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ORIGINAL PAPER

# Lincombian-Ranisian-Jerzmanowician points were used primarily as hunting weapons: morphological and functional analysis of points from Nietoperzowa Cave, southern Poland

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## Abstract
Points from the Lincombian-Ranisian-Jerzmanowician complex (LRJ) evoke numerous comments regarding their cultural patterning and their typo-technological characteristics. The unceasing interest in this group of tools is additionally stimulated by the fact that, in light of the most recent chronometric data, the development of the LRJ complexes in Europe coincides exactly with the period of the Neanderthals' extinction and the niche extension by modern humans. So far, however, scant information has been provided on the weapon systems used by the hunter-gatherers of LRJ. A re-examination of this group of tools from Nietoperzowa Cave in Poland, the richest LRJ set in Europe, provides new data which fill this gap. Using a multi-proxy approach, which involves geometric-morphometric analyses as well as microscopic and technological studies, we concluded that the points form a homogeneous group with respect to their morphology and functional character. Our findings suggest that the shape subject to predominantly laterisation was the result of the selection of half-product or elongated flakes, and the use of a consistently repetitive procedure to form the proximal and distal parts. The microscopic examination provided evidence that the points were mainly used as components of hunting weapons. We also obtained, for the first time, evidence that answers the question of how some points may have been mounted. In terms of tip cross-section indices, the points from Nietoperzowa Cave are intermediate between arrowheads and tips of the atlatl and examples of Middle Palaeolithic points; they differ only slightly from Szeletian points, which are assigned to the late Middle Palaeolithic or Early Upper Palaeolithic (EUP). They show an affinity to some blade EUP industries.

**Keywords** Projectile technology · Geometric-morphometric · Traceological study · Tip cross-section area · Lincombian-Ranisian-Jerzmanowician

## Introduction

The problem of points associated with one of the transitional industries, namely the Lincombian-Ranisian-Jerzmanowician (LRJ) in Europe, has been discussed almost since the beginning of academic archaeology. The first to consider their role was J. Evans 150 years ago (Evans 1872, 450–452), based on finds from Kent's Cavern (UK). At that time, their very broad function was proposed. As observed in an important work on the LRJ by D. Flas (2008), despite the many years that had elapsed since then, not much has been solved.

While assessing the previous attempts at explaining the role of the LRJ points, two concepts can be advanced based on macroscopic observations and typological data. One indicates a multi-functional character of the tools

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(see Jacobi et al. 2007, 245), and another advocates their main use as projectile points (Flas 2011, 611, for further references). The concept of multi-functionality is in agreement with a variety of archaeological observations, which indicate that the points often bear traces of various activities, such as scraping, cutting, digging and, obviously, projection (Nelson 1991, 1997; Rots and Plisson 2014; Shott 1986). The advocates of this concept point also to the versatility and flexibility of this group of tools which determines their usefulness related to a wide range of tasks (Nelson 1997, 374).

In our opinion, despite the universal morpho-functional features of the blades, before imposing a priori their interpretation as multi-functional tools, an assessment of their role should undergo individual tests on each occasion. There are sound reasons to claim that many points from the start of their "life" may have been destined for a variety of tasks during hunting expeditions (Lazuén 2012); thus, it is difficult to consider their form and function as "one-to-one" (see Iovită 2009). Apart from this, we have evidence that in some situations, the points could be utilised as very specialised tools, for example knives (Newman and Moore 2013) or tips of hunting weapons (Geneste and Plisson 1993; Kufel-Diakowska et al. 2016).

In our attempt at estimating the role of the LRJ points, we considered two criteria. The first was the homogeneity of their morphometric features tested with statistical tools. In our opinion, the greater the homogeneity, the larger the probability of association with a structurally complex tool kit, which means a deeper specialisation and a narrower range of roles. Obviously, the criterion is not decisive because of the circumstances mentioned above. The second criterion concerned information on the tool's use, following from the analysis of macro- and microscopic traces on the tools. Considering these criteria, we formulated two working hypotheses. According to the first, the shape of the LRJ points and their function might be discrete (mode: Swiss army knife, i.e. multi-tool); in the second, the LRJ points were originally components of a weapon system, and in the case of necessity, for example dictated by risk minimisation (see Torrence 1989), they were retooled to assume the role of a similar or a quite different tool, for example burin (mode: projectile point first).

We hope that the solution to the above-outlined problem should make it possible to understand the LRJ weapon system in terms of its degree of specialisation. We think that the features of the hunting equipment system may also facilitate the answer to the question regarding which of the populations present in Central Europe 40–45 thousand years ago had a strong association with the LRJ. It should be emphasised that in light of the most recent chronometric and genetic studies the development of the LRJ coincided with the significant extension of the niche of modern humans and the decline of the Neanderthal population (Higham et al. 2014; Fewlass et al. 2020; Prüfer et al. 2021).

In our studies, we used an integrated approach including geometric-morphometric methods, an analysis of tip cross-sectional geometry as well as a traceological analyses, supplemented with technological observations. We based our research on the richest LRJ collection from Central Europe, which originates from Nietoperzowa Cave in the village of Jerzmanowice, situated in the district of Olkusz, Poland (Fig. 1). The collection includes several dozen complete tools and numerous fragments.

The presented results of our analyses indicate a high degree of formal and functional homogeneity. They also show that the LRJ points differ from those of the late Middle Palaeolithic and other Central European points of such industries as the Szeletian culture, which opens a discussion about the authors of their propagation.

## Material and methods

### Material

#### Basic information on Nietoperzowa Cave

The material comes from Nietoperzowa Cave which is located in the southern part of a well-recognised karstic region called the Kraków-Częstochowa Upland (Fig. 1a, N 50°11′38.00″, E 19°46′29.00, 438.4 m a.s.l.). The cave, situated above the uppermost part of the Będkowska Valley and measuring 326 m long, is among the largest karst forms of its kind in Poland (Fig. 1b, c). The first notes on its exploration date from 1854, and the first artefacts from the cave were recovered in the 1870s by F. Römer (1875). The stratigraphic position of the complexes with points was first specified by L. Kozłowski (Kozłowski 1922; Sawicki 1925). He made a trench to the left of the entrance. The excavations were continued between 1956 and 1963 by W. Chmielewski (Fig. 1c). The stratigraphy was presented by T. Madeyska-Niklewska (Fig. 1d) who distinguished several layers with artefacts from various periods, dated from the end of the Middle Pleistocene to MIS 3 (Krajcarz and Madeyska 2010; Madeyska 1982; Madeyska-Niklewska 1969).

The uppermost part of the section, measuring over 6 m, was destroyed during the mining of sediments used as fertiliser. The LRJ artefacts were contained in three of the layers distinguished by W. Chmielewski (1961). The greatest number of finds comes from the lower layer (6) composed of fine rounded limestone debris and loam with a large admixture of charcoal. The finds were accompanied by traces of hearths situated 12 m from the present cave entrance (Chmielewski 1975, 120). The bear bones which were found here provided the basis for the theory that the LRJ people hunted bears in

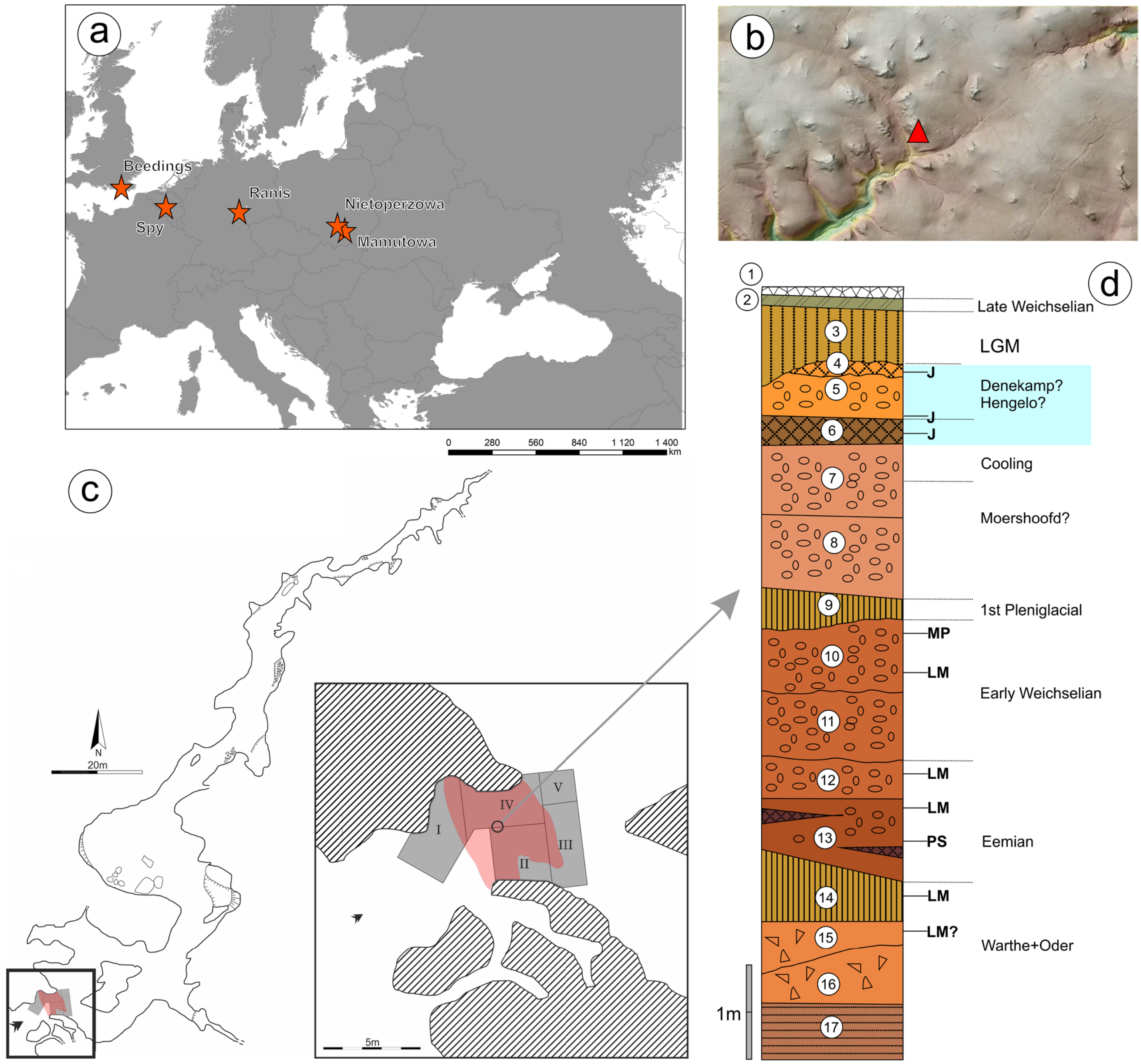



**Fig. 1** **a** Location of Nietoperzowa Cave and other Jerzmanowician sites discussed in the text; **b** location of Nietoperzowa Cave in Będkowska Valley; **c** plan of Nietoperzowa Cave (based on drawing of A. Górny & M. Czepiel) and position of the archaeological trenches of L. Kozłowski (in red) and W. Chmielewski (in grey); **d** simplified cross-section of Nietoperzowa Cave (according Madeyska-Niklewska 1969; Madeyska 1982 and Krajcarz, Madeyska 2010). LRJ artefacts were found in layer 4, 5 and 6th

Nietoperzowa Cave (Chmielewski 1961, 1975). Somewhat fewer finds come from layer 5a, which is composed of loam. The layer also contained one hearth. The artefacts assigned to layer 5a were found on the surface of layer 6 or 1–2 cm above it. Layer 4 was located at a level composed of a mixture of loam and rock debris. It was distinctly separated from layers 6 and 5a. The artefacts were buried in a thin layer covered by the youngest loess. The exact location of some of the finds from the pioneering period of exploration (second half of the 19th c. and the 1920s) is unknown.

