue in spatial cognitive development was first revealed in Acheulean handaxes (Wynn, 2002), but has so far remained a highly controversial issue. The reason for this is that anthropologists disagree among themselves in response to the question: what causes the symmetry? Responses, in general, can be divided into four categories: cognitive factors (Hodgson, 2015; Wynn, 2002), functional, adaptive or social reasons (Kohn and Mithen, 1999; Lycett, 2008; Machin et al., 2007; Mithen, 1994), procedural reasons (McPherron, 2009), and aesthetic reasons (Hodgson, 2009). Generally, what is clear is that the symmetrical structure of Acheulean bifaces trace the cognitive evolution of *Homo species* (Hodgson, 2015) and what is not clear is what causes the survival of symmetry in handaxes. Although the debate about symmetrical handaxes remains controversial, we believe that changing our vision and attention to a wide range of symmetrical tools related to the transition from the Acheulean to the middle Paleolithic can help us in providing an answer to the question. The fact that the second symmetrical tool was the point (middle Paleolithic) shows that these two tools overlapped with each other at the end of the history of handaxes (Mcbrearty and Christian, 2006). Hence the study of points may provide novel insights to understand the nature of symmetry in tool-making and cognitive processes of *Homo sapiens*. It should be noted, however, that such an issue will be resolved when our qualitative methods not only measure the symmetry of stone tools but also help to understand the relationship between cognitive ability of tool makers and the use of symmetry. Thus this paper aims to propose a new methodology for quantitative analysis of the symmetry of points and its relationship with cognitive ability of *Homo*. Therefore, this study focuses on middle Paleolithic points from the Paleolithic site of Mirak, the largest middle Paleolithic open-air site in Semnan, Iran.

2. Archaeological background: Mirak

Mirak is located in the northern edge of the Iranian Central Desert, approximately 16 km south of the modern city of Semnan and 220 km east of Tehran. The approximate area of Mirak is 1.6 km^2. The site includes eight mounds, with relative height between 4–11 m. Discovered in 1985 by Kabiri and Mahryar, the site was surveyed in 2009 by Vahdati Nasab (Rezvani and Vahdati, 2010). The results obtained from the preliminary survey of Mirak showed that Mirak is a major middle Paleolithic site (Vahdati Nasab et al., 2013). Excavation in Mirak started in 2015 under the direction of Vahdati Nasab and Gilles Berillon. To date, the Iranian -French team have undertaken two seasons of excavations in Mirak. The preliminary survey (2009) provided about 9000 lithic fragments (Vahdati Nasab et al., 2013), but this paper focuses on 153 points.

One hundred and ninety-nine of points were obtained from Mirak, but 46 were fragments and excluded from this study. We have not been able to perform any micro wear analysis on Mirak's points. However, the point's breakage pattern and/or morphological characteristics of intact points can be used to estimate their performance. Interestingly, as shown in Fig. 7, the means of morphological characteristics of Mirak are comparable with Tor Faraj Levallois points (Groucutt, 2014). These features include weight, length, max width, width at medial, thickness at medial, maximum thickness, relative platform size. In addition, breakage pattern of Mirak points are comparable with experimental trials of Levallois points that were done by Sisk and Shea (Sisk and Shea, 2009) and a few were comparable with the pattern of breakage of a Levallois point that was embedded in the vertebra of a wild ass in Umm el Tlel (Boëda et al., 1999). With regard to this evidence, we can say that the points of Mirak are like other sites, particularly the sites of Levant. These lithic points were not projectile point; instead, they were hafted point (Sisk and Shea, 2009) and used as thrusting spears. Of course, this does not mean that these points had no other performance.

3. Methodological background: the quantitative analysis of artifact

The use of quantitative analysis is a well-established approach in the analysis of symmetry in artifacts. Saragusti and Sharon (1998) were among the first to provide a method for the quantitative analysis of symmetry using a landmark method. In this method, the margins of images are determined by boundary points called landmarks. Two images will be considered: the original image of the objects, with boundary points indicated in Euclidian space, and its symmetrical image. The symmetrical image is the same original image; the only difference is that the boundary points have been displaced so that the original image has been converted to a symmetrical image. The aim of this work is to find the closest symmetric image (optimal) to the original, such that the displacements of landmarks are minimal (Salomon and Avnir, 1999).

The continuous symmetry measure (CSM) proposed by Saragusti and colleagues displays "the minimum distance that the specified points (Vertices) on a shape go through to achieve optimal symmetry". It is important to emphasize that this formula measured the minimal difference between ordinary shapes (handaxes) with its optimal type.

In the same vein, Lycett et al. (2006) proposed a formula for the analysis of symmetry in handaxes, the "Index of symmetry". In this method, the left and right side (width) measurement is calculated by a crossbeam coordinate caliper. Thus, "Index of symmetry" is the main method used to compare the relative bilateral symmetry of nuclei (Lycett, 2008). These methods are particularly useful because of their quantitative nature, but we believe that the use of landmarks results in measurement error. This means that measurement precision depends on the placement accuracy of a landmark.

3D methods have been developed and introduced to measure the symmetry of Paleolithic artifacts. Researchers have largely focused on handaxes (Beyene et al., 2013; Couzens, 2012; Grosman et al., 2008, 2011; Li et al., 2015; Shipton et al., 2013) and evaluated the degree of symmetry over time. The current paper proposes a new methodology for the symmetry analysis of artifacts in general, and points in particular. The main issues addressed in this paper are:

- selecting an appropriate variable to measure symmetry;
- offering a new formula for "Index of symmetry" and measuring the degree of symmetry deviation using 3D scanning technology;
- offering an intuitive method to understand the deviation of symmetry that exists on the surface of each artifact or lithic point.

4. Materials and methods

The data used in this investigation are 153 lithic points, a total of which were scanned in the Rock Mechanics Laboratory, Tarbiat Modares university, using Optic Scan 3D Scanner, and Version 2.2. Once the digitization was completed, 3D images were analyzed and compared by Geomagic software[1] (version 2013). Also a Marcus Bader Ruler[2] was used to bisect each lithic point (version 5.1). In addition, statistical analysis was performed using SPSS software (version 23).

