Quantification of late Pleistocene core configurations: Application of the Working Stage Analysis as estimation method for technological behavioural efficiency

Über die Quantifizierung spätpleistozäner Kernkonfiguration: die Arbeitsschritt-analyse als Methode der Bewertung technologisch effizienten Verhaltens

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Abstract - Which cores are more productive: Upper Palaeolithic blade cores or Middle Palaeolithic Levallois or discoidal cores? This question discussed since the 1960's and the methodological problems in measuring lithic technological efficiency were the initial points for the present study. As a first step it seemed reasonable to clarify the term efficiency which is often used vaguely defined or runs even undefined in the context of the description of human technological behaviour. In this paper we discuss established approaches to late Pleistocene archaeology in order to analyse which type of efficiency is estimated by the respective methods, and what is defined as resource-input and what is seen as resource-output. In a second step, we apply the already introduced Working Stage Analysis to analyse the configuration of 601 cores shaped following ten different Middle and early Upper Palaeolithic reduction strategies employed at different sites of south western and central Europe. Although we are aware that the use of cores for such a kind of estimation might be critically discussed, this method has the potential to complement existing methods. Our test study of the quantification of late Pleistocene core configuration produced reasonable results which we use to estimate technological behavioural efficiency. Thereby a clear differentiation of the analysed reduction strategies becomes obvious, filling a lack of empirical data for evaluating variable lithic technological efficiency.

Zusammenfassung - *Welche Kerne sind ergiebiger: jungpaläolithische Klingenkerne oder mittelpaläolithische Levallois- oder Diskoid-Kerne? Seit den 1960er Jahren wird diese Frage diskutiert und bildet gemeinsam mit methodologischen Problemen bei der Effizienzberechnung in der Steingerätetechnologie den Ausgangspunkt der hier präsentierten Untersuchung. In einem ersten Schritt schien es angebracht, den Begriff der Effizienz im Zusammenhang technologischen Verhaltens, der oft unklar oder gänzlich undefiniert verwendet wird, zu präzisieren. In dem vorliegenden Artikel werden gängige Analysemethoden der Archäologie des späten Pleistozäns diskutiert, um herauszufinden, welche Art von Effizienz jeweils berechnet wird und was einerseits als Ressourcen-Aufwand und andererseits als Ressourcen-Ertrag verstanden wird. In einem zweiten Schritt wird die bereits etablierte Arbeits-schrittanalyse genutzt, um die Gestaltung von 601 Kernen, die gemäß zehn unterschiedlicher Abbaumethoden konfiguriert wurden und von verschiedenen Fundstellen Südwest- und Mitteleuropas stammen, zu untersuchen. Gleichwohl wir uns darüber im Klaren sind, dass die ausschließliche Fokussierung auf Kerne bei einer solchen Untersuchung kritisch erörtert werden muss, hat die hier vorgestellte Methode das Potential bereits existierende Arbeitsweisen zu ergänzen.*

Unsere Teststudie zur Quantifizierung spätpleistozäner Kerngestaltung brachte nachvollziehbare Ergebnisse und lässt die Berechnung der Effizienz technologischen Verhaltens zu. Dabei wurde eine klare Differenzierung der untersuchten Kernab-baustrategien sichtbar. Darüber hinaus schließt die Untersuchung eine Lücke in der empirischen Datengrundlage zur Bewertung verschiedenartiger technologischer Effizienz in der Steingeräteproduktion.

Keywords - Lithic reduction strategy; Middle-Upper Palaeolithic transition; Blade; Flake
Grundformgewinnung, Mittelpaläolithikum, Jungpaläolithikum, Klinge, Abschlag

Introduction

In their article published in 2008 Eren et al. raise the interesting question whether Upper Palaeolithic blade cores are more productive than Middle Palaeolithic discoidal cores (Eren et al. 2008). One of the obtained results refers to the methodological problem that static measurements "promote an illusion of efficiency" and call for a more "dynamic approach that takes the whole reduction sequence into account." (2008: 952).

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Human efficient behaviour is indeed a broad issue that is especially discussed in psychology, physiology and economy. Many facets of individual abilities such as talent, personal strategy, motivation how resource-input can be directed toward profitable goals, interpretation of signs of fatigue and various distractors have an impact on efficient behaviour (Fryer 1950). To estimate human efficient behaviour today, testees are observed and questioned (Vallée-Tourangeau 2012). This approach is obviously not an appropriate method in prehistoric archaeology. For this reason, prehistoric human efficient behaviour can only be indirectly estimated by analysing the archaeological material remains. According to ethnographic studies, economisation of resources was of vital interest and part of adaptation strategies in hunter-gatherer communities. Mobility and changing accessibility to predictable and non-predictable resources govern economic behaviour (Casimir 1992; Kuhn 1995; Fowler & Turner 1999; Wallace & Shea 2006). Considering late Pleistocene archaeology, the discussion on the determination of the economic value of the different core reduction strategies has a long tradition, and follows various lines of argument. Some authors argue that the economic value of lithic technology can be deduced from the degree of schematisation of the working processes, e.g., the production of blanks as well as their subsequent processing to retouched tools (Hering & Kraft 1932; Feustel 1985). Others focus on the degree of exploitation of a given raw material volume. In addition to that, the amount of waste products, the number of intended end-products (Brantingham & Kuhn 2001; Cole 2009; Pasda 1998; Uthmeier 2004) and the cumulative length of the produced sharp cutting edges of the blanks (Leroi-Gourhan 1964; Leroi-Gourhan 1988) are seen as indicators as well.

In this paper we resume the established estimation methods in order to precise the respective analytical application in the estimation of technological behaviour efficiency. This seems necessary because efficiency describes only the ratio of resource-input and product-output without further precision. While using this ratio, the existing methods use different data as resource-input and product-output. Consequently they estimate different things.