In recent decades, several attempts at radiocarbon dating have been carried out which reveal a more complex chronostratigraphic situation which questions the existence of two chronologically distinct settlement episodes that show questions (Kozłowski 2002; Kozłowski and Kozłowski 1996). Based on the dating of charcoal and bone remains, the finds were assigned to the period of 44 to 35 kyr (Chmielewski 1961; Kozłowski 2000; Krajcarz et al. 2018; see also Kot et al. 2020). The dating places the industry in a period later than the Szeletian or Bohunician cultures, which were included in one group: the EUP industries (Kozłowski 2017). It should be emphasised that other scholars classify Szeletian as the Late Middle Palaeolithic and Bohunician as the Initial Upper Palaeolithic (Demidenko et al. 2020; Hublin 2015).

### Artefacts

The numbers of artefacts given by W. Chmielewski (1961) as well as Kozłowski and Kozłowski (1977) and Flas (2008) are somewhat disparate: from 244 to 338 finds, including between 69 and 88 points. The summary presented by W. Chmielewski (1961, 26–27, 30–31, 34–35), in which he combined his own finds with artefacts discovered by F. Römer and L. Kozłowski, is the most credible (88 points and several dozen fragments). Later, the collection was dispersed among several institutions. It is now stored at the Institute of Archaeology and Ethnography, the Polish Academy of Sciences, the National Museum of Archaeology in Warsaw, the University of Warsaw, and the Ojców National Park Museum.

In our studies, we relied on materials which showed a connection to the manufacture or use of retouched tools, including points. The analysis focused on 66 specimens of points or their fragments (Table 1). Overall, the fragmentation of the whole collection is considerable. Among the points 55% are damaged; single specimens had been in contact with fire. Fragments of tips and bases predominate among the collection. The middle parts may have undergone strong fragmentation and thus were omitted during exploration conducted without sieving.

## Methods

In this paper, concerning LRJ, points are interpreted as symmetrical forms with a shaped tip and base, often with traces of regularisation of their sides and devoid of backs. They are divided into blade points, which as a rule, predominate in the complexes and bifacially worked pieces (Jacobi et al. 2007; Jacobi and Higham 2011, 185). There also exists a division into points that were retouched on one or two sides (Flas 2011; Kozłowski 1922; Kozłowski and Kozłowski 1996) or into leaf points (bifacially worked point) and blade points (e.g. Pettitt and White 2012). The traditional name of Jerzmanowice points refers to blade and flake forms (Müller-Beck 1968). We use the term points for all the specimens, noting the range of retouch: partially retouched or fully bifacially retouched.

**Table 1** Complete tools and its fragments

| Points | *n* | % |
|---|---|---|
| Balde/flake points | 26 | 39.39 |
| Bifacial | 1 | 1.52 |
| Fragments | 36 | 54.55 |
| Modified-retooled | 3 | 4.55 |
| Total | 66 | 100 |

In order to answer the question regarding the appearance and function of the artefacts called points, we performed an array of different studies. A part of the results that supplement the main research path is presented in Electronic Supplementary Information 1–4.

We made another attempt to analyse selected features of the raw material and technology, using the approach proposed by researchers who analysed the principles of core reduction systems and production of Palaeolithic points (Aubry et al. 2008; Bradley et al. 2010; Inizan et al. 1999). Because of the absence of characteristic core reduction waste or cores, the analysis was limited to the pattern of scars on the dorsal sides of blades and flakes, which served for point production. Additionally, the type of butt was considered.

In the analyses aimed at reconstructing the scheme of point formation, we used a techno-functional approach (Boëda 2013) oriented at assessing the function of knapping or their series executed at each plane of the half-product. Here, the knapping series is defined as several strikes aimed at the same plane in the sense accepted in the scar pattern—working step analysis (Kot 2016).

The artefacts were measured with an electronic calliper and photographed. ImageJ, v. 1.52 software (Abramoff et al. 2004), was used to assess the approximate surface area of entire specimens. All metric and qualitative data were collected in the database, which is stored at the Institute of Archaeology of the University of Wrocław, Poland. The datasets are available from the corresponding author on reasonable request.

The shape of complete specimens was analysed using the geometric-morphometric method (GM), with Procrustes superimposition technique 2D (Fig. 2). Standard procedures of outline acquisition, orientation and conversion of xy into landmarks were applied; in recent years, this method was repeatedly used for characteristics of tools such as points, handaxes or knives (Buchanan et al. 2011; Buchanan and Collard 2010; Ioviţă 2010, 2011; Lycett et al. 2006, 2010; Serwatka 2018; Serwatka and Riede 2016; Shott and Trail 2010). There are several advantages to using this method. The most important is that it captures more data reflecting the actual shape than traditional form description techniques using a diagonal system (see remarks Iovită 2010). Separation of shape and size and, in consequence, comparisons of both these variables are important (Lycett et al. 2006). The received data allow to ask about the degree of uniformity of the set and possible shape changes.

The process of preparing the documentation and the analysis were as follows:

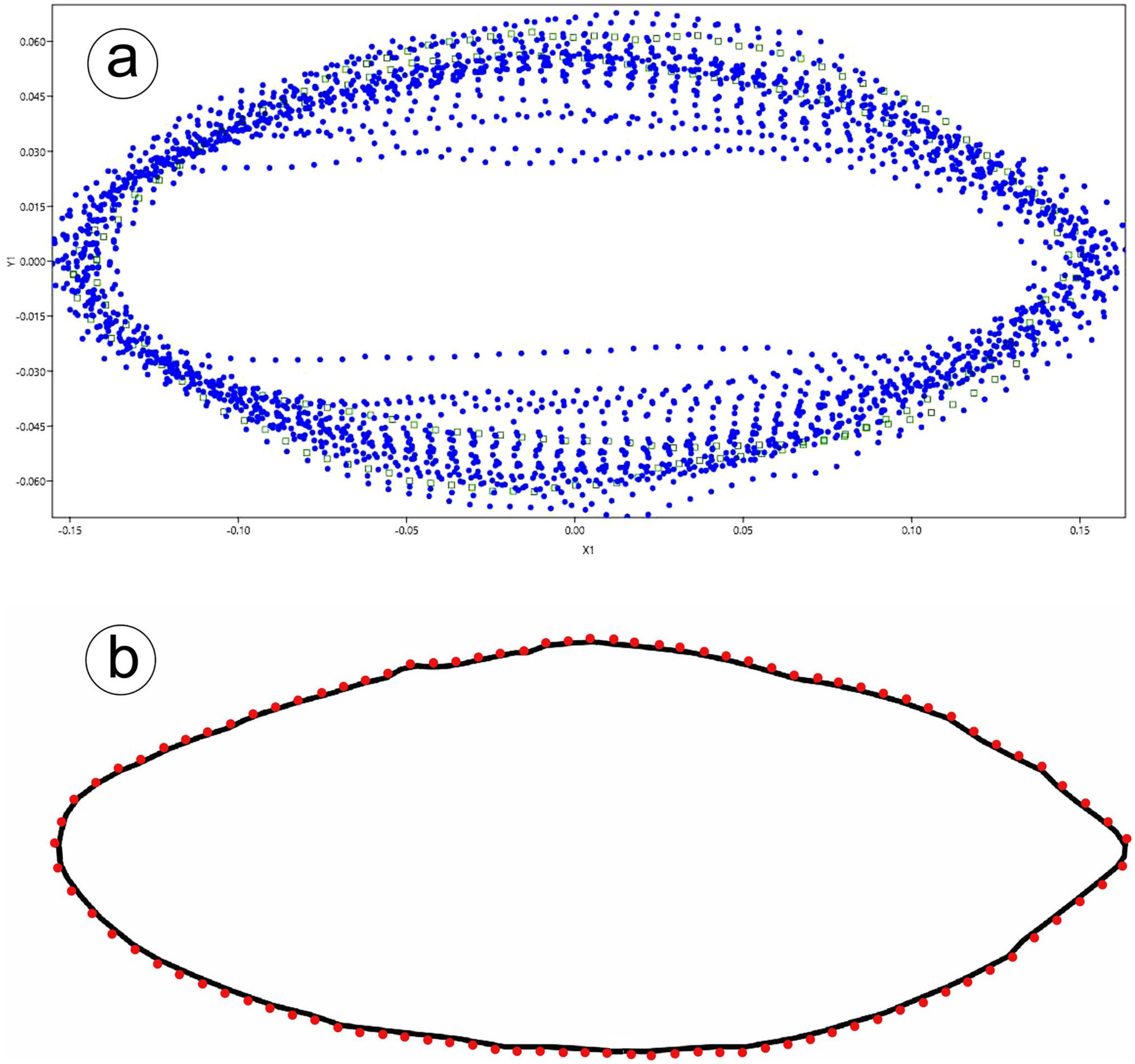



**Fig. 2** Documentation scheme for landmarks: **a** superimposition of all specimens after performing the Procrustes analysis; **b** location of semi-landmarks

- Taking digital photographs of a flat-lying object, drawing the outline of its edges and orienting each object in such a way that its long axis was horizontal;
- Landmark preparation. The TpsUtil (Rohlf 2016a) programme was used to process the image (outline). The prepared file was opened with TpsDig2 (Rohlf 2016b) software, where the outline was scaled. The set was analysed using two kinds of landmarks. The first 100 pseudo-landmarks were used. The first landmark was placed in the middle of the point base;
- Superimposition of landmarks using the Procrustes method. PAST (Hammer et al. 2001) software was used for this purpose. In this operation, all outlines are superimposed around a centroid, which corresponds to the 0.0 coordinates on the XY axis. The Procrustes superimposition also subtracts the mean or consensus shape from all the coordinate values, allowing for further tracking of shape deformations of specimens in relation to the consensus shape (see Fig. 2);
- The dataset resulting from this transformation was entered into a sheet of multivariate analysis PCA, due to which the number of variables became limited. Significant information was obtained on the variance of

objects depending on the main component. The variance was presented in scatter diagrams.

Subsequently, we subjected our data to regression analysis considering the basic dimensions, i.e. length and width, and the variables that resulted from the PCA analysis and had the greatest effect on the variation (first 6 variables with proportion > 1.0). We intended to test if there was allometry. In other words, whether the proportions of point dimensions changed. The calculations were done with PAST and StatSoft (StatSoft, Inc. 2014) software.

The next stage of research involved use-wear analysis. The analysis included a set of 44 flint artefacts obtained from layers 6, 5a and 4; these represented the group of points. Prior to a detailed microscopic examination, the specimens were cleaned by wiping with acetone. The examination was conducted with the use of a metallographic microscope (Nikon LV150), with magnifications from 50 × to 500 × and a digital microscope (Keyence VH-Z100R), with the range of magnifications from 50 × to 1000 ×. The observations focused on various kinds of macro- and microscopic traces: micro-flake scars, fractures, rounding, linear traces and polishes.

All the abovementioned points were subject to analysis. A part of the flint points had undergone modification. Their surface was covered with gloss and also with a whitish or blue-white patina. This rendered it difficult or impossible to perform a detailed microscopic examination of use-wear traces. The macroscopic analysis focused on distinctive fractures and flake scars.

The recorded traces were interpreted in terms of the possible function of the points and their hafting. The character of the traces associated with the morphology and location of micro- and microscopic traces was compared with the reference base (the collection with its documentation kept at the Faculty of Archaeology, University of Warsaw), composed of experimental tools used for everyday activities which may have been performed by Palaeolithic people. At the same time, the results of traceological analyses were compared with literature data (see Macro- and microscopic analysis).

Also, we estimated the tip cross-sectional area (TCSA) and the tip cross-sectional perimeter (TCSP) (Fig. 3). With this method (Hughes 1998; Shea 2006; Sisk and Shea 2011), we attempted to determine the penetration depth of the LRJ points and obtain information regarding the kind of weapon system with which the studied points could be associated. Thus, we intended to gain information on the internal diversity of the collection and its similarities and differences in relation to ethnographic and Palaeolithic data (see, e.g. Shea 2006). We paid particular attention to comparisons with examples of points of the most widespread Central European industry, i.e. Szeletian leaf points.

A cross-sectional area (TCSA) is a simple calculation obtained by multiplying the maximal width and thickness of an artefact and dividing the result by two (Fig. 3). It is calculated in the same way, irrespective of the shape of the cross-section: rhomboid or triangular. The reliability of TCSA is subject to much criticism (Clarkson 2016; Rots and Plisson 2014) because of its rather large inaccuracy in the case of complicated cross-sections and the lack of relationship between the TCSA value and the actual depth of penetration (Sisk and Shea 2009). Other objections relate to the uncritical approach to drawing conclusions solely on the basis of TCSA regarding the association of blades with a given weapon system (Rots and Plisson 2014).