The mathematical definition of bilateral symmetry is fundamental to the quantitative study of the symmetry of stone tools. In mathematics an object is symmetric when its right side is congruent to its left side. This means that one side is not larger or smaller than the other one. Therefore, those who work on symmetry in three-dimensional space usually, in addition to landmarks, focus on volume, area, or both of these variables. One of the big advantages of these two main types of variables is that they are independent of landmark placing.

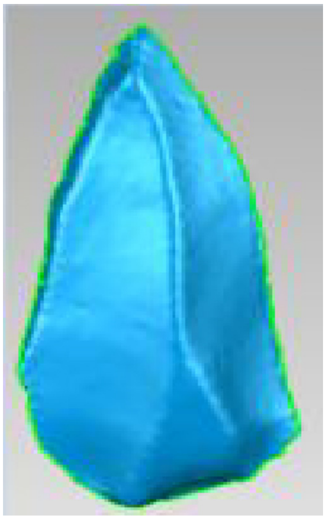


Fig. 1. Mesh Model.
Fig. 1. Modèle Mesh.

The present paper initially focuses on obtaining a formula for "Index of symmetry". To begin this process Geomagic software was used as follows. When data scanning is finished, the points are displayed in the form of cloud points in the software. In the second step, the cloud points is inverted to a real and 3D image from the scanned image. For this reason, depending on the research strategy, two surfaces will be created: A Mesh Model (test model) (Fig. 1) and a CAD Model (reference model) (Fig. 2).

The Mesh Model is structural building of a 3D model containing polygons. In this model, software computes a triangle (a polygon) from any three (several) points that are not on a straight line, such that the total of the lithic point is covered by small triangles, and at a glance one can recognize the lithic point structure. In this case, each triangle has length, width and height of itself that calculated by its *X*, *Y*, *Z* coordinates. In addition to countable surface, the reference model (CAD) was created to compare the surface characteristics. The reference model is thus a 3D map of the exact surface of objects. It can be said that the reference model (CAD) defined the geometry of the surface. This means that all topographic characteristics were determined precisely and adjusted with Mesh Model, such that the Mesh Model is placed over this surface and the surfaces are compared by the software.

This operation permits mathematical calculations on a triangulated surface (Mesh Model). All surface points were meshed by means of Geomagic Studio 2013. Then, the total surface area of lithic point was calculated by means of Geomagic Studio 2013. In addition, a Reference Model (CAD) was created to eliminate the measurement error. Finally a Mesh Model was fitted on the CAD Surface. Combining the two models will eventually allow dividing of the lithic

---

[1] Geomagic®, Morrisville, North Carolina
[2] © Markus Bader - MB-Software solutions

Fig. 2. CAD Model.

Fig. 2. Modèle CAD.

point with more precision than using Mesh Model alone. This new lithic point is called the 3D lithic point for ease of recognition. The 3D lithic point is divided into two parts along dividing the line of the lithic point using MB-ruler in the following steps. Each 3D lithic point is inscribed in a quadrangle, so that four (or three) vertices of the lithic point are tangent to the four sides of the quadrangle (Fig. 3). Next, as shown in Fig. 4, the quadrangle is halved and each triangular lithic point is divided into two smaller triangles (the right and left) and the areas of the two triangles are calculated (Fig. 4). Obviously, if the left and right are equal then the difference between the two sides of the lithic point will be equal to zero. Hence, symmetry is perfect. But in the reality, perfect symmetry is impossible and there is always a numeric value ($S_L - S_R \neq 0$). In fact, this numeric value is the deviation of perfect symmetry (DS) and IDS is equal to DS divided by the total area of a lithic point (S_T).

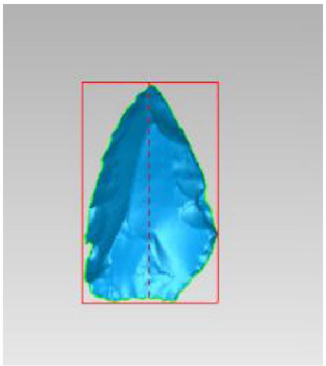


Fig. 3. Each point is being inscribed in a quadrangle.

Fig. 3. Chaque pointe est inscrite dans un quadrangle.

$$D.S. = |S_L - S_R|$$

$$I.D.S = \frac{|S_L - S_R|}{S_T}$$

S_R = the right side.
S_L = the left side.
DS = deviation from symmetry.
IDS = index of deviation of symmetry.

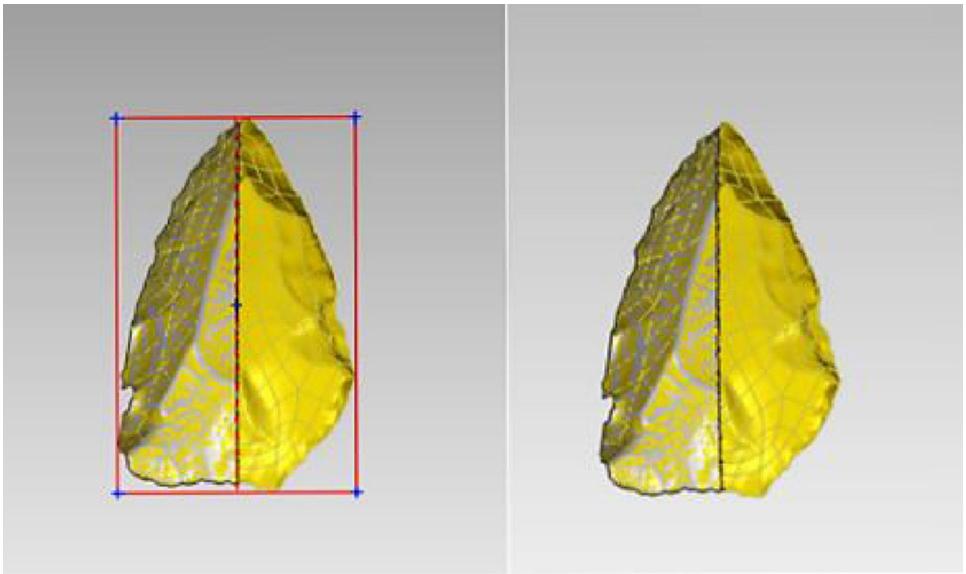


Fig. 4. Halving quadrangle is causing halving tools.