It seems promising to clarify this situation in order to get clear descriptions of which type of efficiency is estimated by the established methods. The established estimation methods exclude cores from the analysed data set although cores are beyond doubt an important data source of technological information. As an alternative estimation method we apply the Working Stage Analysis (Pastoors & Schäfer 1999; Pastoors 2001). The basic idea of this approach is to record the different connected working stages that are conceivable on the reduction surfaces of cores and which reflect the individual cognitive choice of the manufacturers. This approach works independent from size and volume of the analysed cores.

Finally, our core based approach is applied to analyse the efficiency of different Middle and early Upper Palaeolithic reduction strategies and subsequently a comparison of the lithic technological behaviour efficiency of the analysed sites is made.

Discussing established estimation methods

There is a panoply of different methods to estimate the efficiency of lithic production systems (Brantingham & Kuhn 2001; Cole 2009; Pasda 1998; Uthmeier 2004). The methods applied so far are based nearly exclusively on blanks and vary only slightly in their methodological approach. Basically, available blanks are classified and quantified; cores are not taken into account (Fig. 1).

Within their paper Brantingham and Kuhn (2001) discuss the hypothesis put forward by Foley and Lahr (Foley & Lahr 1997) that the appearance and stability of the Levallois reduction technology is linked to the dispersal of Homo heidelbergensis and “its phylogenetic descendents” (Brantingham & Kuhn 2001: 747). Thereby they develop a mathematical model that describes the volumetric definitions of the Levallois concept and which “suggests that Levallois core technology as currently defined is efficient in minimizing preparation waste and productive in maximizing the number of usable end products and amount of usable cutting edge.” (Brantingham & Kuhn

author	resource-input	product-output	kind of efficiency
Brantingham & Kuhn (2001)	total number of blanks	maximal number of usable end-products and cutting edges	blank usability & cutting edge lenght
Cole (2009)	total number of blanks & formal tools	maximal number of usable end-products (blanks and formal tools)	blank portability, distance attrition, nodule size
Uthmeier (2004)	technological marker	maximal number of usable end-products and cutting edges	blank usability & cutting edge lenght
this contribution	negatives of technological marker (on reduction surfaces of cores)	maximal number of negatives of predetermining and predetermined blanks and usable end-products (on reduction surfaces of cores)	core configuration

Fig. 1. Estimation methods of lithic production efficiency.

Abb. 1. *Methoden der Bewertung der Effizienz der Grundformgewinnung.*

2001: 748). By modelling different parameters such as the shape and the size of the original nodule, the platform position and the platform angle, the number of potential end-products and cutting edges they convincingly demonstrate the interdependence of the different parameters and the overall efficient nature of the Levallois technology. Whereas this mathematical model functions as a theoretical basis to contrast different reduction concepts, its application to a concrete lithic assemblage to define the efficiency of human behaviour in place is impossible but was also not the intention of the authors. Moreover, Brantingham and Kuhn (2001: 758) themselves state that "aspects of core reduction that reflect dynamic decision making processes are difficult to model from a geometric standpoint". In their model they use the total number of blanks as resource-input and maximal number of usable end-products and cutting edges as product-output.

Cole (2009) conceived efficiency as "the ratio between useful product and unused raw material. Useful product consists of blanks struck from a core and any formal tools, whereas unused material consists of the mass left in the wasted core and unused debitage and shatter" (Cole 2009: 130). Efficiency is further understood as an optimal relation between a maximum of useful products, their transport size and shape and the transport distance. By analysing different patterns in tool and blank sizes of local and non-local raw material Cole aims to test three hypothesis to which he refers as "the blank portability", "the distance attrition", and "the nodule size" hypotheses (Cole 2009: 130). Thereby the conservation of energy and raw material costs as observed from four different Initial Upper Palaeolithic assemblages (one Châtelperronian and three Aurignacian assemblages) of the Perigord should be evaluated. The "blank portability hypothesis" assumes that people took preferably "smaller and more useful products" of non-local raw material in order to guarantee the transport of an optimal tool size by a minimum of transport costs. The "distance attrition hypothesis" to the contrary states that lithic artefacts decrease in size with increasing distance from the raw material source. Cole further explains that "if distance attrition alone can account for the smaller size of transported products, then the smaller size of non-local products is not automatic evidence of increased efficiency" (Cole 2009: 132) as assumed by the "portability hypothesis". As only retouched pieces are affected by size attrition, blanks can be used to test the hypothesis. Last, the "nodule size hypothesis" seeks to explain the fact that non-local raw material nodules may occur in smaller sizes than local raw material cobbles which would result in smaller blanks and tools of non-local raw material. Obviously, the smaller sizes of non-local artefacts would then have nothing to do with efficient processing of raw material, but solely result from naturally given parameters. After sorting the artefacts to raw material varieties he compares the differences in artefact (blanks and tools) size/weight of local and non-local raw material, the retouch frequency, and the technological composition and ascribes either efficient or less efficient technological behaviour to the referred assemblages. Cores are also excluded from his analysis. In this analysis the total number of blanks and formal tools is seen as resource-input and the maximal number of usable end-products (blanks and formal tools) as product-output.