Another system of measuring the coefficient, the so-called tip cross-sectional perimeter (TCSP) is better adapted to weapons from the Middle Palaeolithic or the boundary of the Middle and Upper Palaeolithic (Sisk and Shea 2011). It

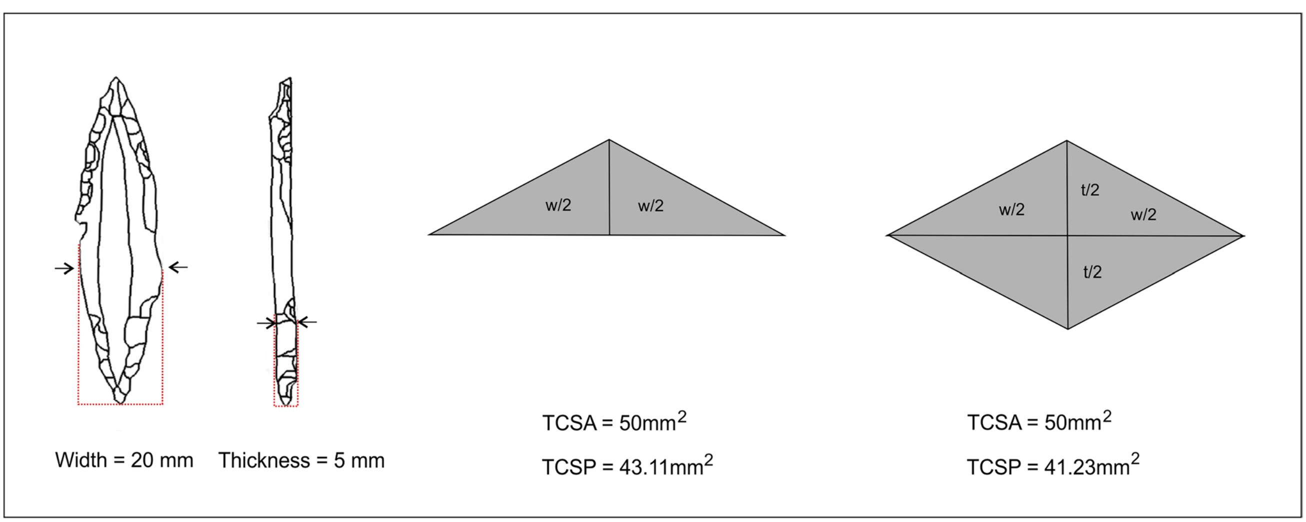



**Fig. 3** Schematic diagram showing the measurements and calculation of TCSA and TCSP

is calculated based on multiplying by a factor of four (rhomboid cross-section, Fig. 3):

$$TCSP = 4 \times \sqrt{\left(\frac{Width}{2}\right)^2 + \left(\frac{Thickness}{2}\right)^2}$$

or two (triangular cross-section):

$$TCSP = 2 \times \sqrt{\left(\frac{Width}{2}\right)^2 + Thickness^2}$$

It was experimentally demonstrated that the TCSP index is much more precise in estimating the penetration depth of the point (Grady 2017; Hughes 1998). However, also in this case, some researchers question the dependence between the TCSP and the depth of penetration (Clarkson 2016; but see also Sitton et al. 2020).

## Results

### Raw material, half-product and retouch range

The points are made of five kinds of siliceous rock, with a predominance of the so-called Jurassic flint. The artefacts are also made of chocolate and Świeciechów flints (Fig. 4), as well as of red radiolarite and cretaceous flint. The nearest outcrops of some of these rocks are located about 130–160 km from Nietoperzowa Cave (further details in ESI1).

Most of the complete tools are made of blades or elongated flakes. Some of them bear cortex on their dorsal side, most however come from an advanced stage of core exploitation, when the natural surface has been removed from the flaking surface. The set includes single specimens originating from the core preparation—crested blades. The preserved forms indicate the shaping of the longitudinal convexity of the core with knapping across the core axis. Noteworthy is the massive form of the crested blade, like most of the blades and flakes converted into tools (cf. 3.3). Unfortunately, the cores contribute little to our understanding. The forms distinguished by W. Chmielewski (1961) are residual. The largest specimens of points and blades indicate that the size of the half-product may have exceeded 140 mm.

Since retouching has modified the proximal parts of the half-product, it is difficult to say anything about the preparation of butts or precisely specify the knapping technique. Butts were preserved on single blades and fragmentarily on one point. They are flat and their thickness does not exceed 5 mm. Based on the observations of the morphology of blanks, the pattern of arrises, shape of blade/flake edges as well as distinct and irregular waves of ventral sides, it can be supposed that direct percussion was used during production. Unfortunately, nothing more precise can be said about the technique. The presence of lips, in Flas' opinion (Flas 2008, 39), may suggest the use of a soft hammer.

The pattern of removal negatives could be established for 25 tools and fragments. Based on this, it can be inferred that the flaking surfaces were mostly uni-directionally reduced (19 specimens, 76%). Only four specimens (16%) indicate the possibility of reduction from opposite platforms, and only two (8%) suggest centripetal reduction. The cross-section of the studied forms suggests the use of a semi-tournant method. The use of frontal flaking surfaces cannot be excluded.

Considering the range of retouch on complete points, the following classification can be proposed (Fig. 5): (1) points with wholly or partially retouched dorsal and ventral face (12 specimens); (2) points with a partial or complete retouch of the dorsal face (5 specimens). It should be emphasised that the forms with a completely retouched dorsal face are distinctly more massive; (3) points with the retouch focused on the ventral face (6 specimens); (4) points with minor modifications encompassing isolated parts of dorsal or ventral faces (4 specimens).

It should be borne in mind that, considering the above classification and the data on the attribution of the points to particular layers, i.e. 6, 5a and 4, there is no discernible tendency, except the fact that layer 6 contained points from all categories.

### Techno-functional features of the points

From a techno-functional point of view, the blade/flake points show a tendency to minimise the procedures applied. The basic planes of the blades/flakes, the flat ventral face and the convex dorsal face of triangular or trapezoid cross-section, are in most cases preserved. Thus, the procedures applied are subordinate to the original asymmetry of the blade/flake. The removal negatives on the ventral face are usually flat and sometimes extend far onto the surface. Their function is thinning of the tool. The negatives on the dorsal face are mostly semi-steep. The results were slightly bent small flakes (chips), which were thicker at the base in the proximal part. The aim was to shape the tip outline and, in some cases, also the base. Unfortunately, no artefacts of this type were found in the collection from Nietoperzowa Cave.

As shown in Fig. 6, the shaping of the tool was executed through the application of two types of knapping, subordinate to the form of the half-product. In the case of bent or slightly twisted forms, the knapping series was to flatten the ventral face in the tip- and bulb part or in only one of these parts. Another knapping series focused on the dorsal face, served as delineation which was aimed at obtaining a lens-like outline from a half-product which did not require flattening, but whose edges considerably departed from the desired lenticular shape. Only a series of semi-steep

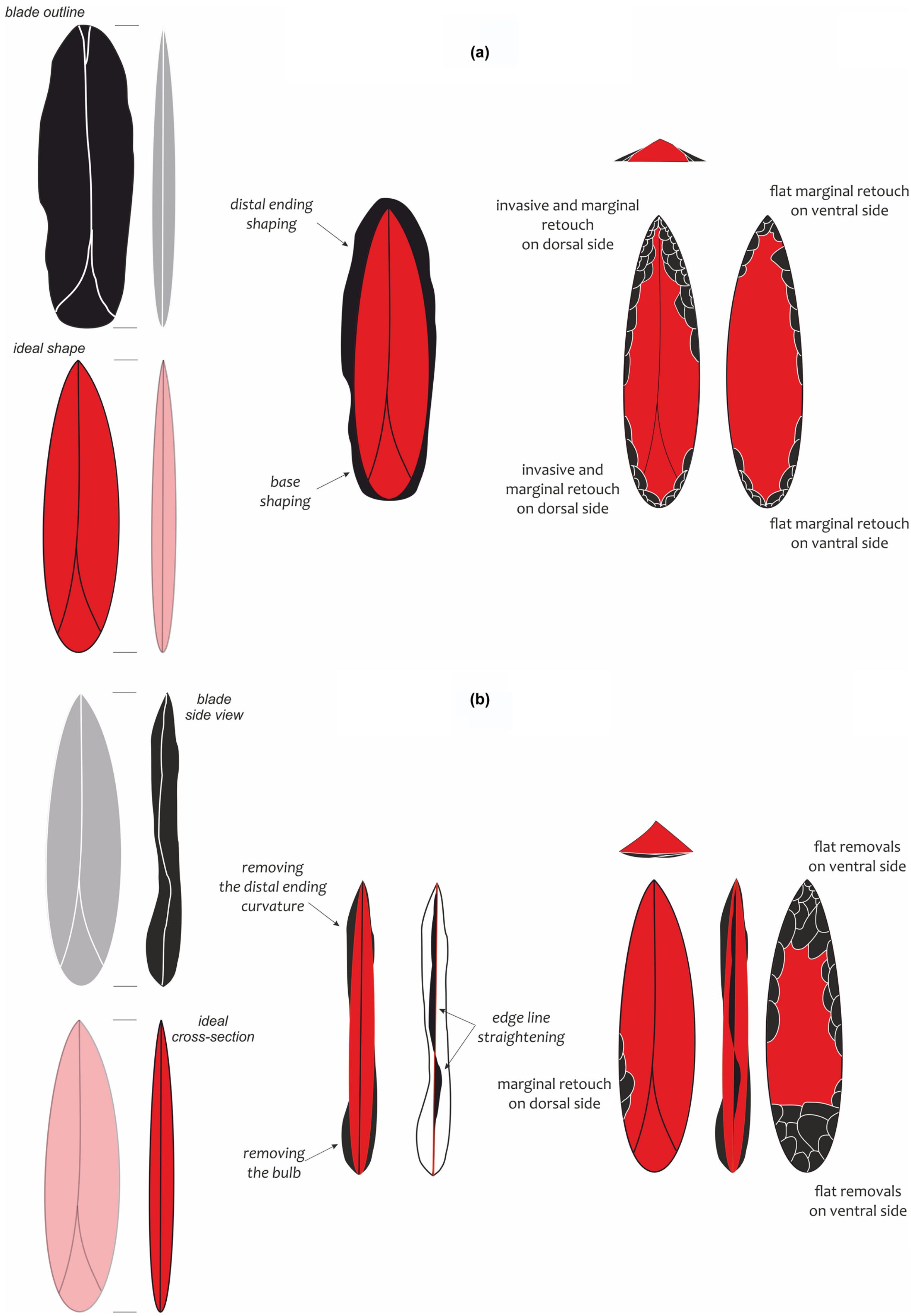

**Fig. 4** Examples of points made of various flint types: 1, Jurassic; 2, chocolate; 3, Turonian (Świeciechów)

detachments was executed on the dorsal face to shape the edges in such a way that they formed a shape of the inverted leaf. Considering the above observations, three functional zones can be distinguished: (1) passive base of point; (2) tip with converging edges; (3) middle part with two cutting edges. The zones correspond fairly closely to the character of Solutrean blades (Schmidt 2015, 494).

## Basic metric features of the points

The considerable size of the complete points is noteworthy: the median length is 84.31 mm (n = 27). The smallest specimens are 57.32 mm long, the largest, outlying examples, are 132.62 mm long (mean—85.58, Coeff. var—21.42) (Fig. 7). The analysed metric data show a slight right skewness (0.8).


**Fig. 5** Examples of points illustrating various retouch ranges: 1, type 1; 2 and 3, type 2; 4 and 5, type 3; 6, type 4 (description in the text)


blade outline
(a)
ideal shape
distal ending shaping
base shaping
invasive and marginal retouch on dorsal side
flat marginal retouch on ventral side
invasive and marginal retouch on dorsal side
flat marginal retouch on vantral side
blade side view
(b)
ideal cross-section
removing the distal ending curvature
removing the bulb
edge line straightening
marginal retouch on dorsal side
flat removals on ventral side
flat removals on ventral side

◂**Fig. 6** Schema showing the formation of points from blades (elongated flakes) based on finds from Nietoperzowa Cave: 1, modification of blank shape using reduction of edge parts; 2, thinning of ventral and dorsal sides

However, it should be noted that the distribution of length for alpha = 0.05 in the Shapiro–Wilk test slightly exceeds the critical value and is 0.93. Very similar values of variation of indices are shown by the width and thickness of the specimens. The width of complete forms ranges from 17.6 to 46.1 mm, and the median is 28.3 mm. The thickness varies from 5.87 to 16.69 mm, with a median of 9.7 mm. For the point fragments (n = 30), the median width is 27.99 mm whilst the median thickness is 9.23 mm (Fig. 7), showing a close compatibility with the complete specimens.