Fig. 4. Le quadrangle de réduction détermine les outils réduits en deux.

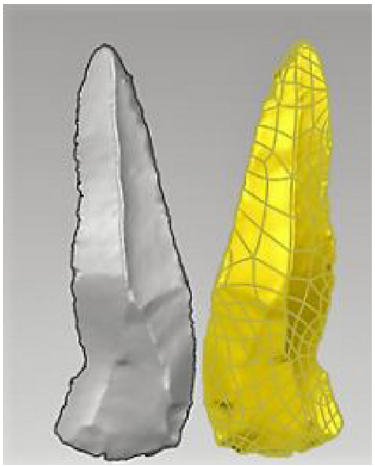


Fig. 5. The surface of any point is compared with its mirrored surface.
Fig. 5. La surface de chaque pointe est comparée à la surface de son reflet dans un miroir.

This method is particularly useful in studying the degree of deviation of symmetry. However, it is necessary but not sufficient to have an index to estimate the amount of deviation on the grounds that this index will tell us what the percentage of deviation is, while it is unable to answer other questions such as how this deviation is dispersed on the surface. Furthermore, this index ignores other important variables that exist entirely on the surface, including the characteristics of shape and topography. Thus, we offer a supplemental method to consider other variables called “3D Compare”.

Our approach follows a simple logical model. When an object is symmetric then the two sides (left and right) coincide with each other along its longest axis. It is clear that artifacts do not have perfect symmetry and even if these artifacts are symmetric, the two sides cannot fully overlap each other and there is a degree of deviation. This method is used to provide a deeper insight in the degree of deviation, and to evaluate the effectiveness of other surface variables. The method is based on the comparison of surface morphology, which means that the surface of each lithic point is compared with its mirror-image surface (Fig. 5). In this way, the left side is compared with the right side and vice versa. This geometric process in Geomagic software is as follows.

In this method once again, the Mesh Model is placed on the CAD Model. The difference is that prior to putting the Mesh Model above the CAD Model, it is essential that the CAD Model should be reflected by mirror function in Geomagic Qualify 2013. Then, the Mesh Model is imported onto Geomagic Qualify 2013 and two model mirrors are facing each other (Fig. 5). In order to compare the two sides of the lithic point, it is essential that the Mesh Model be placed on top of the CAD Model (Fig. 6). This process is performed using Best Fit Alignment of the Germanic Qualify 2013. Best Fit Alignment uses an iterative closest point algorithm to best fit the objects. Once the alignment is completed, the 3D compare function is activated and deviation analysis is performed. This is a method to calculate the degree of deviation of symmetry. The output parameters generated from the 3D comparisons, including positive and negative deviations, explain how much the surface of the Mesh Model is above or below the surface of the CAD Model, respectively. In this case, 3D deviation is measured and its amount showed how much the left side of the lithic point deviated from the right side and vice versa (Fig. 6). The software shows the deviations using a color spectrum. The great advantage of this spectrum is that it is highly intuitive in showing the degree of deviation of two surfaces. In fact, the colors are the representation of numerical interval. The maximum deviations of two surfaces in the lithic points of Mirak is ±3 mm We considered (±0.5) as the minimum degree of deviation, and the greater the distances, the more the degree of deviation until the distances were about ±3 mm. Then, we chose a color spectrum to display these numeral interval, so that each colors represents a degree of deviation. For example, on the spectrum, the red and navy color show that numerical maximum deviation between (+3, +2.5) and (−3, −2.5), respectively and if the deviation is less than this value, the color range is closer to green so that the minimum deviation is (±0.5, 0 mm) and its color is green. It should be noted that the color spectrum in this paper includes 13 colors: 6 colors for the points are above the reference surface, 1 color for the deviations are less than ±0.5 and 6 colors for the points are below the reference surface.

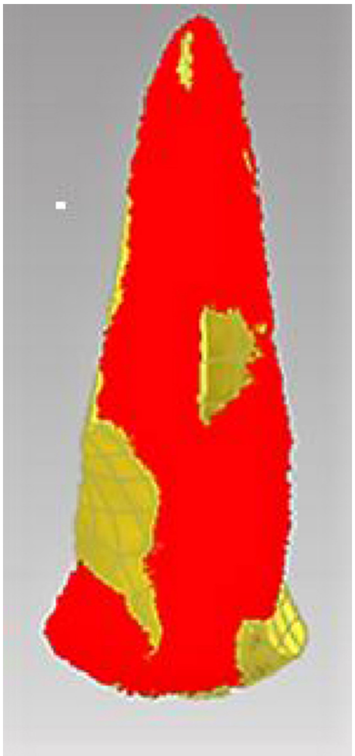
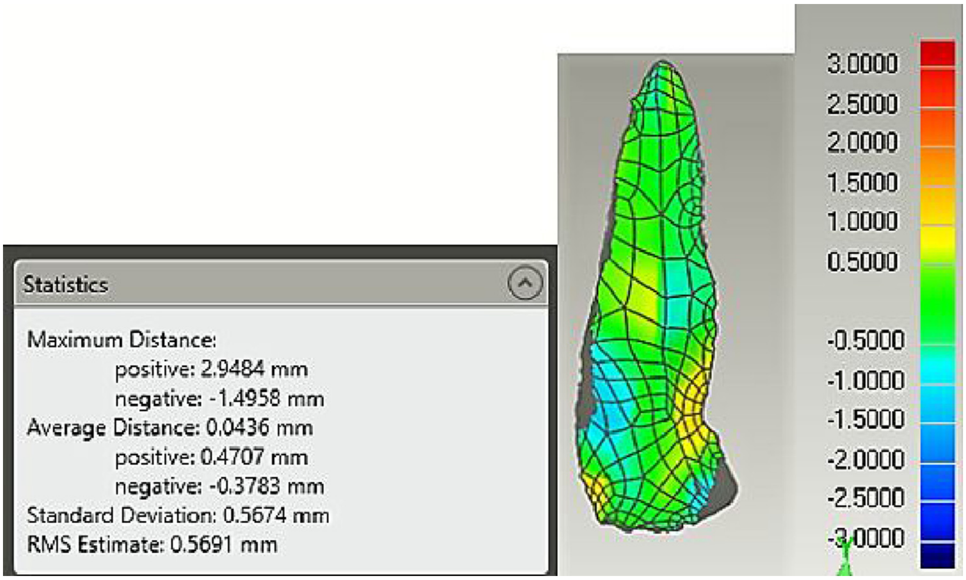


Fig. 6. Mesh Model is placed on top of the CAD Model.
Fig. 6. Le modèle Mesh est placé au sommet du modèle CASH.