In his work about the transition from the Middle to the Upper Palaeolithic in Bavaria Uthmeier (2004) addresses the hypothesis of an improved extraction which has been put forward by Leroi-Gourhan (1964-1965: 177). The hypothesis states that the replacement of the Levallois concept by the blade concept is due to a higher productivity ("Mengenaspekt") of the latter: more blanks can be produced accompanied by a decrease of preparational blanks and, as a result of the laminar shape, a higher number of cutting edges can be produced ("Formenaspekt") (Uthmeier 2004: 358ff.). Comparable to our approach Uthmeier distinguishes between predetermining blanks, predetermining and predetermined blanks and predetermined end-products (Uthmeier 2004: 359; for clarification on terminology see 2.4). With the help of this so-called extraction-analysis, he calculates and compares the efficiency of the blank production of different late Middle Palaeolithic, Aurignacian and Gravettian assemblages. Thus he compares the shares of the three different blank types, whereas those assemblages with the highest amounts of predetermined end-products are interpreted as most efficient. Similar to other methods, cores are excluded. His results point to a diachronic increase of efficiency towards the Gravettian, in other terms: the Upper Palaeolithic blade concept appears to be more efficient than the Levallois concept in terms of economic handling of raw material costs. This is explained by an extension of settlement areas from the Micoquian to the Upper Palaeolithic that requires a higher planning depth and makes an economisation of the raw material and a reduction of transport costs necessary. However, it is important to note that Uthmeier himself submits that this calculation is complicated by export and import states of the artefacts influencing the assemblage composition. Hence, within the Gravettian assemblage of Mau-3 (Weinberghöhlen-6) flakes of the preparational phase may be under-represented, because cores have been prepared off-site. As resource-input Uthmeier uses technological marker (predetermining blanks, predetermining and predetermined blanks and predetermined end-products) and as product-output the maximal number of usable end-products and usable cutting edges is taken.

The three methods cited above for the estimation of lithic production systems efficiency make use of different data as resource-input: total number of blanks, total number of blanks & formal tools and technological marker. Based on this material they calculate the maximum number of comparable end-products as product-output. In doing so, the authors estimate different types of technological behaviour efficiency: blank usability, blank portability, distance attrition, nodule size, and cutting edge length.

Experiments

In addition to the empirical analysis of archaeological remains, experiments play an important role in analysing the efficiency of different blank production strategies. The aim of most of these studies is to determine efficiency by measuring and comparing the production of "usable flakes" (flakes >25mm), which are either counted, weighed or the length of their cutting edges is measured. Therefore they estimate blank usability in different ways. Even if Jennings et al. (Jennings et al. 2010: 2159) state: "[...] core efficiency experiments are an imperfect means to fully test hypotheses regarding past lithic technological systems", they undoubtedly have to be considered as an important means to complement empirical archaeological analysis. In an experiment published by Prasciunas (Prasciunas 2007) ten bifacial and ten opportunistic cores were reduced to exhaustion in order to determine the strategy that displayed a higher degree of efficiency in producing usable flakes. No significant difference in the amount of usable flake edges could be detected between the different strategies. However, her results suggest that opportunistic cores are more efficient than bifacial cores when the weight of the produced usable flakes is to be measured. In another experiment presented by Rasic and Andrefsky (Rasic & Andrefsky 2001), one bifacial core and one blade core were reduced. Whereas the bifacial core yielded more usable flakes, measured by usable flake count, the blade core displayed a higher efficiency in conserving stone weight. This study however is of minor importance as the data are based on only two cores, which additionally differed significantly in their initial core sizes.

Recently a study by Jennings et al. (2010) was published that compared the efficiency of bifacial and blade cores. In the course of their study, six bifacial and five wedge-shaped blade cores were reduced. No significant differences between the number of produced usable flakes and the weight of material transformed into usable flakes could be detected. As usable flakes those greater than 2.5 cm in any dimension were considered. In their opinion, usable flake weight is a more useful measure of core efficiency than flake counts and consequently they define efficiency "only by usable flake blank weight as a percentage of the initial core weight" (Jennings et al. 2010: 2160). They emphasize the assumption that for smaller cores (<300 g – 500 g) opportunistic reduction seems to be more efficient for the production of usable flakes, in terms of transport-efficient strategies, than bifacial reduction (Jennings et al. 2010: 2163). In the context of Paleo-Indian studies, Jennings et al. suggest that transport-efficient strategies were applied where raw material sizes were more varied, while less or equal efficient bifacial reduction was applied in areas where raw material occurred in large nodules and no efficient processing was necessary.

Application of the Working Stage Analysis as alternative estimation method

The Working Stage Analysis was developed in the mid-1990's by Jürgen Richter and one of us (AP) while studying the lithic materials from Sesselfelsgrotte (Richter 1997) and Salzgitter-Lebenstedt. The method is explained in detail (Pastoors & Schäfer 1999) and was first applied to the lithic material of Salzgitter-Lebenstedt (Pastoors 2001). Further studies of lithic technology exist, that are based on the Working Stage Analysis (Kurbjuhn 2005; Tafelmaier 2011). Likewise, the recently published article by Perreault et al. (2013) on measuring diachronic technological complexity resembles our approach in reconstructing the production process of lithic artefacts by combining so-called "procedural units" (Perreault et al. 2013: 399). Although the Working Stage Analysis has already been published in the 1990's, the methodological principles are summarized in the following.

The Working Stage Analysis is a method for analysing the production process of lithic artefacts; the term "production process" covers all alterations of the artefact including those caused by usage or thermal influence, modern damage, etc. The basic idea is to interpret one or more interconnected negatives having the same function as one working stage. These working stages are in turn classified according to production method, appearance and subsequently chronologically related to neighbouring working stages. Thus, the production process of the entire artefact is described in chronological order.

In contrast to a typological description of the artefacts, the Working Stage Analysis aims not at describing the appearance of the entire artefact but at analysing the dynamic production process which gave the artefact its shape.

In the analytical process, partial areas can be studied and compared individually or in combination with several partial areas. It is possible to discern standardized and non-standardized production concepts as well as certain individual preferences. The Working Stage Analysis allows artefact types and production processes to be compared with each other. However, the Working Stage Analysis is still an up-to-date possibility to collect and to quantify the variety of information and to present the results by means of combination, statistical analyses as well as illustrations.