The mean value of the Length/Width index (L/W) for the complete specimens is 2.96, the W/Th is 3.1. It can be assumed that these parameters indicate a slender shape of the studied tools. Kendall's tau correlation of length and width indicates a moderately strong relationship (0.476). A similar correlation was observed between thickness and length (0.363) and thickness and width (0.425). It should be conjectured that this is the effect of the tendency to select, as half-products for most of the analysed objects, blades/flakes within a small thickness range.

The weight of the artefacts ranges from 9.98 to 49.76 g. The weight of the points exceeds that of specimens interpreted as arrowheads and dart tips. The surface area of the points varies widely, from 8.13 to 43.1 cm$^2$. However, the median is ca. 17.1 cm$^2$. A comparison of surface area with length and width using Kendall's tau correlation shows a close relationship (L/S 0.75, W/S 0.67, $p < 0.05$). There is no such strict correlation for thickness (Th/S 0.43).

The analysis of metric data of the points from Nietoperzowa Cave reveals metric similarities, especially with regards to unilateral specimens from Nietoperzowa Cave and artefacts from other localities which for a long time were interpreted as LRJ (see ESI 3). This is especially visible in relation to localities such as Ranis and Spy (Fig. 8; Flas 2013; Hülle, 1977).

## Geometric-morphometric analysis

In the geometric-morphometric analysis, we considered two methods of data comparison using PCA. In the first, we applied semi-landmarks. The PCA analysis of the results showed that the first two components explained 87.3% of the variance; consequently, we focused on these components (Table 2).

In the scatter plot presenting both PCAs, we marked a 95% concentration ellipse (Fig. 9). According to Hammer (1999–2000), it shows an area where 95% of population points are expected to fall. PC1 describes most of the variance (approx. 78%) and there seems to be a clear separation of specimens according to the PC1 axis (Fig. 10). The negative values are mostly occupied by points with an expanded midsection and lenticular shape. This refers mainly to points at the advanced stage of shaping. The most elongated points, made exclusively of slender blades, are scattered on the opposite side of the plot. There are two most extreme specimens like this, which are located beyond the prediction ellipse. The meaning of the distribution described by PC 2 is harder to interpret, as this component covers only 10% of the total variance. When observing relative warp deformations according to the component 2 axis it appears that this PC describes the degree of point lateralisation of the left or right side of the point.

There seems to be a relationship between the overall shape of points and the invasiveness of retouch. Based on retouch intensity and the location of the analysed points on our PCA plot, it was possible to distinguish four categories. Points with the most invasive retouch on both faces are the most scattered and these form group 1. The second category is formed by points located more in the centre of the plot. It consists of lenticular forms with its maximum width located in the midsection. Groups 3 and 4 overlap and they are formed by the most elongated specimens with very little retouch applied usually on the ventral side.

Furthermore, we wanted to check if the point size and surface area depended on the shape to any degree. For this purpose, we used multiple regressions (Table 3). The dependent variables were metric features; the independent variables were results of the first six components with variance proportion exceeding 1. The results show that the model of dependence of shape and size and the surface area does not apply in the analysed case. In other words, the form of the LRJ points is probably not strongly correlated with metric features.

## Macro- and microscopic analysis

Microscopic examination of the points was rendered difficult due to the presence of gloss as well as white and blue patina. The limited occurrence of diagnostic traces on the points was also a result of the nature of the analysed tools, which is manifest as a varied propagation of diagnostic traces, depending, among other things, on the usage and on the mass of the tool—the problem discussed in detail by Rots and Plisson (2014). For these reasons, a microscopic traceological analysis could be applied in fewer cases compared to macroscopic observations.

As a result of traceological analyses, the following categories of macro- and microscopic traces were identified (Figs. 11, 12, 13, 14, 15 and 16; Table 4).

Macroscopic traces include the following changes:

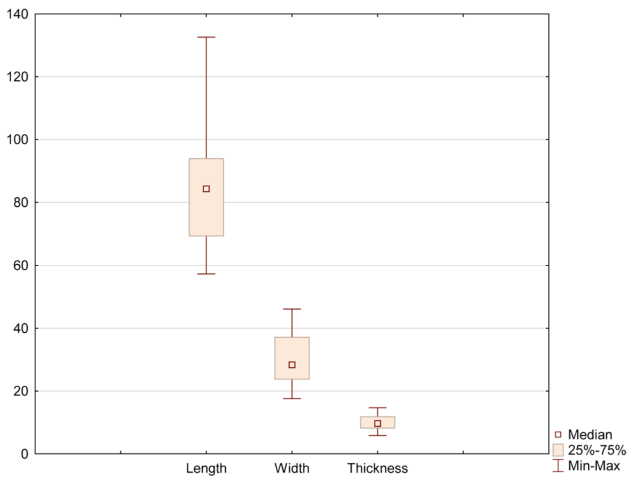



**Fig. 7** Basic metric features of complete points from Nietoperzowa Cave on the box plot

– Diagnostic impact fractures: burin-like fracture (impact burination), step/hinge terminating bending fractures;
– Spin-off fractures > 6 mm;
– Non-distinctive fractures with straight profile;
– Non-characteristic edge crushing.

Such traces were observed in the tip region and, in single cases, in the region of the base.

Diagnostic impact and spin-off fractures, which are commonly identified with hitting a target, were recorded in 13 specimens (Figs. 11 (3); 12 (2); 14 (3) and 16 (2)). This is indicated by various series of experiments (see, i.e. Bergman and Newcomer 1983; Coppe and Rots 2017; Fischer et al. 1984; Hutchings 2016; Lombard 2005; Odell and Cowan 1986; Shea et al. 2001; Rots and Plisson 2014). The relatively high proportion of such damage in the studied set is compatible with the opinion that it may in great likelihood be associated with the use of tools as projectile weapons (cf. Hutchings 2016, 8). The remaining kinds of fractures, including those with a straight profile, may be associated with the effects of various factors, including post-depositional events, and are not classified as distinctive traces.

Microscopic traces include the following changes:

– Microscopic linear impact traces;
– Abrasions and polishes of protruding parts, arising during contact with organic raw material;
– Non-characteristic polishes.

Microscopic linear impact traces were recorded in only five cases (Figs. 13 (2); 15 (2, 3) and 16 (3)). Linear traces are visible in the form of scratches and streaks of polishes near the point tips. They are probably a result of target penetration (mainly animal body parts). They are situated parallel or slightly obliquely to the tool axis.

The position and course of linear traces also inform how the tool was set in its haft. Arrowheads and spear heads were set parallel to the axis of symmetry of a composite tool. Similar traces were obtained during pioneering experimental

**Fig. 8** Basic metric features of complete points from Nietoperzowa (Nt), Ranis (R), Spy (Sp) and Mamutowa Cave (M)

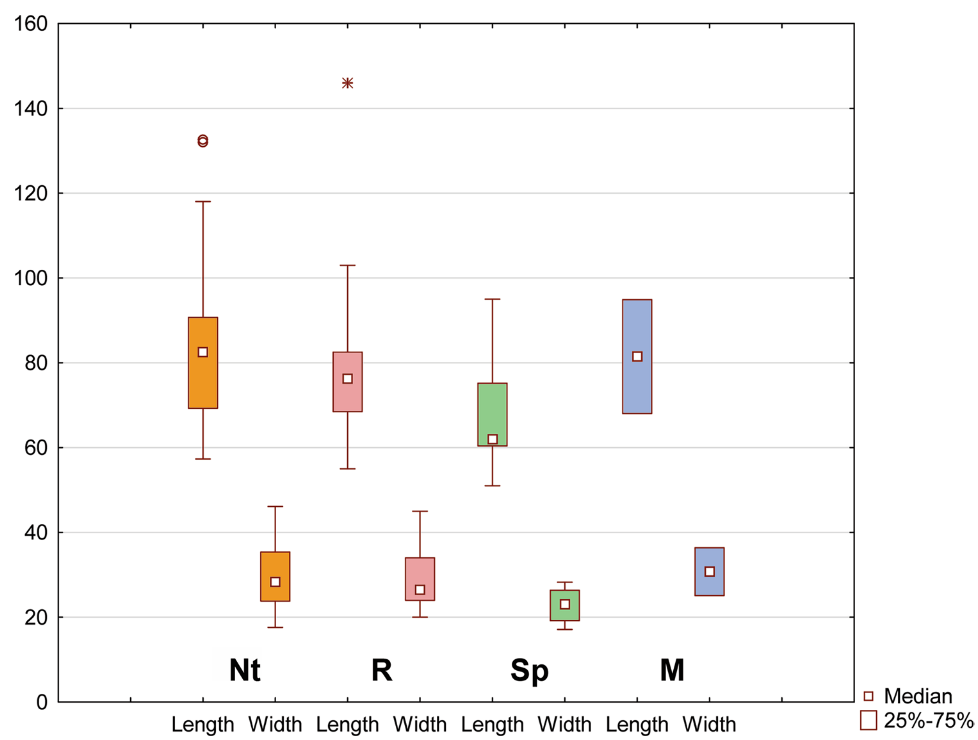


**Table 2** Eigenvalue contribution of pseudo-landmarks

| PC | Eigenvalue | % variance |
|---|---|---|
| 1 | 0.00454397 | 77.572 |
| 2 | 0.000569954 | 9.7299 |
| 3 | 0.000222497 | 3.7983 |
| 4 | 0.000163544 | 2.7919 |
| 5 | 9.92E-05 | 1.6941 |
| 6 | 7.31E-05 | 1.248 |
| 7 | 4.25E-05 | 0.72578 |
| 8 | 3.03E-05 | 0.51657 |
| 9 | 2.46E-05 | 0.42028 |
| 10 | 1.94E-05 | 0.33203 |

studies (see, i.e. Fischer et al. 1984). Analogous range and trajectory of changes limited to the place of arrowhead setting were recorded by one of the authors (KP) during her own experiments (Dmochowski and Pyżewicz 2012; Pyżewicz 2013, 31–36).

It is noteworthy that abrasions, slight rounding and polishes, sometimes more or less regularly arranged, can be observed on arrises and other exposed parts of the points (Figs. 11 (2); 13 (3); 15 (4) and 16 (4)). Unfortunately, in many cases, it is impossible to decide whether they arose during use or are associated with the effects of post-depositional factors. Some regularity in their arrangement can be observed in two cases—they are visible at the base of the tools and in their middle parts. They probably arose as a result of contact between the flint surface and the haft (see Rots 2003, 2009). The distribution of these traces indicates that the points were placed inside the haft to a height of 1/3 to 1/2 of the specimen. Unfortunately, it is impossible to specify the haft material.

The analysed points bear no micro- or macroscopic traces suggesting their use during other operations, for example cutting or dividing animal carcasses. The results of macro- and microscopic studies indicate thus that the studied points were used as hunting weapons.