The outputs were presented in the form of a deviation distribution of points (*x*, *y*, and *z*) and in the form of output parameters generated from the 3D comparisons. The deviation distribution is the deviation of points (*x*, *y*,


Statistics

Maximum Distance:
positive: 2.9484 mm
negative: -1.4958 mm
Average Distance: 0.0436 mm
positive: 0.4707 mm
negative: -0.3783 mm
Standard Deviation: 0.5674 mm
RMS Estimate: 0.5691 mm

Fig. 7. The deviation of symmetry.
Fig. 7. Déviation de la symétrie.

and z) of two surfaces in three-dimensional space. In this paper about 9,000 to 45,000 points were processed for each lithic point according to its area and meshed surface. Next, we defined mathematical conditional functions to find the deviation of each point and then obtained the frequency of the distribution of deviations in numerical intervals for each lithic point. The 3D deviation analysis between two sides of a lithic point revealed maximum positive and negative deviation, average positive and negative deviation, and root mean square (RMS) values and standard deviation (Fig. 7). The study of these aspects shows the importance of topographical characteristics to make a symmetrical lithic point. Therefore, these two values of deviation are numerical scales for the comparison of topographical features of the two sides of a lithic point.

As mentioned earlier, the management and analysis of all these data were performed using SPSS 23.

In addition to 3D comparison, a directional comparison was performed. In this comparison, deviations are reported as the distance from the Test to the Reference in a single user-defined direction. In this paper, we selected the height direction (z) of the lithic point because overlapping the height direction is greater than other directions (x, y) in uneven surfaces.

The reason for this is that we found that symmetrical lithic points have a certain pattern during 3D comparison. This means that when a symmetrical lithic point is halved, the two sides have a conventional scale and a regular pattern in terms of ridges and troughs (Fig. 8).

Consequently, the difference in the depth of the two sides is a key factor in geometric measure of symmetry.

The logic of using this type of qualitative method is to measure the difference in the preparation of left and right sides for each lithic point. In addition, the directional comparison as an auxiliary variable is effective in subsequent analysis.

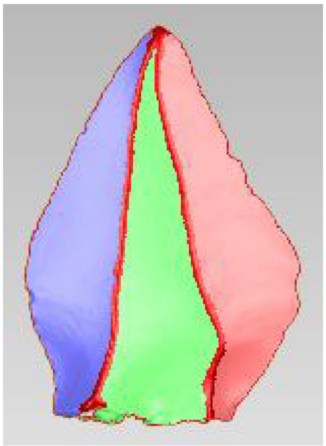


Fig. 8. Symmetrical point with a regular pattern in terms of ridges and troughs.
Fig. 8. Pointe symétrique avec configuration régulière des crêtes et des creux.

Thus, it seems that height or depth axes as directional axes are valuable variables for quantitative analysis of the deviation from symmetry. The execution procedure of directional deviation method is similar to 3D deviation in Germanic Qualify 2013.

In addition, paired t test (0.05) was used to analyze the relationship between variables related to symmetry in Mirak. This test will be more completely discussed in the results section.

5. Results

The first step of analysis aimed to determine the IDS for the points of Mirak. The results obtained from the preliminary analysis of this data are illustrated in Table 1.

Table 1
Summary of preliminary analysis. The average of IDS and area.
Tableau 1
Résumé de l'analyse préliminaire. Moyenne d'IDS et de surface.

	Area (mm^2)	S_R = right area	S_L = left area	DS	IDS
n		153	153	153	153
Mean	1250.8	628	622.7	89.5	0.07
Std. error of mean	38.4	19.8	19.8	6.7	0.005

Table 2
Deviation distribution between two sides of the Mirak points at regular intervals.
Tableau 2
Distribution de la déviation entre deux côtés de pointes de Mirak à intervalles réguliers.

Statistics	< 0.5%	$d < 1$	$1 \leq d < 1.5$	$1.5 \leq d < 3$
n	Valid	133	133	133
Mean	49.1	75.75	13.1	11.1
Std. deviation	16.3	14.8	6.4	9.4
Minimum	18.3	35.3	1.5	0.1
Maximum	87.8	98.9	29.30	42.70

As can be seen, the average area of the Mirak points is 1250.8 mm^2 and the IDS average is equal to 0.07.

The second step of the analysis aimed to determine the value of coordinate deviation of symmetry. The results of the average of deviations is presented in Table 2. Fig. 7 demonstrates that the range of color represents a numerical distance ranging from maximum to minimum deviation (compare Table 2 and Fig. 7). On the spectrum, red and navy colors show maximum numerical deviation between (± 3 ± 2.5 mm). If the deviation is less than this value, the color range is closer to green and the numerical deviation is (± 0.5, ± 0 mm). It is apparent from Table 2 that most deviations are less than 1 mm (75.75%), whereas approximately half of all deviations (49.1%) are less than 0.5 mm and only 11% of deviations are more than 1.5 mm. In other words, about 76% of deviations belongs to intervals that have less than the 1/3 (mm) total deviations, and it is a small amount. It is essential to remember that the maximum deviation is ± 3 mm.