Fundamental principles of the Working Stage Analysis

The production process can be tracked by all negatives, all natural surfaces and the ventral surface of blanks, covering the artefact surface. Thus, facial working, modification of the edges, usage and other alterations can be reconstructed. Sometimes even remains of the former blank can be found. Recycling cannot be made out directly, but becomes apparent after relating the different, reconstructed working stages.

Negatives, which originate from the same edge, have been produced for the same purpose and are in direct sequence, are interpreted as one working stage. Accordingly, one working stage can be an individual, isolated negative as well as groups thereof, if they comply with the above-mentioned conditions. Also use wear traces and natural surfaces (cortex, joint plane, etc.) are considered as a working stage.

To understand the chronological order of the working stages five attributes are of special importance; all chronological and functional relationships between the bordering ridges of a working stage and the neighbouring working stages must be recorded. The internal sequence of the individual negatives within one working stage is neglected.

In the immediate area of the shared ridge separating the negatives, a chronological sequence of the negatives is discernible macroscopically or by using a 10 x magnification. Usually, it is even sufficient to feel the increased concavity of the younger negative in the immediate area of the separating ridge with the fingertip. The chronological relation of two neighbouring negatives is characterized by the following attributes (Fig. 2):

- 1. The younger negative lies deeper and is more concave in the immediate area of the separating ridge than the previous negative.
- 2. The younger negative has lateral lances; those of the older negative were cut off by the younger one.
- 3. The lances of the younger negative are frequently accompanied by lance-shaped, often multistage microchips
- 4. The contour of the younger negative follows the relief of the older one and cuts across it.
- 5. In the terminal area of the younger negative Wallner lines are clearly recognizable.

Each working stage is given an address in order to localize it on the artefact surface. Thus, one address represents one individual working stage, which is the prerequisite for reconstructing the production process. The address contains information concerning which surface it belongs to as well as from which direction the working stage proceeded. Therefore, the artefact has to be oriented following a uniform pattern. In order to assign addresses to the working stages the different surfaces of the artefact have to be labelled, with regard to the type of artefact analysed: tool or core. Principally, an artefact is divided into an upper and a lower surface in case a core with different reduction surfaces is analysed, each surface has to be labelled individually, but by applying a replicable pattern. The upper surface is generally marked with the letter “u”, the lower surface with the letter “l”. This works both for surface shaped tools as well as for discoidal or Levallois cores. The point or the distal

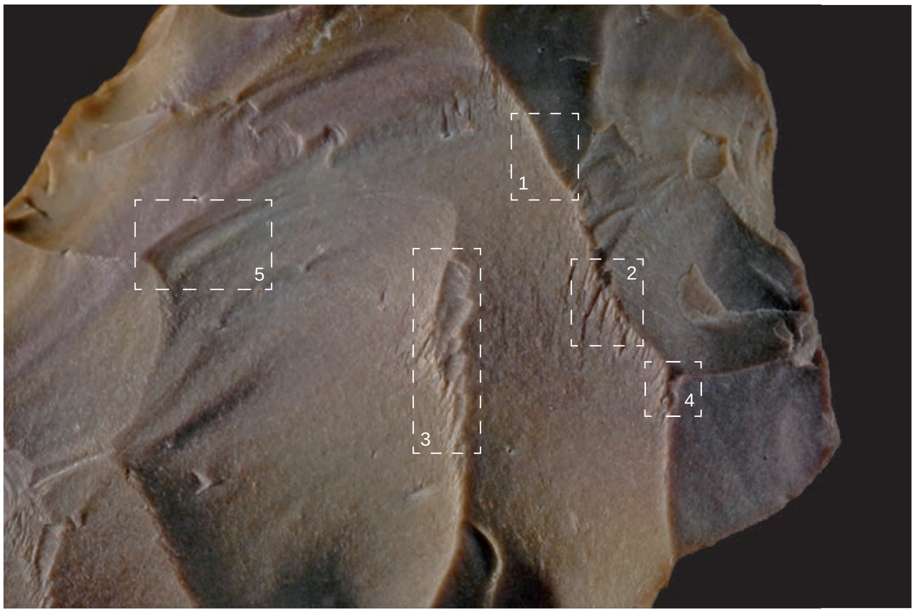

Fig. 2. Attributes of the chronological relation between neighbouring negatives.
Abb. 2. *Merkmale der zeitlichen Beziehung zwischen benachbarten Negativen.*

end is given the number “1”. Starting from there, the edge areas are numbered clockwise on the upper surface, and vice versa on the lower surface counter-clockwise, from “2” to “4”.

If several working stages originate from the same edge area, they are given an additional number (1, 2,...). Only those edge areas are addressed which are defined by a working stage.

Chronological relationship between the individual working stages

In order to reconstruct the production process of a lithic artefact the chronological position of each working stage has to be defined. Hence, it is necessary to establish the relationships of one working stage to all neighbouring working stages using mathematical comparative operators (example: u21 > u22; u21 > l2; l21 < l1; ‘>’ = older and ‘<’ younger).

Determining the chronological position of the working stages

Since the aim is to reconstruct the production process of a lithic artefact, all chronological relationships between the defined working stages have to be arranged into an integral sequence. This is the pre-requisite for all subsequent analysis. A software to guarantee an all-encompassing description of all observed working stages and their relationships, is the “Harris-Matrix-Analysis” of the e.g. Bonn Archaeological Software Package (BASP). With the help of this program all relationships can be combined in one diagram representing the chronological sequence of all working stages. Simultaneously the program checks for circular arguments (e.g.: u21 > u22 > l2 > u21). In a tree diagram direct chronological relationships are represented by connecting lines and boxes in bold outline (Fig. 3).