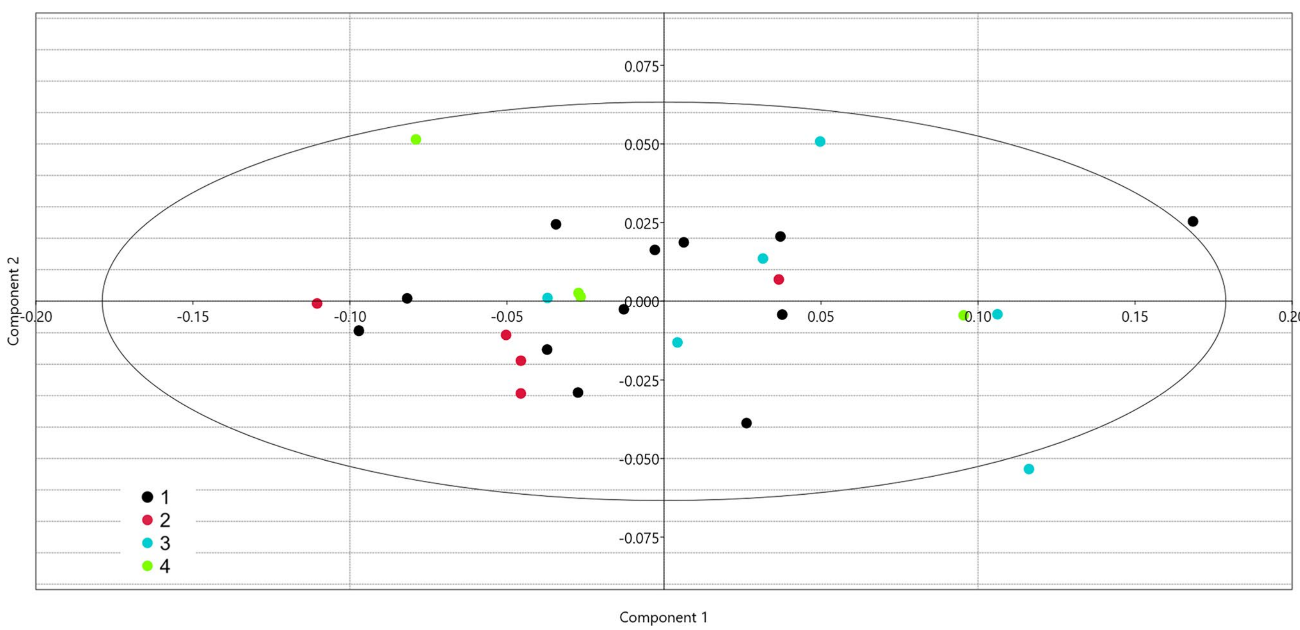



**Fig. 9** Scatter plot showing results of the PCA. Colours illustrate the groups of points presenting a various range of retouch: black, type 1; red, type 2; blue, type 3; green, type 4

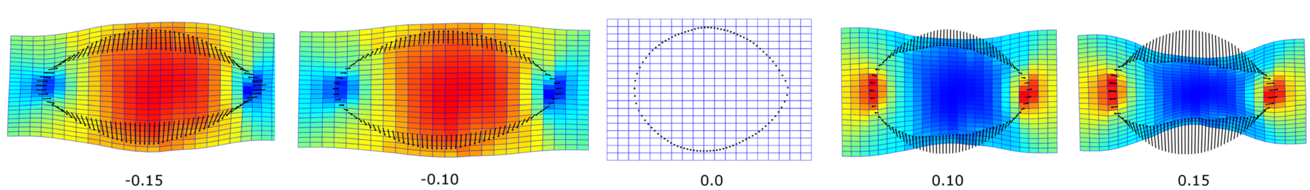



**Fig. 10** Simplified morphospace illustrating the transition of form according to PC1

**Table 3** Regression results involving a comparison of metric properties and the first six principal components

| Feature | Multiple *R* | *R* square | *F* | Significance *F* |
|---|---|---|---|---|
| Length | 0.51 | 0.27 | 1.2 | 0.34 |
| Width | 0.52 | 0.28 | 1.28 | 0.3 |
| Thickness | 0.35 | 0.12 | 0.46 | 0.8 |
| Area | 0.3 | 0.09 | 0.34 | 0.9 |

## TCSA and TCSP of points

In the TCSA and TCSP estimates of the points' ballistic properties, we applied the test for difference in population means (Tables 5 and 6; Fig. 17). The TCSA values of the points from Nietoperzowa Cave have no exact counterparts in our reference base. There is also a difference in the range of TCSA between the points from Nietoperzowa Cave and the Szeletian points from Vedrovice V and Szeleta Cave. However, the difference could not be statistically confirmed (0.89). Earlier, G. Tostevin (2003) obtained a similar value of TCSA – 197 mm$^2$ for Vedrovice V. It is not surprising that the TCSA value for the points from Nietoperzowa Cave is very close to such values obtained from large unilateral points of the Solutrean culture (Shea 2006, p. Figure 10), which have an analogous structure (Table 6).

The TCSA data from the Middle Palaeolithic are varied, although most show a relationship with the range of throwing or thrusting spears. Sometimes, however, these values, as in the case of the late Middle Palaeolithic complex of the Mauern type, Germany (MIS 3, 154 mm$^2$) (Hopkinson 2004), or an older industry from Bouheben, France (?MIS 6, only Mousterian points – 165 mm$^2$) (Villa and Lenoir 2009, see Table 5.8), are fairly similar to the LRJ from Nietoperzowa Cave. In other cases, the values differ considerably, for example compared to the Mousterian

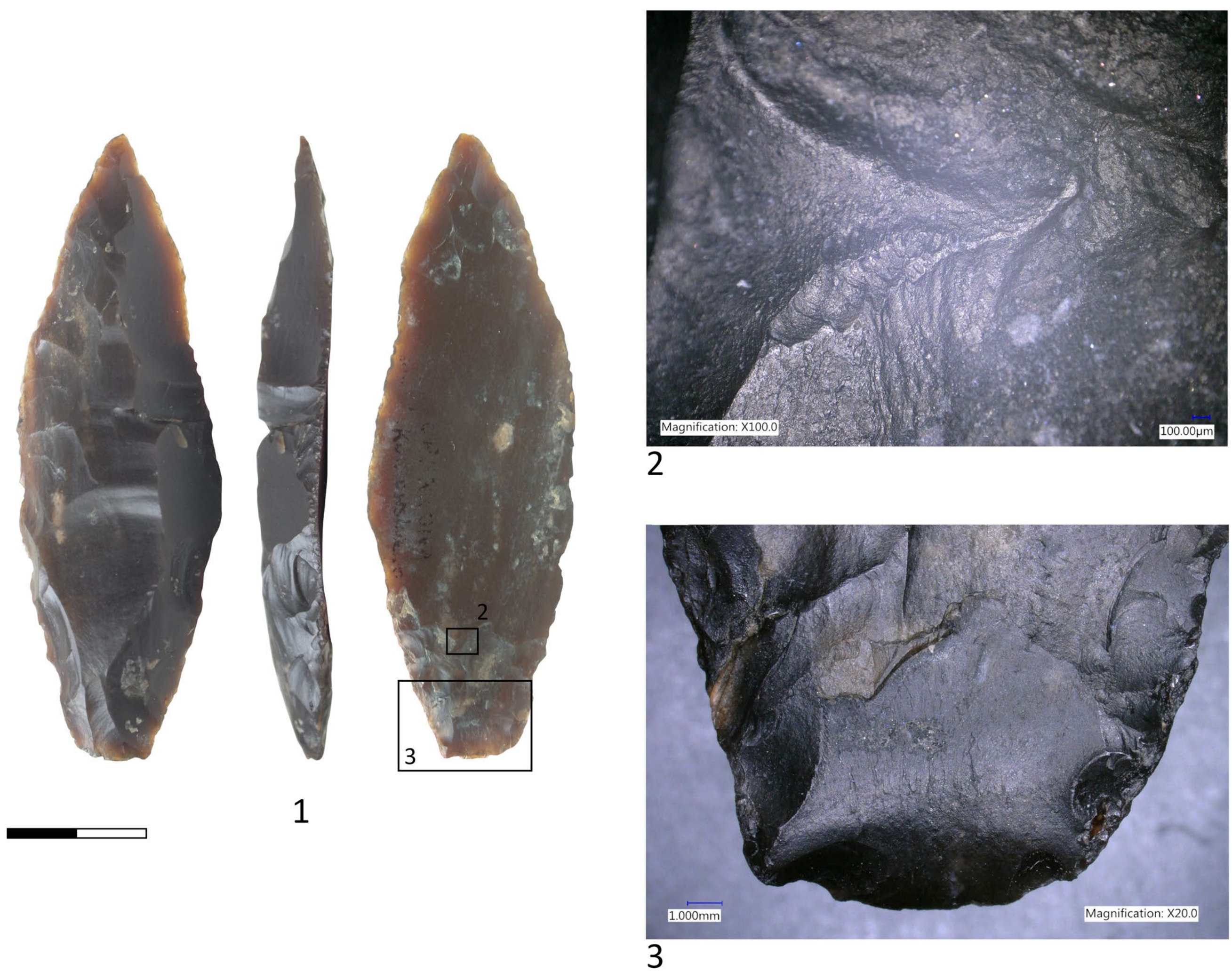



**Fig. 11** 1, leaf point from Nietoperzowa Cave; 2, potential microscopic hafting traces; 3, hinge terminating bending fracture

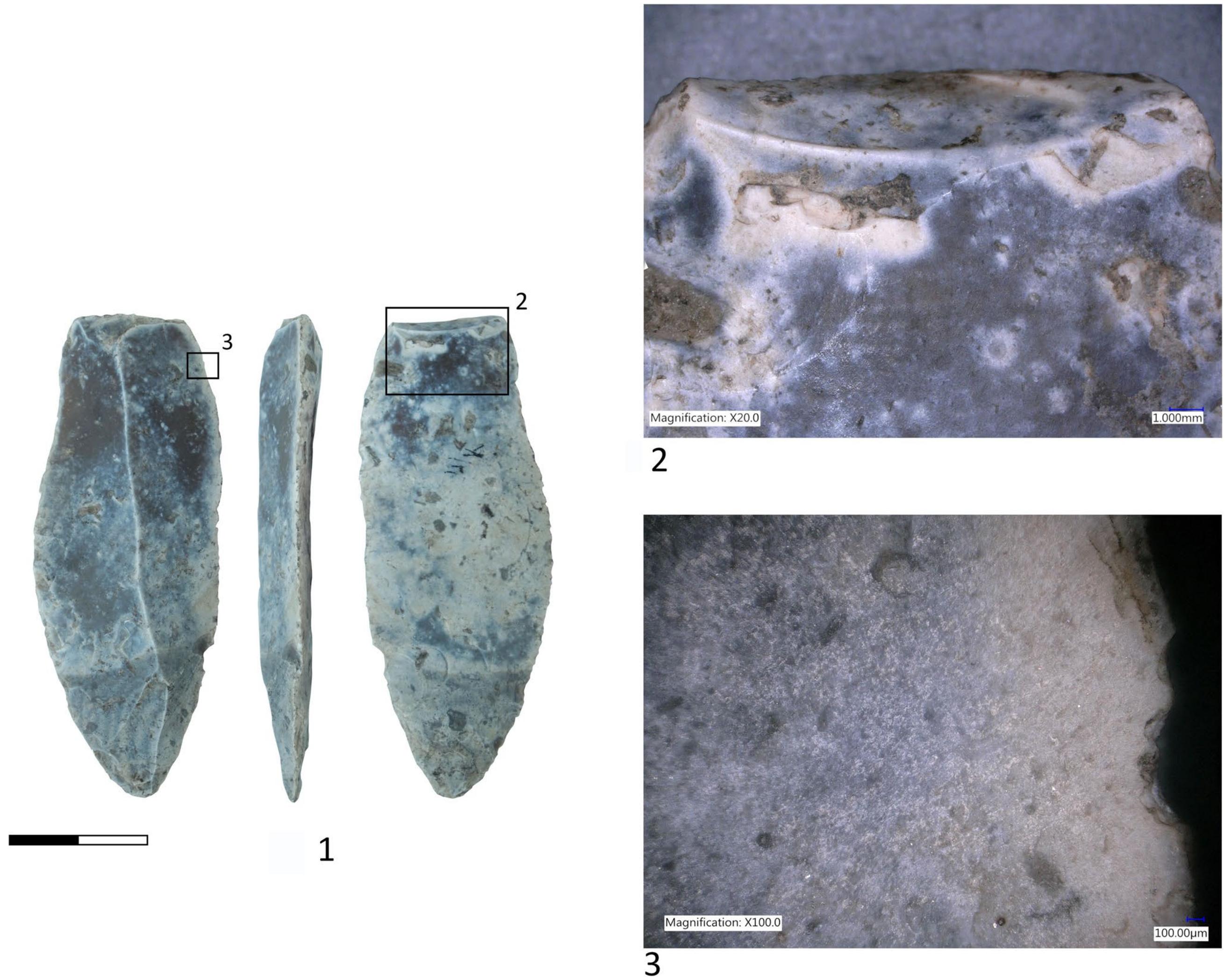



**Fig. 12** 1, leaf point from Nietoperzowa Cave; 2, hinge terminating bending fracture; 3, the state of preservation of the artefact—visible gloss or blue-white patina

points from eastern Cantabria, Spain, with a mean value of 90 mm$^2$ (Rios-Garaizar 2016, see Table 15.1). Lazuén earlier obtained similar values for the Middle Palaeolithic localities of the region (2012, see Fig. 4). Much larger differences were found between the values for the Mousterian and Levalloisian points from the locality of Le Moustier (40–56 Ka), where the TCSA value ranges from 332 to 353 mm$^2$ (Shea 2006, 835). More similar values to those of the LRJ points from Nietoperzowa Cave are presented by tools from the early Middle Palaeolithic Near East, reported by Shea and Sisk( 2010, Table 3). They differ from the points of the Late Palaeolithic and transitional industries. It follows that the data, especially those for the Middle Palaeolithic, vary widely in their TCSA. Instead, the fact that TCSA reflects the cross-section only to a limited extent, the effect of local conditions, such as raw material or site function, should be considered.