It can be seen from the data in Table 2 that the least deviation is related to the most symmetrical sample (87.7% of the surface of the points that had a deviation less than 0.5, Fig. 9) and the least degree of symmetry is related to the points which had the most deviation (42.2% of the surface of the point had a deviation more than $1.5 \leq d$, Fig. 10). The Table 3 illustrates deviation distribution between the two sides of these two lithic points.

The third stage of analysis aimed to assess the deviation of symmetry at the two sides of lithic points using the quantitative analysis of surface topography and morphology. The results of this comparative method are presented in Table 4.

It should be noted that positive values in the Table 4 indicate outward deviation and negative values indicate inward deviation.

As shown in Tables 1 and 2, the number of lithic points in this method has fallen to 133 pieces because the two sides of other lithic points do not overlap each other along an axis of symmetry (Fig. 11). The reason for this is the two sides of other lithic points have the significant differences in their surface morphology characteristics along the axis of symmetry (Fig. 11). For example, the height of one side may be different than its other side. In this case, one lithic point coincides with its mirrored-image along the most similar morphology and cannot overlap along axis of symmetry.

In other words, the two surfaces overlap along the most similar surface structures. In addition, the averages of the largest positive and negative differences between the two surfaces are equal to 2.88 and −2.81, respectively. The value of the root mean square deviation (RMS) is associated indirectly with the degree of deviation. For example, consider the evidence of qualitative analysis of the most symmetrical and the least symmetrical Mirak point (Table 5).

What is interesting in this data is that surface morphological characteristics are closely linked to the degree of deviation of symmetry of the points in particular, and stone tools in general. In other words, symmetry and the degree of preparation removals are related to each other.

The value of root mean square deviation (RMS) for the most symmetrical and the least symmetrical Mirak point is equal to 0.38 and 1.53, respectively (Table 6). This shows that the surface difference between the two sides of lithic points along a symmetry axis is a key factor in

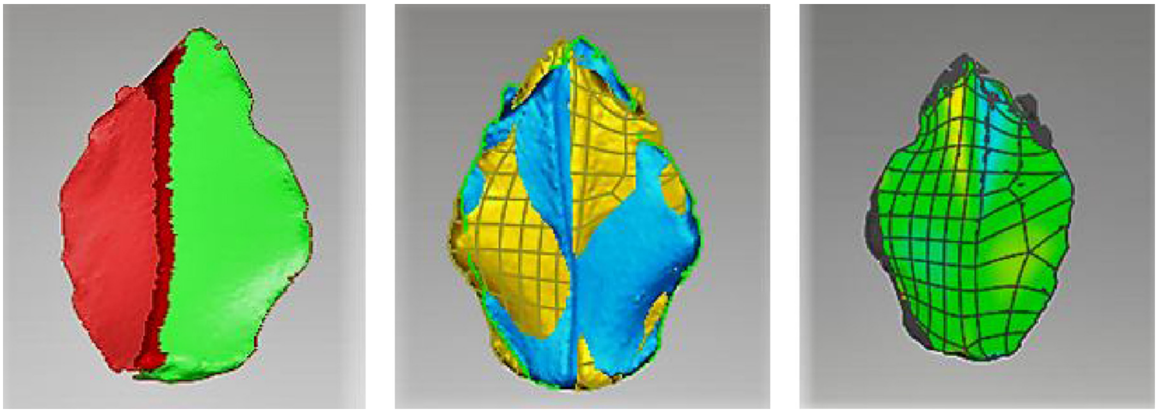


Fig. 9. The most symmetric Mirak point figures, a regular pattern in terms of ridges and troughs.
Fig. 9. Figures de pointes de Mirak avec la meilleure symétrie, à configuration régulière en termes de crêtes et de creux.

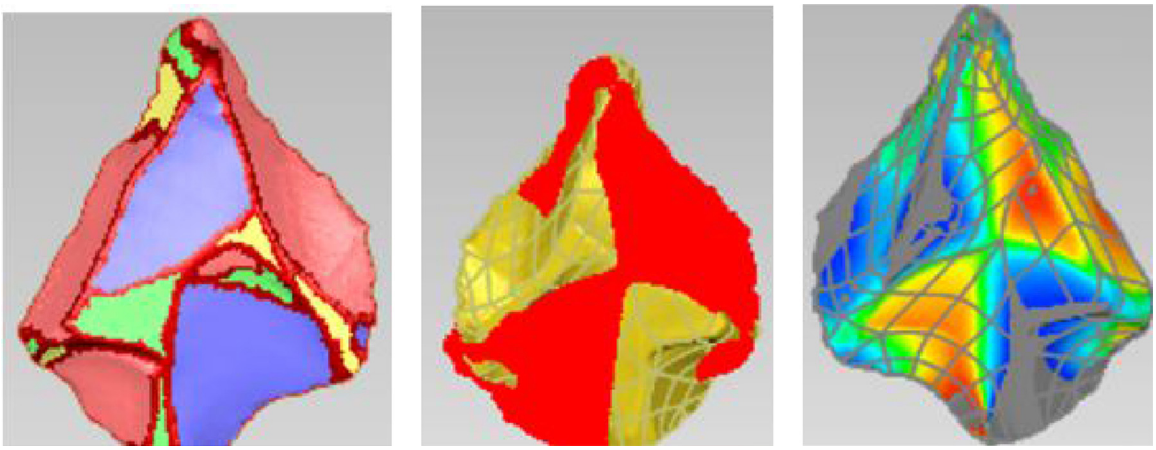


Fig. 10. The least symmetric Mirak point.
Fig. 10. Pointe de Mirak avec la moins bonne symétrie.

Table 3
Deviation distribution between the two sides of the most symmetric Mirak point and the least symmetric Mirak point.
Tableau 3
Distribution de la déviation entre les deux côtés de pointes de Mirak, celle à la meilleure symétrie, l'autre à la plus mauvaise.