Ideally, each working stage for a lithic artefact can be allocated to one chronological position, all of which constitute a chain. In practice, it is impossible to reconstruct the complete working stage sequence of an artefact to such an extent that only one working stage is placed on each allocated chronological position. This is mostly due to the destruction of the required relationships by younger working stages. The following example serves to illustrate this problem (see also Pastoors 2000): The working stages l21, l4, l41, l42 and l43 are directly related to each other and therefore constitute a definite chronological sequence, in this case l21 > l4 > l41 > l42 > l43. The working stage l3 now joins the chain because it is directly related to the working stages l4 and l43 (l4 > l3 > l43). It becomes obvious that the chronological position of the working stage l3 cannot be clearly defined. It is certainly younger than l4 and certainly older than l43 and thus must be located somewhere between both.

The Harris-Matrix-Analysis offers two classification possibilities. Working stages whose chronological position cannot be defined exactly, could either be placed at the oldest possible or the youngest possible position. Why it is advisable to choose the latter option (youngest possible position) will become clear by the following considerations. In case that a lithic artefact is recycled, the relationships between the negatives that are placed further away from the edge disappear and the originally discernible, definite sequence of the working stages is difficult to perceive. As a consequence the older working stages according to the working stage sequence accumulate on the lower chronological positions. We understand this phenomenon as an indication of recycling. As recycling has considerable influence on the interpretation of the formation process, it is necessary to determine especially these older stages of the production process with as much accuracy as possible.

The usage of the artefact chronologically ranges at the end of the production process and therefore has, in most cases, exclusively unidirectional relationships to just one individual working stage. Thus, usage represents the most recent alteration of a lithic artefact.

Quantification of core configurations

The Working Stage Analysis is a useful tool to reconstruct the production process of different lithic artefacts in a transparent manner. Because the focus of the present study lies on the quantification of core configuration it is necessary to define the applied method more precisely.

The reduction surfaces of the cores are thus in the centre of interest. Technological terms and definitions are mainly in-line with the work of Boëda, Geneste

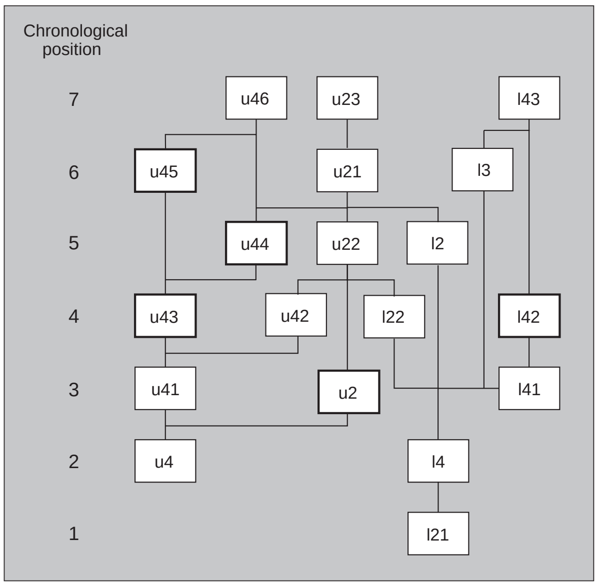

Fig. 3. Harris-Matrix diagram showing the chronological relationship between the recorded working stages.

Abb. 3. *Harris-Matrix Diagramm der zeitlichen Beziehungen zwischen den aufgenommenen Arbeitsschritten.*

and Meignen (Boëda 1990, 1994; Boëda et al. 1991; Delagnes & Meignen 2006; Révillion & Tuffreau 1994) and Delagnes for the unidirectional Le Pucheuil-type flake method (Delagnes 1993). The chronological position of the working stages are not analysed within the current study.

Following Boëda (1994: 28 ff.), the negatives on the reduction surfaces are divided into preparational flakes that provide convexity (predetermining), end-products that profit from the convexity (predetermined) and end-products that establish convexity (predetermined and predetermining) (compare Fig. 4). Within several experiments and a cross-check with archaeological material, Boëda (1994) demonstrated the validity of his classification a long time ago.

These three types of negatives which cover the reduction surfaces of cores reflect the intertwining processes of intentional preparation, exploitation and maintenance of extractable volume. More generally, these three types of negatives mirror the repeated interaction between the construction and the levelling of cores' convex reduction surfaces. Predetermining flakes proceed on the designated reduction surface and this way create the required convexities. They are considered as preparational flakes. In contrast, predetermined flakes make use of the prepared extractable volume without establishing further usable convexities. In this sense an "end-product" has to be seen as an intermediate stage of the production sequence and not as its terminal point. Finally, some flakes have a double function (predetermined and predetermining): they make use of prepared extractable volume and, at the same time, establish convexity.