We also analysed the TCSP values of the same set of points, assuming that such values are more precise than TCSA (Sisk and Shea 2011). We obtained a mean of 42.6. For points with rhomboid cross-section, the value was 61 mm$^2$; for those of triangular cross-section, it was 36 mm$^2$. The difference between the two values is large since the range is more than 71. The results for both kinds of cross-sections show right-sided asymmetry. Because of this, we used the Monte Carlo procedure for 27 observations with 1000 iterations. The results are compatible with the actual mean (mean 42.74, StdD = 2.79, St. error = 0.088).

Considering the value of the TCSP index, combined with the reference data in the table, it can be seen that the values from Nietoperzowa Cave are similarly situated, together with the Szeletian points, between dart tips and spear points (Fig. 17). The mean values of the TCSP of the tips from Nietoperzowa Cave and the Mousterian points from Spain

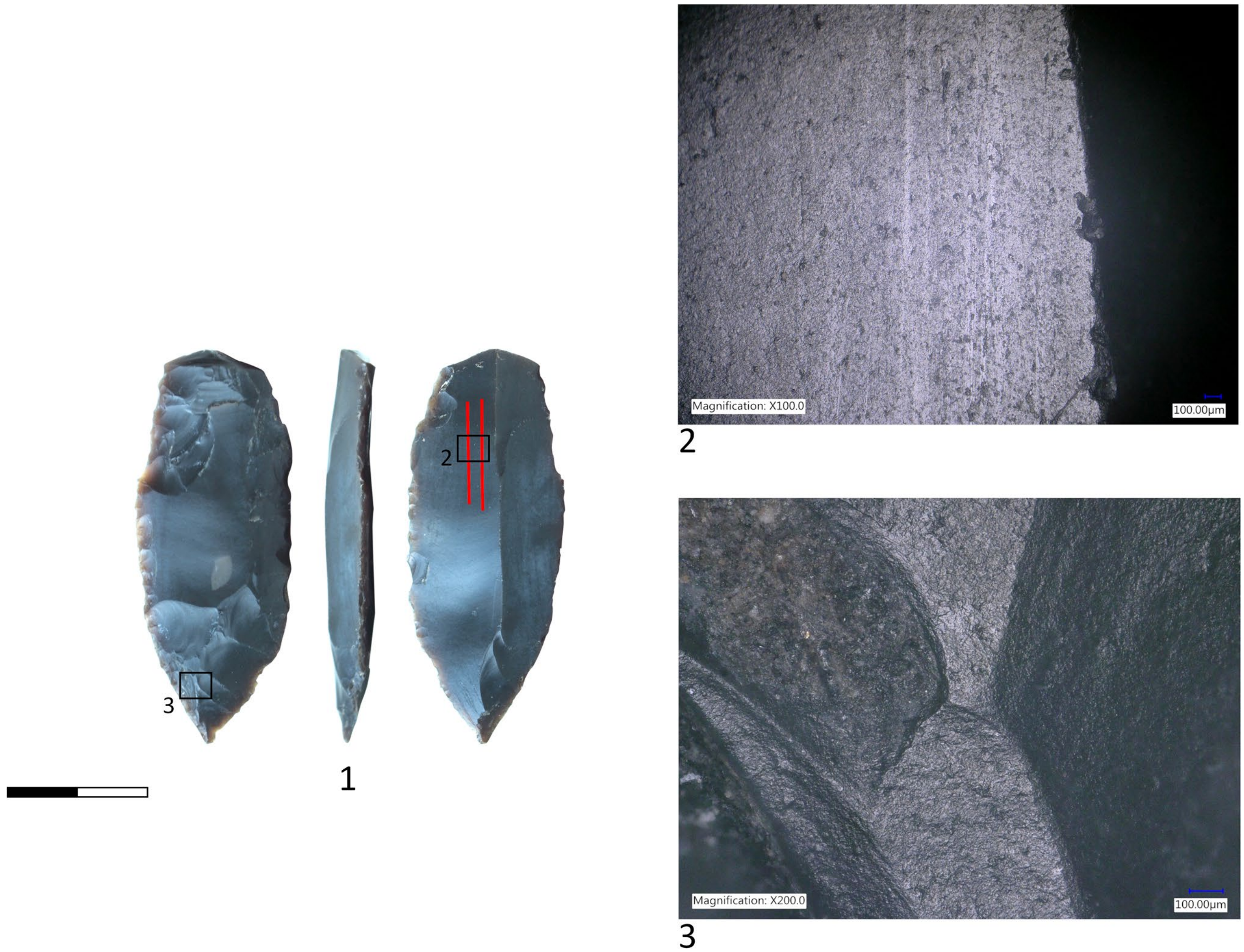



**Fig. 13** 1, leaf point from Nietoperzowa Cave; 2, microscopic linear impact traces; 3, potential microscopic hafting traces

(55 mm$^2$ according to Rios-Garaizar 2016) are similar. The points from Nietoperzowa Cave are also similar to the Early Upper Palaeolithic points from the Near East, for example Ksar Akil type – 60 mm$^2$ (Shea 2006; Table 5; Sisk and Shea 2011, Table 2; see also comments on function Eren and Kuhn 2019). This supports the hypothesis that, in terms of the more precise index, the points from Nietoperzowa Cave fit better with the IUP industry than with the Middle Palaeolithic points.

## Discussion

In this article, we emphasised morphological and functional analyses, supplementing them with remarks on technology. Among other things, they raise questions regarding the occurrence of multi-functionality in this and other industries of that period in question. The results of technological and morphometric studies also encouraged us to address the industry's origin from Nietoperzowa Cave and other localities included in the LRJ.

### Form and technology

In the case of LRJ points, not fully bifacial, which predominate in Nietoperzowa Cave, the character of the half-product and the way of shaping and repairing the tools, were decisive. It should be remembered that part of the points made of high-quality materials, brought from remote places, have a very similar shape with a lenticular outline and a maximum width near mid-length of the object. So far as a lenticular 2D outline is encountered in industries of both the late Middle Palaeolithic (Altmühlian), and the Early Upper Palaeolithic of Central Europe (Behm-Blancke 1960; Bosinski 1967; Kot 2016; Mester 2014; Richter 2009), the idea of the wide use of blades or elongated flakes appears only in the LRJ. It is sporadically manifest in the Szeletian and Bohunician (Flas

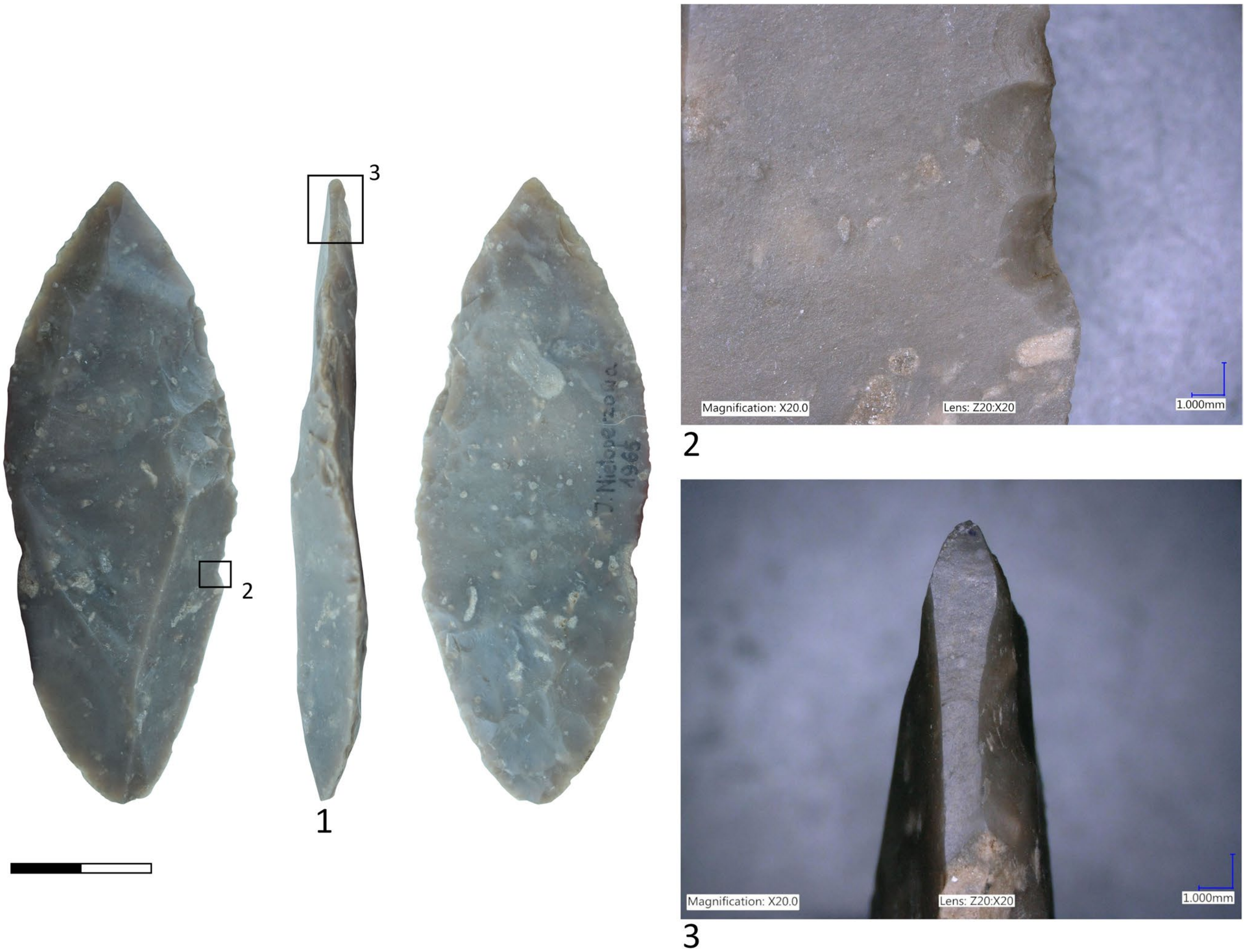



**Fig. 14** 1, leaf point from Nietoperzowa Cave; 2, edge crushing, potential macroscopic hafting traces; 3, burin-like fracture;

2015; Oliva 2007). It should be emphasised that the variance of the shape landmarks of the studied points is small.

The TCSP of a cross-section should be considered in the shape analysis; according to our calculations, its values place the points from Nietoperzowa Cave between arrowheads, spear points and some examples of Mousterian points. The unexpectedly small values of the surface area (the mean is 42.6) indicate a tendency to reduce resistance, thus increasing the efficiency of the discussed weapons (but see Clarkson 2016). From a ballistic point of view, we are dealing with the introduction and propagation of an effective form.