Variable	< 0.5%	$0.5 \leq d < 1$	$d < 1$	$1 \leq d < 1.5$	$1.5 \leq d < 3$
The most symmetric point	87.8	10.2	9.8	1.5	0.6
The least symmetric point	23.6	24.9	48.5	20.6	31

Table 4
Summary of deviation analyses. d_{max} (+), the largest positive difference between two surfaces; d_{max} (−), the largest negative difference between two surfaces; d_{vag} (+), mean positive difference between two surfaces; d_{vag} (−), mean negative difference between two surfaces; RMS, root mean square of deviation; RMS_d, root mean square of directional deviation.
Tableau 4
Résumé des analyses de déviation : d_{max} (+), la plus grande différence positive entre deux surfaces ; d_{max} (−), la plus grande différence négative entre deux surfaces ; d_{vag} (+) différence positive moyenne entre deux surfaces ; d_{vag} (−) différence négative moyenne entre deux surfaces ; RMS quadratique moyen de la déviation ; RMS_d, quadratique moyen de la déviation directionnelle.

Variable	d_{max1}	d_{max2}	d_{vag1}	d_{vag2}	RMS	RMS_d
Mean	2.88	−2.81	0.70	−0.69	0.89	0.99
Std. deviation	0.28	0.39	0.24	0.29	0.38	0.26

Table 5
Summary of deviation analyses the evidence of qualitative analysis of the most Symmetrical and the least symmetrical Mirak point.
Tableau 5
Résumé des analyses de déviation sur la pointe de Mirak la plus symétrique et sur la pointe de Mirak la moins symétrique.

Variable	d_{max1}	d_{max2}	d_{vag1}	d_{vag2}	RMS	RM_d
The most symmetrical Mirak point	1.27	−1.9	0.26	−0.30	0.38	0.43
The least symmetrical Mirak point	3	−3	1.17	−1.41	1.53	1.61

Table 6
Directional deviation distribution between the two sides of the Mirak points.
Tableau 6
Distribution de la déviation directionnelle entre les deux côtés des pointes de Mirak.

Statistics	<0.5%	$0.5 \leq d < 1$	$d < 1$	$1 \leq d < 1.5$	$1.5 \leq d < 3$
Mean	43.2	26	69.3	14.6	15.6
Std. deviation	16.3	5.7	16.4	6.1	11.9

determining the degree of symmetry. As shown in Fig. 9 the more symmetric the lithic point is, the more the regular pattern preparation. Therefore, we performed the directional comparison (height) to study structure and surface morphology of two sides of each lithic point and its impact on the degree of deviation of symmetry.

The reason for this is that the comparison of one side of the lithic point with the other side shows that the preparation pattern of symmetric and asymmetric lithic points are quite distinct (Figs. 11 and 12). Therefore, directional comparison helps us understand the degree of difference between the two sides of a lithic point.

Data from this table can be compared with the data in Table 2 which shows that both of these methods produce almost the same results. In addition, the result of paired t test indicates that there is significant difference between RMS and d RMS ($sig = 0.00$, $t = 6$) using the two methods as the increasing proportion of preparation removals of lithic point (decrease indirectional RMS) and the decrease in deviation of symmetry (decrease in RMS). Overall, both methods focus on the pattern preparation removals (Table 7).

As mentioned, symmetry is an evolutionary phenomenon in terms of both physical and cognitive abilities. The fact that hominids intended to enhance the deadly power of their weapons without approaching targets and enemies. For this purpose, they were required to use tools which had sharp tip, lightweight and balance. With this purpose in mind, they needed to produce symmetrical balance in their thrusting and throwing points. The left and right side of the points should be trimmed around the symmetrical axis so that the tools have approximately the same shape, size, weight and height on both of the sides. Imposing symmetry and hafting the spear point extended the symmetrical axis, increased force, and

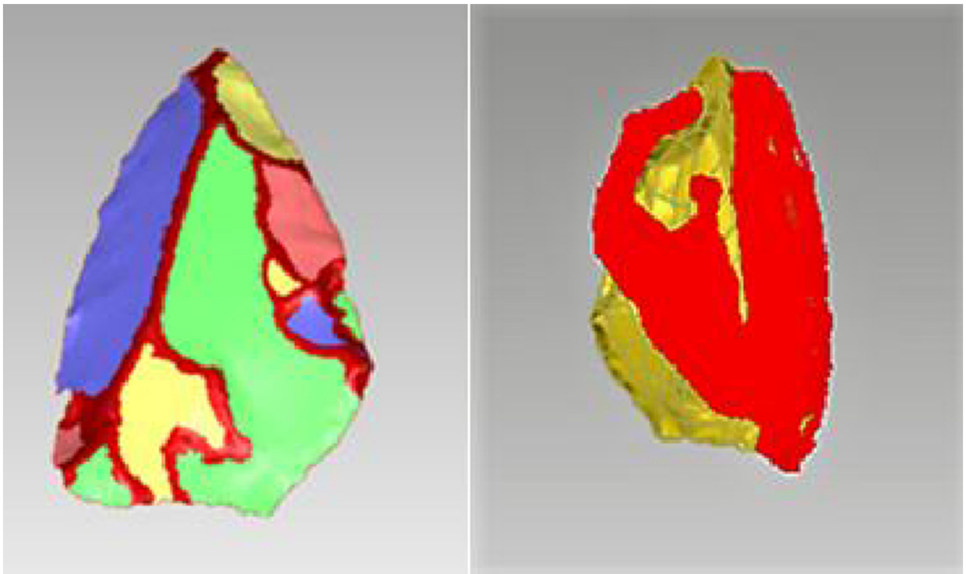


Fig. 11. Unsymmetrical point (the impact of preparation removals on asymmetry).
Fig. 11. Pointe asymétrique (impact des enlèvements en cours de préparation sur l'asymétrie).