It is relatively easy to differentiate the three types of negatives on the respective reduction surfaces of the cores. Likewise, the frequency of each type of negative is quantifiable. Under the perspective of efficient human behaviour, we interpret negatives covering the reduction surfaces as resource-input and the maximum number of negatives of any kind of predetermined blanks as product-output. Within this context however, it is necessary to emphasize that we do not consider preparational blanks as waste products that were useless to the knapper. Undeniably those products have been used either modified or unmodified and hunter-gatherers relied on those predictable products. Nevertheless, the different applied reduction concepts can be defined by a characteristic ratio of predetermining and predetermined products. Based on these data we quantify the core configuration to estimate technological behaviour efficiency. Admittedly, only the last stage of core configuration and exploitation can be considered by

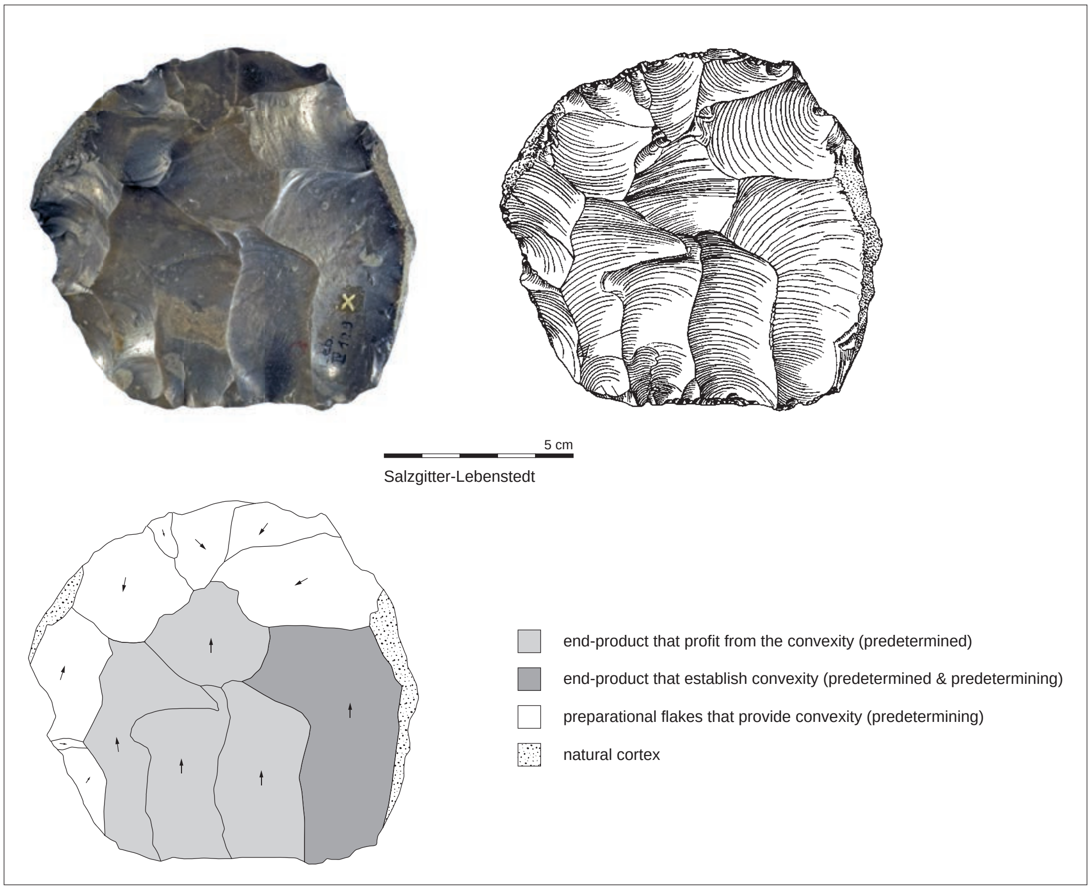

Fig. 4. Core number iv129 from Salzgitter-Lebenstedt with indication of the different working stages.
Abb. 4. *Kern Nummer iv129 von Salzgitter-Lebenstedt mit Kennzeichnung der unterschiedlichen Arbeitsschritte.*

the here presented approach. Due to that, possible switches between different employed techniques during the reduction of a given raw volume cannot be taken into account. However, this is true for all here considered assemblages.

To illustrate the basic concept of the presented method, a Levallois recurrent unidirectional core from Salzgitter-Lebenstedt (number iv129) serves as an example. It provides negatives from four end-products that profit from the prepared convexity, one end-product that establishes convexity and eight preparational flakes that provide convexity (Fig. 4). Translated in a relative ratio of the different types of negatives, 31 % end-products profit from prepared convexity, 8 % end-products establish convexity and 62 % preparational flakes provide convexity. First, this ratio reflects the expected distribution, and second it offers a tool for comparative studies. Thereby only the number of end-products solely profiting from the established convexities, is seen as a parameter for the efficiency of the working process (here 39 %).

Finally, the core iv129 shows a high amount of preparational flakes that provide convexity, and therefore a small amount of end-products is identifiable. Referred to analysed objects from Salzgitter-Lebenstedt, the arithmetic mean of end-products per reduction surface varies between 13 % (Levallois preferential unidirectional) and 73 % (unidirectional bladelet) and shows the different degrees of efficiency of the identified reduction strategies in Salzgitter-Lebenstedt (Fig. 5). All cores, regardless which reduction strategy was applied, apart from the unidirectional bladelet method, confirm the low degree of efficiency in lithic technological behaviour in Salzgitter-Lebenstedt.

Test study: Estimation of technological behavioural efficiency compiled with the Working Stage Analysis

To test the reliability of the Working Stage Analysis as an estimation method for technological behavioural efficiency, cores from different Middle Palaeolithic, transitional and early Upper Palaeolithic sites in South Western and Central Europe were analysed. A total of 601 cores from the sites of Cueva Morín level 13 - 9, El Castillo level 22 - 16, Jarama VI level III - II, Arbreda level F and G, Abric Romani level B - G (all Spain), Salzgitter-Lebenstedt and Balver Höhle level I - IV (both Germany) were studied (Figs. 6 & 7). Apart from the open air site Salzgitter-Lebenstedt, all sites are cave sites. Detailed long lasting research in all these sites is documented in numerous publications.