We think that the phenomenon should be regarded as a novelty in Central Europe. Contemporary or somewhat older industries associated with the environment of the Middle Palaeolithic were mainly based on bifacial tooling of a different degree of preserved symmetry (Kot 2016; Nerudová 2009; Nerudová and Neruda 2017; Weiss et al. 2018). Here, the results of PCA analyses of the 2D shape of the points from Nietoperzowa Cave should be mentioned again. They indicate a tendency towards axial symmetry, which makes these specimens different from Szeletian points. Here again, it is worth noting the captured differences in the cross-section TCSP structure of LRJ points and Szeletian examples. In summary, we believe that the indicated differences between LRJ points and their "fossil" counterparts in the Szeletian culture or late Middle Palaeolithic industries are due to differences in the standardisation of the half-product manufacturing and differences in the standardisation of the production of the tool form (see more extensive comments in Marks et al. 2001; Monnier and McNulty 2010). We think that the recorded morphological homogeneity in LRJ is a signal of structuring, going in the direction of equipping tool kits with, among others, blade/flake points. There is, however, no evidence that the observed change is a sign of the evolution of behavioural modernity of the LRJ manufacturers. An overall view of the remains of this unit shows that, apart from the mentioned points, the inventories are similar to many other industries of that period from the area north

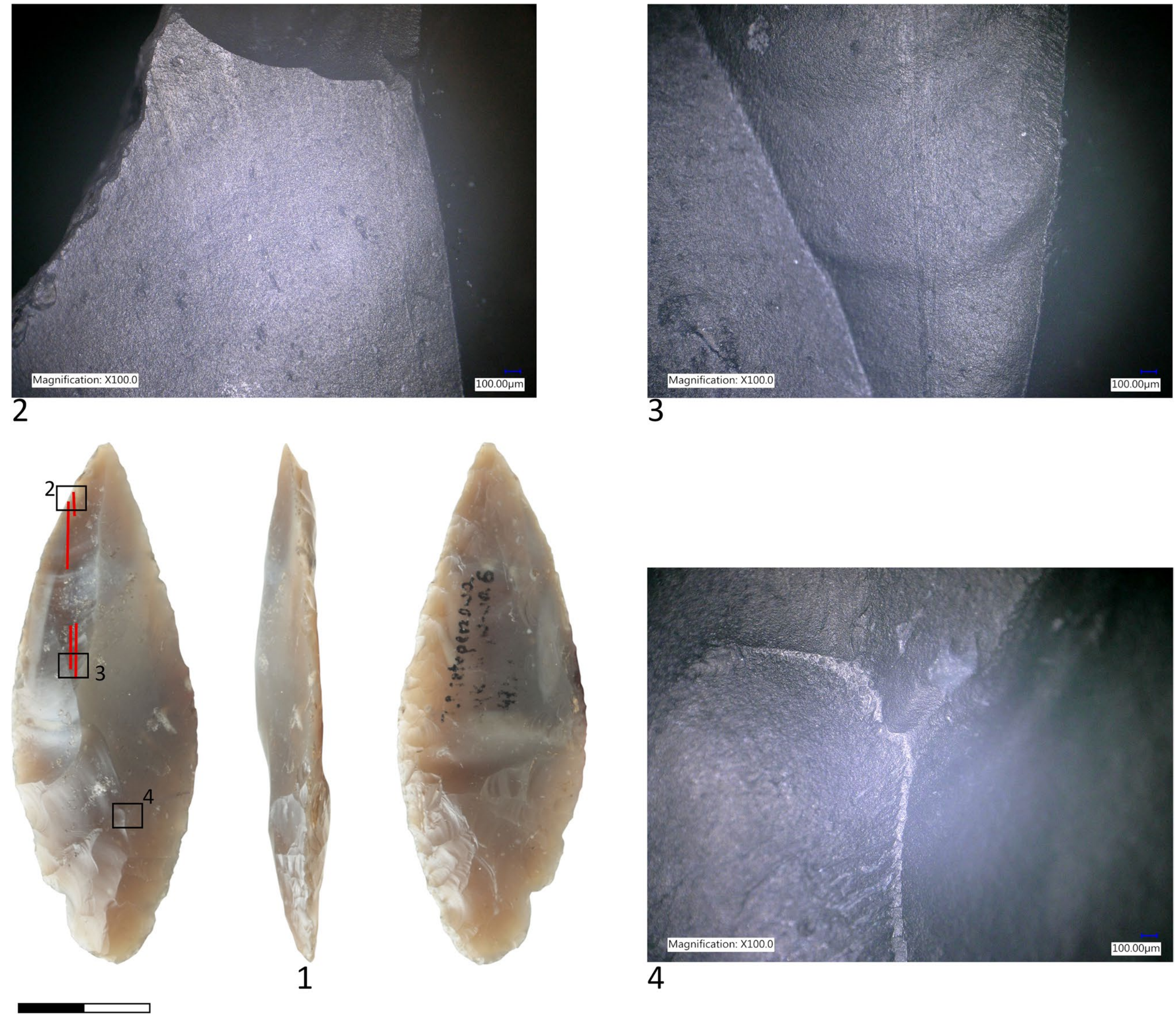



**Fig. 15** 1, leaf point from Nietoperzowa Cave; 2–3, microscopic linear impact traces; 4, potential microscopic hafting traces

of the Sudetes and Carpathians. They are simply traces of a very mobile and short-term activity (for a wider discussion see Cascalheira and Picin 2020).

## The function of points and activity in Nietoperzowa Cave

The analysis of the functional aspect leads to the question of the way of use. The points from Nietoperzowa Cave do not bear micro- or macroscopic traces which might suggest their use during different activities, for example being associated with cutting or scraping. The preserved traces suggest an association with hunting weapons. Obviously, the size of the sample bearing the abovementioned traces does not justify a statement that all the LRJ points were treated in the same way. It appears, however, that the traces of setting in a haft and the cross-sections of the points from Nietoperzowa Cave indicate their role as hunting weapons rather than a multi-tool, which is illustrated by tools such as handaxes.

Is there any similar compatibility of form and function in other cases outside the LRJ? The possibilities of comparisons in Central Europe for the studied set of points are regretfully rather limited since there were no systematic traceological and morphological studies on that group of artefacts earlier. Few attempts at traceological analyses were made in the last decades for points from the Szeletian culture. Those analyses considered, among others, two Czech localities: Vedrovice V and Moravsky Krumlov IV (Nerudová et al. 2010; Valoch et al. 1993, p. 199). With respect to functionality, the tools from those localities seemed to

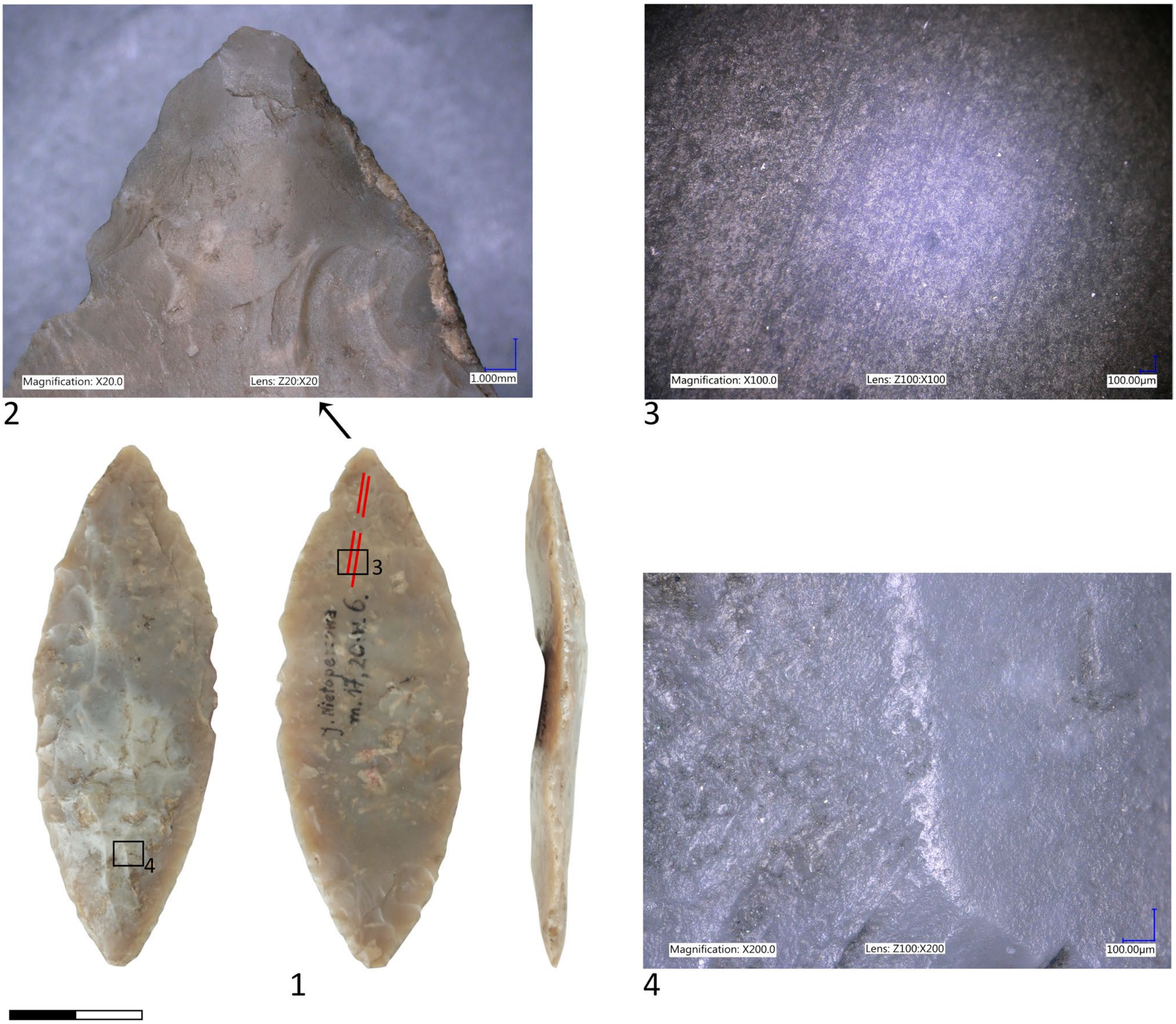



**Fig. 16** 1, leaf point from Nietoperzowa Cave; 2, hinge terminating bending fracture; 3, microscopic linear impact traces; 4, potential microscopic hafting traces

**Table 4** Macroscopic and microscopic traces on leaf points from Nietoperzowa Cave

| Type of point | N | Type of fractures | | | | Microscopic traces | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Burin-like | Spin-offs | Step terminating bending | Hinge terminating bending | Linear traces | Polish on protruding parts (possibly contact with organic material) | Rounding edges and protruding parts | Other microscopic traces |
| Blade/flake points | 16 | x | x | x | x | xxx | xx | xxx | |
| Bifacial | 2 | | x | | x | | | x | |
| Fragments | 25 | | xxxx | xxx | xxx | xx | xxx | xxxx | |
| Modified-retooled | 1 | | | | | | | | x |

correspond more to the model of multi-functional tools. Besides indistinct traces indicating the possibility that they were weapon points, there were mainly traces associated with hide processing, scraping of soft or moderately hard material (perhaps also skins) and drilling or piercing of moderately hard materials. Examples of a similar use of points

**Table 5** Summary of TCSA values for the Nietoperzowa Cave blades and experimental and ethnographic points

| Tip cross-sectional area (TCSA) | | | | | | |
|---|---|---|---|---|---|---|
| Sample | $n=$ | Min | Max | Mean | MD | versus NC points |
| NC points | 27 | 58.4 | 275.1 | 153.3 | n.n | n.n |
| Spear points | 8 | 50.0 | 392.0 | 189.4 | 36.1 | $t=1.14$, $p=0.049$ |
| Dart tips | 70 | 17.6 | 88.1 | 46.9 | 106.4 | $t=11.79$, $p<0.05$ |
| Arrowheads | 120 | 732.0 | 140.5 | 31.8 | 121.5 | $t=17.62$, $p<0.05$ |
| Szeletian points | 10 | 80.5 | 322 | 183.6 | 3.7 | $t=0.13$, $p=0.89$ |

were also found in other localities (Shalagina et al. 2019). Preliminary results of traceological studies of leaf points of the Moravany type from the Slovakian Szeletian culture indicate their earlier role as exclusively hunting weapons (Pyżewicz and Nemergut 2021).

It follows from the above that the points from Nietoperzowa Cave differ from the leaf points of slightly older or partly chronologically overlapping industries, i.e. those assigned to the Szeletian culture. The LRJ points illustrate a narrower range of uses, while the Szeletian points show features of Middle Palaeolithic tools of many tasks.