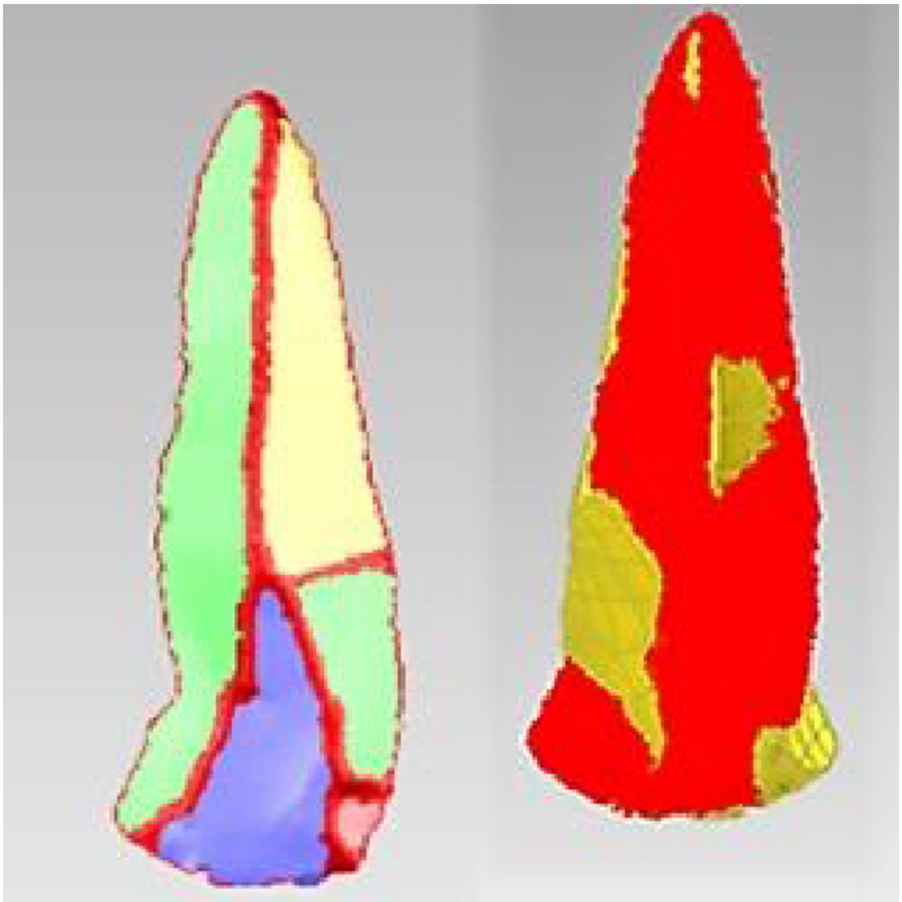


Fig. 12. Symmetrical point (the impact of preparation removals on symmetry).
Fig. 12. Pointe symétrique (impact des enlèvements en cours de préparation sur la symétrie).

Table 7
Compare descriptive statistics for Levallois point morphology of Tor Faraj (Groucutt, 2014) and Mirak.
Tableau 7
Comparaison de statistiques descriptives relatives à la morphologie de pointes Levallois de Tor Faraj (Groucutt, 2014) et de Mirak.

Mirak	*n*	Min	Max	Mean	S.d.	Tor Faraj	*n*	Min	Max	Mean	S.d.
All points											
Weight (g)	153	2.87	51.6	12.59	7.4		107	1.1	44.6	14.4	8.5
Length (mm)	153	32.0	98.0	51.6	10.7		107	21.4	97.1	54.9	13.4
Width at med (mm)	153	11.3	45.3	24.6	6.3		107	12.9	46.4	28.2	7.4
Max width (mm)	153	6.3	63.9	28.4	7.9		107	16.4	64.51	37.0	9.8
Thickness at med (mm)	153	3.1	20.7	7.5	2.5		107	2.1	11.5	6.2	1.9
Max thickness (mm)	153	3.4	43.1	9.2	4.4		107	2.5	13.1	7.9	2.3
Relative platform size (mm^3)	153	0.65	14.5	4.9	2.4		107	1.8	42	8.9	5.9

produced greater destructive power. Applying this particular geometry, more than anything else, required the evolution of "conscious attention".

It should be noted that conscious attention, along with balancing the depth of both sides of the stone points, not only was a key factor in the proper operation of the stone points of the Middle Paleolithic but also is one of the main components of cognition. In current research, conscious attention assumes a considerable place because there had been an overlap between two independent factors "consciousness" and "attention" which serves as a practical purpose (Haladjian and Montemayor, 2015). This means that conscious attention is focused on high- level processing which is made by the combination of small units so as to hit a target (Coolidge and Wynn, 2009). It is a well-established fact that the combined small units had been "unconscious attention" or "low-level visual processing" that can be found in all species (Haladjian and Montemayor, 2015). What is more, it should be mentioned the fact that there is a tight relation between attention and working memory (Coolidge and Wynn, 2009). There is no doubt that higher-level visual processing needed attention in order to carry out maintenance in working memory structures, and also establish relationship with the contents stored in their long-term memory. Therefore, it can be inferred that the evolution of conscious attention stem from the interaction between attention and working memory (Haladjian and Montemayor, 2015). On the other hand, archaeological evidence suggests that the Levallois reduction method is more complicated in comparison with biface reduction and thus it is required to a larger attention capacity and more working memory. What is more, it utilizes more resources of long-term memory compared to biface reduction (Wynn and Coolidge, 2010). As a result, it requires more conscious attention. In addition, it can be noted that perception and making a Levallois or a Mousterian point need greater cognitive capacity in comparison to Acheulean handaxes.

Symmetry is a good indicator to help to understand cognitive and behavioral capacities of hominids. Most studies in the field of symmetry have only focused on the first symmetrical tools, Acheulean handaxes, and quantitative methods have been used to investigate this case. These studies have attempted to assess the deviation of symmetry by a numerical index (for example, Lycett et al., 2006; Saragusti et al., 1998). In contrast, the present study is designed to propose a new methodology for quantitative analysis of the symmetry of lithic points using IDS method and 3D comparison. The most obvious finding to emerge from the analysis is that the index of deviation of symmetry measured only the difference between surface areas of two sides of the same tool. It is interesting to note that we did not find a statistical correlation between IDS and other variables such as topographical characteristics.