The Iberian sites display stratigraphies reaching from the Middle to at least the early Upper Palaeolithic. The sites of Cueva Morín (González Echegaray & Freeman 1971, 1973, 1978; Vega del Sella 1921) and El Castillo (Cabrera-Valdés 1984; Cabrera-Valdés et al. 2005; Cabrera-Valdés et al. 2006) are both located in the Cantabrian region, and not far from each other. Whereas El Castillo possesses a long sequence with 26 levels reaching continuously from the Lower Palaeolithic till the Mesolithic, Cueva Morín yields a stratigraphy of 22 different levels from the Middle to the Epipalaeolithic.

The Abric Romani (Vaquero et al. 2001) is a large rock shelter near Capellades (Catalunya), situated in the north-eastern part of the Iberian Peninsula. It yields a 20 m deep stratigraphic record that spans a time range from ca. 70 ky BP until 40 ky BP (Bischoff et al. 1994; Bischoff et al. 1988). Most of the archaeological levels can be attributed to Middle Palaeolithic occupations.

lithic reduction system		predetermined	predetermined & predetermining	predetermining	total negatives	total cores
SzLeb		%	%	%	N	N
Bladelet	unidirectional	8	65	27	46	4
Levallois recurrent	centripetal	21	24	55	98	9
	bidirectional	23	34	43	48	5
	unidirectional	28	10	62	176	16
Levallois preferential	divergent	30	5	65	87	10
	bidirectional	31	2	67	53	6
	unidirectional	11	2	87	114	9
total (mean)		**23**	**15**	**62**	**622**	**59**

Fig. 5. Efficiency of different reduction strategies in Salzgitter-Lebenstedt.

Abb. 5. *Effizienz der verschiedenen Strategien der Grundformgewinnung in Salzgitter-Lebenstedt.*

Fig. 6. Map of Europe with studied sites indicated.
Abb. 6. *Europakarte mit Kennzeichnung der untersuchten Fundstellen.*

Together with the famous sites of Reclau Viver and Mollet, the cave of Arbreda is situated in the Paratge del Reclau (Serinya, Catalunya) north of Girona. Similar to the other sites, the Arbreda cave yields a long, continuous stratigraphy reaching from the Middle Palaeolithic till the Neolithic and hence documents the transition from the Middle to the early Upper Palaeolithic (Soler Masferrer & Maroto 1987a, 1987b; Soler Masferrer et al. 2001).

Jarama VI is a cave in the Jarama valley on the southern slope of the Spanish Central Range, near Guadalajara and reveals three levels with Middle Palaeolithic occupations (Jordá Pardo 2007; Jordá Pardo et al. 2013; Kehl et al. 2013).

Neither German site – Salzgitter-Lebenstedt and Balver Höhle – reveals stratigraphically verifiable Upper Palaeolithic remains. Whereas in Salzgitter-Lebenstedt near Wolfenbüttel (Lower Saxony), a rich industry of the late Middle Palaeolithic was found (Pastoors 2001), the Balver Höhle (North Rhine Westphalia) displays a stratigraphy of at least four Middle Palaeolithic levels (Günther 1964).

First results

In the following a short overview about the specific features of the detected lithic reduction systems and the core configurations of the studied levels is given. In total 3'903 negatives of the aforementioned types are registered on the reduction surfaces of the 601 cores, with an average of six negatives per core. Figure 7 lists the included cores of each analysed stratigraphic unit according to the applied reduction concepts.

site	level	attribution	cores
Cueva Morín (CM)	13	MP	5
	12	MP	6
	11	MP	6
	10	CHA	52
	9	AUR	28
El Castillo (EC)	22	MP	68
	20	MP	48
	18	TRANS	64
	16	AUR	14
Jarama VI (JA)	III	MP	31
	II	MP	3
Arbreda (AR)	G	AUR	7
	F	GRA	5
Abric Romani (RO)	FG	MP	8
	E	MP	15
	BCD	MP	19
Salzgitter-Lebenstedt (SzLeb)	-	MP	59
Balver Höhle (BA)	I	MP	3
	II	MP	60
	II/III	MP	21
	III	MP	26
	IV	MP	53
total			**601**

Fig. 7. Studied data corpus.
Abb. 7. *Datenbasis der vorliegenden Untersuchung.*

Cueva Morín (Fig. 8)

The studied five levels from Cueva Morín cover late Middle Palaeolithic (CM-13, CM-12 and CM-11), transitional (CM-10) and early Upper Palaeolithic (CM-09) occupations. From these levels 97 cores with in total 513 negatives on the reductions surfaces were analysed. Cueva Morín exemplarily illustrates the variety of technological knowledge during late Middle and early Upper Palaeolithic. Whereas unidirectional bladelet and discoidal methods are present in all levels, Levallois recurrent methods appear only in the upper levels (CM-11, CM-10 and CM-09) and the Levallois preferential method is present only in the transitional an early Upper Palaeolithic levels (CM-10 and CM-09). Furthermore, an increase of bladelet end-products that establish convexity (predetermined and predetermining) from lower to upper levels becomes apparent.

El Castillo (Fig. 9)

From El Castillo four levels with 1'110 negatives on the reduction surfaces of 194 cores were studied. They also cover late Middle Palaeolithic (EC-22 and EC-20), transitional (EC-18) and early Upper Palaeolithic (EC-16) occupations. The sequence of El Castillo ideally demonstrates that during the late Pleistocene technological knowledge underlies not a simple evolution. Bladelet methods as well as Levallois methods are distributed over the whole sequence in different proportions.