The association of LRJ tools with hunting practices is not, however, as well documented contextually as, for example in the case of Upper Palaeolithic artefacts (Geneste and Plisson 1993; Wojtal et al. 2015). In the past, Chmielewski (1961, 1975) presented a hypothesis of the association of the finds from layer 6 with organised autumn bear hunting in Nietoperzowa Cave. During his taphonomic analyses, Wojtal (2007, 115) found a cut mark on a cave bear bone (metatarsus) from layer 6. Interestingly, a greater number of such traces come from older layers of the cave, where tools which are not points predominate. On this basis, it can be concluded that people in Nietoperzowa Cave interacted with cave bears almost all the time. It is doubtful, however, that the points abandoned at this site are associated with the hunting of bears at the cave entrance; the remains are probably largely associated with natural death during hibernation. It is noteworthy that layers 6, 5a and 4 in Nietoperzowa Cave contain a considerable proportion of reindeer remains (Wojtal 2007, Tab. VII.1). Also, other species of game animals were found in LRJ localities; those may have been the object of hunting, for example the horse in Glaston (Cooper et al. 2012). Accumulations of LRJ points in various places, but most often in cave localities, are associated with hunting stops, where there was an exchange of equipment and expedient modifications of its function. They are not directly related to killing sites.

## The issue of the emergence of the LRJ industry

Three hypotheses can be considered regarding the problem of the appearance of the LRJ industry with points: (1) it was a kind of facies of the EUP industries known from the south; (2) it was an effect of an endemic invention or the result of diffusion and (3) it was a remnant of an influx of immigrants with ready-made templates. The first hypothesis was presented by several researchers who claimed that the LRJ complexes in Poland were facies of Szeletian or Bohunician (see Flas 2011, p. 615, see for other references). Unfortunately, it was based on the inventory from Mamutowa Cave, with its problematic numbers (Kowalski 1969) and on the locality of Dzierżysław 1, with its problematic archaeo-stratigraphy (Bluszcz et al. 1994; Fajer et al. 2005; see Wiśniewski et al. in press). It should be added that the putative source—the Szeletian culture—used a completely different approach to tool production, based completely on bifacial technology (Adams 1998; Allsworth-Jones 1986; Svoboda 2001; Mester 2010; Markó et al. 2003; Markó 2009; Nejman et al. 2017; Nerudová 1997; Nerudová and Neruda 2017). Sometimes, however, Szeletian leaf points are made of flakes or irregular blades (Nerudová 2000; Škrdla 1999; Svoboda and Svobodová 1985).

The second hypothesis points to the LRJ being the result of the technological evolution of the native Neanderthal

**Table 6** Summary of TCSP values for the Nietoperzowa Cave points, experimental and ethnographic tools

| Tip cross-sectional perimeter (TCSP) | | | | | | |
|---|---|---|---|---|---|---|
| Sample | $n=$ | Min | Max | Mean | MD | versus NC points |
| NC points | 27 | 32.4 | 103.9 | 42.6 | n.n | n.n |
| Spear points | 59 | 38 | 125 | 90.8 | 28.2 | $t=5.97$, $p<0.05$ |
| Dart tips | 70 | 31.6 | 65.0 | 47.3 | 15.3 | $t=4.33$, $p<0.05$ |
| Arrowheads | 120 | 19.1 | 60.9 | 30.5 | 32.1 | $t=13.27$, $p<0.05$ |
| Szeletian points | 10 | 48.1 | 96.2 | 63.8 | 1.2 | $t=0.15$, $p=0.87$ |

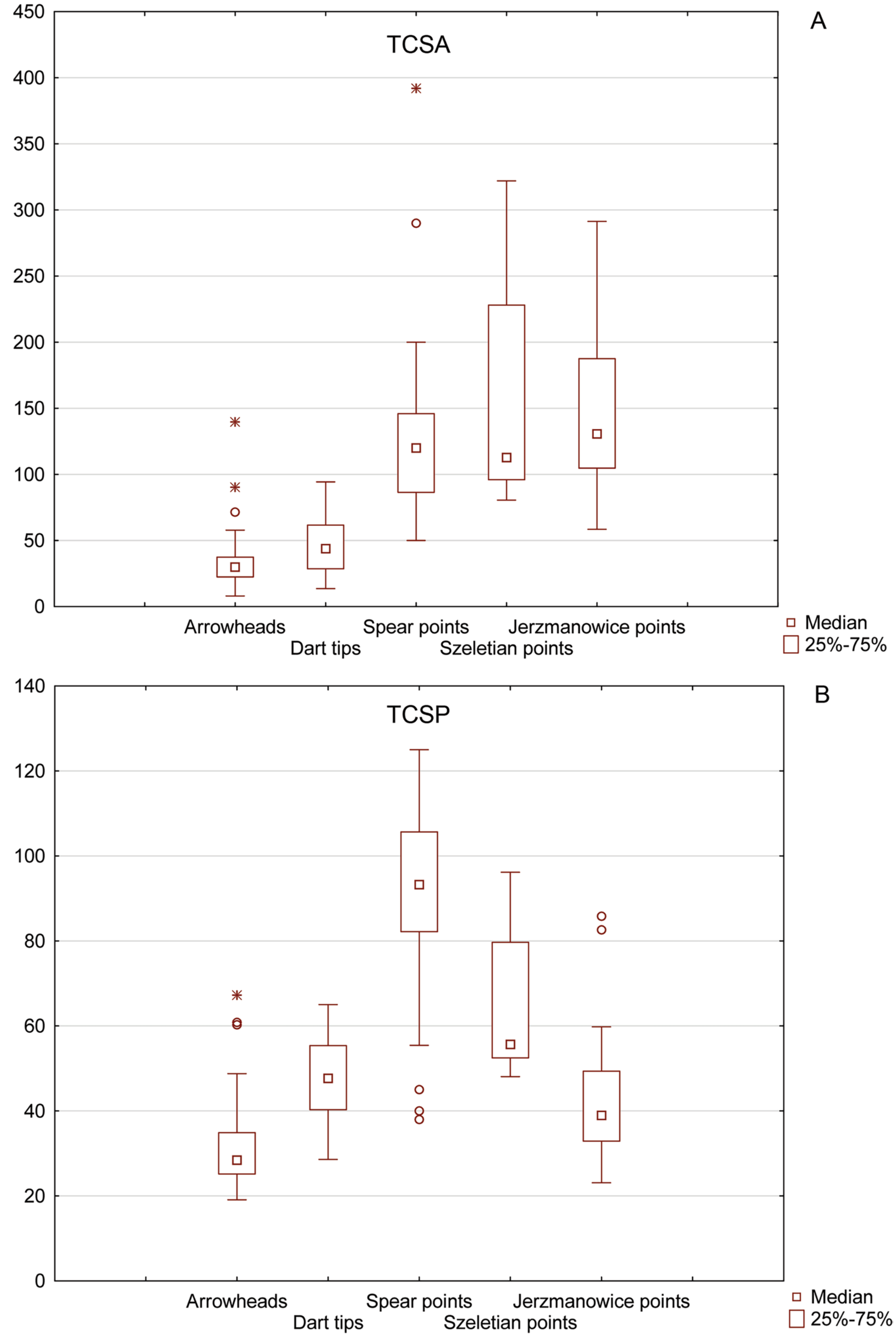



**Fig. 17** Variation in tip cross-sectional area value (TCSA) (**A**) and tip cross-sectional perimeter (TCSP) area value (**B**) for points from ethnographic context and the Late Middle Palaeolithic and Early Upper Palaeolithic sites

community. Among other things, this would require an assumption of the origin of innovation as an effect of a random sequence of events or an error (see O'Brien and Shennan 2010), earlier (e.g. Altmühlian: Kozłowski 1995, 95); there was no production of blade half-products or blade points (Kot 2014; Richter 2009). Admittedly, in the Middle Palaeolithic of Central and Western Europe, there are impulses of blade technologies (Bar-Yosef and Kuhn 1999; Conard 1992), but there is no evidence that they were applied as the basis for the preparation of points of projectile weapons, not to mention the fact that such complexes seem to be limited to MIS 5 (Révillion 1995).

Another variant of the same hypothesis is the concept of acculturation which assumes that the development of LRJ was mainly influenced by the transmission of templates from the environment of the Aurignacian culture. This hypothesis was based on chronological data, with a resolution and range much smaller than today (Desbrosse and Kozłowski 1988; Jacobi 1999; Jacobi et al. 2007; Jöris and Street 2008; Flas 2011; Otte 1990). At present, the complexes with a developed Aurignacian culture seem to be younger than some of the LRJ complexes.

The third possibility is the idea that the whole technological package arrived from the outside with its creators. The concept emphasises the association of the LRJ with the polymorphic group of Initial Upper Palaeolithic (Clark 1997; Demidenko et al. 2020; Hublin et al. 2020; Hublin 2015; Kuhn and Zwyns 2014; Meignen 2006; Škrdla 2013; Zwyns et al. 2012). The LRJ complexes, like the associated complexes of Central Europe: Bachokirian, Bohunician, Proto-Aurignacian and Early Kozarnikian, show similarities in their tendency to base their production on blade cores or maybe flake cores, uni- and bi-directionally reduced toward opposite striking platforms. Among the Central European complexes, the Bohunician is included in the IUP since it is based on a technology which is close to the Levalloisian but absent in the LRJ (cf. Kuhn and Zwyns 2014; Svoboda and Skrdla 1995).

The question of the association of the LRJ with the genetic background remains open. In the past, advocates of the hypothesis of endemic development or diffusion of templates suggested that their authors were the last Neanderthals from the northern fringes. A number of researchers support the association between the LRJ and AMH, based on bone finds from Kent's Cavern (Higham et al. 2011; Pettitt and White 2012; but see Zilhão 2013). We think that the recent data from Bacho Kiro Cave (Bulgaria), which indicate an earlier arrival of the AMH in Central Europe (ca. 2–3 thousand years before the earliest LRJ dates in Poland), very seriously support AMH as the main propagator of the LRJ complexes (Hublin et al. 2020; Fewlass et al. 2020; Hajdinjak et al. 2021; Prüfer et al. 2021). The discovery of modern human remains from Grotte Mandrin, Malataverne, in France, dated to 56,800 and 51,700 years ago (Slimak et al. 2022), is coming to play an important role in this discussion.

## Conclusions

The re-examination of the points of the LRJ complex from Nietoperzowa Cave, using a multi-proxy approach, has provided important insights. Metric and morphological data show that variation mainly involved lateralisation. It was observed, however, that the repetition shape was independent from metric parameters. The size and shape of the points appeared to be independent from the quality of and distance from the outcrop of the material from which the points were made. The technological studies indicate that in terms of design and its execution the points form a very uniform group. The blade/flake forms which predominate in the inventory show an economic approach which consists in distinguishing crucial techno-functional zones.

The traceological examination of the points from Nietoperzowa cave revealed traces of their use as projectile weapons. Single observations indicate a weapon mounted in the haft. Analyses of the cross-sectional area, especially the TCSP, simultaneously argue for a relationship with the spearheads. We think that our observations revise the earlier interpretations which compared the points to multi-functional tools of the Middle or Lower Palaeolithic. In our opinion, the indicated group of features distinctly points to a mono-functional character of these tools. The use of points for other tasks was secondary to their original purpose.

We believe that this morphometric and functional homogeneity of the points from Nietoperzowa Cave, as well as the compared tools from other LRJ assemblages from Europe, provides evidence that they are part of a structurally advanced piece of everyday hunting equipment that has no references in the earlier history of tool technology development of Central and Western Europe.

In our opinion, the phenomenon should be regarded as part of a packet of industries close to the EUP with blade technology, without Levalloisian features. Nothing can be said about its origin. It could originate from AMH groups, but it cannot be excluded that those were in biological contact with the native peoples. At present, the long-surviving hypothesis of acculturation of the native Neanderthal people or local evolution of the Middle Palaeolithic industries toward the LRJ is becoming increasingly unlikely.

**Supplementary Information** The online version contains supplementary material available at https://doi.org/10.1007/s12520-022-01552-z.

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## Declarations

**Conflict of interest** The authors declare no competing interests.

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