It is reasonable to assume that surface morphology and topographical characteristics of tools can affect the deviation of symmetry. When the two halves of a lithic point are aligned, depending on the similarity of surfaces, they can have a degree of overlap (Fig. 12). This is the reason why in this study, exactly 20 lithic points were asymmetrical and excluded from analysis. Thus, the IDS method may be proper for measuring the deviation of symmetry in handaxes. However, lithic points have a different performance when hafted as thrusting points or projectiles (in next period). Force needed to be distributed symmetrically on lithic point in order to follow aerodynamic rules. Therefore, these points require an exact method for measuring the deviation of symmetry.

Generally, the results indicate that the increase in preparation removals on the two sides of tools may be an important factor in the significant decrease in the deviation of symmetry. Hence, the results of this study indicate that considering all the surface features is essential for symmetry analysis. The association of these factors needs to be investigated in future studies.

References

Ambrose, S.H., 2001. Paleolithic technology and human evolution. Science 291, 1748–1753.

Beyene, Y., Katohc, S., WoldeGabriel, G., 2013. The characteristics and chronology of the earliest Acheulean at Konso, Ethiopia. National Academy Sciences USA 110 (5), 1584–1591.

Boëda, E., Geneste, G., Griggo, J.M., et al., 1999. A Levallois point embedded in the vertebra of a wild ass (*Equus africanus*): hafting, projectiles and Mousterian hunting weapons antiquity (73)., pp. 395–402.

Coolidge, F.L., Wynn, T., 2009. The rise of *Homo sapiens*: the evolution of modern thinking. Wiley-Blackwell, New York [209 p.].

Couzens, R.A., (Thesis) 2012. An analysis of the symmetry of large cutting tools within the South African Acheulean. Faculty of science, university of the Witwatersrand, Johannesburg (45 p.).

Grosman, L., Goldsmith, Y., Smilansky, U., 2011. Morphological analysis of Nahal Zihor handaxes: a chronological perspective. Paleo Anthropology, 203–215.

Grosman, L., Smikt, O., Smilansky, U., 2008. On the application of 3-D scanning technology for the documentation and typology of lithic artifacts. J. Archaeol. Sci. 35, 3101–3110.

Groucutt, H.S., 2014. Middle Palaeolithic point technology, with a focus on the site of Tor Faraj (Jordan MIS 3). Quat. Int., 1–22.

Haladjian, H., Montemayor, C., 2015. On the evolution of conscious attention. Psychon. Bull. Rev. 22 (3), 595–613.

Hodgson, D., 2009. Evolution of the visual cortex and the emergence of symmetry in the Acheulean techno-complex. C. R. Palevol. 8 (1), 93–97.

Hodgson, D., 2015. The symmetry of Acheulean handaxes and cognitive evolution. J. Archaeol. Sci. Rep. 2, 204–208.

Kohn, M., Mithen, S., 1999. Handaxes: products of sexual selection? Antiquity 73 (281), 518–526.

Li, Kuman, K., Chaorong, L., 2015. The symmetry of handaxes from the Dajyangkou reservoir region (central China). Quat. Int., 1–8.

Lycett, S.J., 2008. Acheulean variation and selection: does handaxe Symmetry Fit neutral expectations? J. Archaeol. Sci. 35, 2640–2648.

Lycett, S.J., von Cramon-Taubadel, N., Foley, R.A., 2006. A crossbeam coordinate caliper for the morphometric analysis of lithic nuclei: a description. Test and empirical examples of application. J. Archaeol. Sci. 33, 847–861.

Machin, A.J., Hosfield, R.T., Mithen, S.J., 2007. Why are some handaxes symmetrical? Testing the influence of handaxe morphology on butchery effectiveness. J. Archaeol. Sci. 34, 883–893.

Mcbrearty, S., Christian, T., 2006. From Acheulean to Middle Stone age in the Kapthurin formation, Kenya. In: Hovers, E., Kuhn, S.L. (Eds.), Transitions before the transition evolution and stability in the middle Palaeolithic and middle Stone age. Springer, pp. 257–277.

McPherron, S.P., 2009. Perspectives on stone tools and cognition in the early Palaeolithic record. In: Sanz, J., Call, J., Boesch, C. (Eds.), Tool use in animals: cognition and ecology. Cambridge University Press, New York, pp. 286–309.

Mithen, S., 1994. Technology and society during the middle Pleistocene: hominid group size. Social Learning and industrial variability. Camb. Archaeol. J. 4, 3–32.

Rezvani, H., Vahdati, N., 2010. A major Palaeolithic open site at Mirak. Semman Province, Iran. Antiquity 84, 323.

Salomon, Y., Avnir, D., 1999. Continuous symmetry measures: a note in proof of the folding/unfolding method. J. Math. Chem. 25, 295–308.

Saragusti, I., Sharon, I., 1998. Quantitative analysis of the symmetry of artefacts: lower Palaeolithic handaxes. J. Archaeol. Sci. 25, 817–825.

Shea, J.J., 2013. Stone tools in the Palaeolithic and Neolithic Near East: a guide. Cambridge University Press, Cambridge [82 p.].

Shipton, C., Clarkson, C., Palb, J.N., et al., 2013. Generativity, hierarchical action and recursion in the technology of the Acheulean to Middle Palaeolithic transition: a perspective from Patpara, the Son Valley, India. J. Hum. Evol. 65 (2), 93–108.

Sisk, M.L., Shea, J., 2009. Experimental use and quantitative performance analysis of triangular flakes (Levallois points) used as arrowheads. J. Archaeol. Sci. 36, 2039–2047.

Vahdati Nasab, H., Clark, G.A., Torkamandi, S., 2013. Late pleistocene dispersal corridors across Iranian plateau: a case study from Mirak, a middle palaeolithic site on the northern edge of the Iranian Central Desert (Dasht-e Kavir). Quat. Int., 1–8.

Wynn, T., 2002. Archaeology and cognitive evolution. Behav. Brain. Sci. 25, 389–438.

Wynn, T., Coolidge, F.L., 2010. How Levallois reduction is similar, and not similar to, playing chess. In: April, N., Davidson, I. (Eds.), Stone tools and the evolution of human cognition. University Press of Colorado, Colorado, pp. 83–103.

Wynn, T., Coolidge, F.L., 2012. How to think like a Neanderthal. Oxford University Press, New York (153 p.).