Jarama VI (Fig. 10)

Only two levels from Jarama VI with in total 34 cores and 237 relied negatives were studied (JA-III and JA-II). With different Levallois and discoidal methods level III corresponds to the expected late Middle Palaeolithic range. Level II only yielded three cores and therefore is only of minor significance.

lithic reduction system		**predetermined**	**predetermined & predetermining**	**predetermining**	**total negatives**	**total cores**
CM-13		*%*	*%*	*%*	**N**	**N**
Bladelet	unidirectional	*21*	*56*	*23*	**29**	**5**
total (mean)		***21***	***56***	***23***	**29**	**5**
CM-12		*%*	*%*	*%*	**N**	**N**
Bladelet	unidirectional	*100*	-	-	**5**	**3**
Le Pucheuil-type	unidirectional	*56*	-	*44*	**9**	**1**
Discoidal	with flat base	-	*82*	*18*	**11**	**1**
	without flat base	-	*69*	*31*	**16**	**1**
total (mean)		***59***	***25***	***16***	**41**	**6**
CM-11		*%*	*%*	*%*	**N**	**N**
Bladelet	unidirectional	*55*	*45*	-	**9**	**2**
Discoidal	without flat base	-	*78*	*22*	**9**	**1**
Levallois recurrent	centripetal	-	*71*	*29*	**7**	**1**
	unidirectional	*17*	*17*	*66*	**17**	**2**
total (mean)		***24***	***46***	***31***	**42**	**6**
CM-10		*%*	*%*	*%*	**N**	**N**
Bladelet	unidirectional	*2*	*80*	*18*	**78**	**18**
	bidirectional	-	*100*	-	**9**	**2**
Le Pucheuil-type	unidirectional	*8*	*50*	*42*	**10**	**2**
Discoidal	without flat base	-	*100*	-	**6**	**1**
Levallois recurrent	centripetal	-	*75*	*25*	**84**	**19**
	bidirectional	-	*71*	*29*	**7**	**1**
	unidirectional	*33*	*67*	-	**33**	**8**
Levallois preferential	unidirectional	*12*	-	*88*	**8**	**1**
total (mean)		***6***	***75***	***19***	**235**	**52**
CM-09		*%*	*%*	*%*	**N**	**N**
Bladelet	unidirectional	-	*76*	*24*	**66**	**12**
	bidirectional	-	*88*	*12*	**8**	**1**
Discoidal	without flat base	-	*88*	*12*	**26**	**4**
Levallois recurrent	centripetal	-	*66*	*34*	**35**	**7**
	bidirectional	-	*75*	*25*	**8**	**1**
	unidirectional	*22*	*35*	*43*	**16**	**2**
Levallois preferential	unidirectional	*14*	-	*86*	**7**	**1**
total (mean)		***2***	***70***	***28***	**166**	**28**

Fig. 8. Efficiency of different reduction strategies in Cueva Morín.

Abb. 8. *Effizienz der verschiedenen Strategien der Grundformgewinnung in Cueva Morín.*

lithic reduction system		predetermined	predetermined & predetermining	predetermining	total negatives	total cores
EC-22		%	%	%	N	N
Bladelet	unidirectional	-	89	11	42	5
Le Pucheuil-type	unidirectional	27	59	14	118	25
Levallois recurrent	centripetal	-	62	38	158	31
	bidirectional	25	50	25	8	2
	unidirectional	11	17	73	45	5
total (mean)		**11**	**59**	**29**	**371**	**68**
EC-20		%	%	%	N	N
Le Pucheuil-type	unidirectional	-	100	-	11	3
Discoidal	without flat base	-	79	21	30	3
Levallois recurrent	centripetal	-	69	31	205	37
	unidirectional	20	7	73	15	2
Levallois preferential	unidirectional	15	-	85	21	3
total (mean)		**2**	**65**	**33**	**282**	**48**
EC-18		%	%	%	N	N
Bladelet	unidirectional	2	97	1	294	46
Discoidal	without flat base	-	100	-	23	2
Levallois recurrent	centripetal	-	95	5	67	15
	bidirectional	-	100	-	2	1
total (mean)		**1**	**96**	**2**	**386**	**64**
EC-16		%	%	%	N	N
Bladelet	unidirectional	-	100	-	31	9
Blade	unidirectional	-	100	-	15	2
Discoidal	without flat base	-	79	21	14	1
Levallois recurrent	centripetal	-	83	17	6	1
	unidirectional	20	20	60	5	1
total (mean)		**1**	**92**	**7**	**71**	**14**

Fig. 9. Efficiency of different reduction strategies in El Castillo.
Abb. 9. *Effizienz der verschiedenen Strategien der Grundformgewinnung in El Castillo.*

lithic reduction system		predetermined	predetermined & predetermining	predetermining	total negatives	total cores
JA-III		%	%	%	N	N
Le Pucheuil-type	unidirectional	11	67	22	9	1
Discoidal	with flat base	3	73	24	51	6
	without flat base	-	79	21	53	5
Levallois recurrent	centripetal	3	74	23	59	14
	unidirectional	24	31	45	26	4
Levallois preferential	unidirectional	13	-	87	15	2
total (mean)		**6**	**65**	**30**	**213**	**31**
JA-II		%	%	%	N	N
Levallois recurrent	centripetal	4	53	43	24	3
total (mean)		**4**	**53**	**43**	**24**	**3**

Fig. 10. Efficiency of different reduction strategies in Jarama VI.
Abb. 10. *Effizienz der verschiedenen Strategien der Grundformgewinnung in Jarama VI.*

Arbreda (Fig. 11)

Apart from the dominant opportunistic lithic reduction system focused on Quartz in the lithic assemblages of Arbreda, other reduction systems are only scarcely present. That´s why only levels F and G from the Corominas excavation are integrated in the present study (Soler Masferrer & Maroto 1987b). They are attributed to the evolved Aurignacian (G) and the Gravettian (F). In total, 12 cores with 68 negatives on their reduction surfaces were analysed. Beside the unidirectional bladelet method, the Le Pucheuil-type and Levallois recurrent methods prove the variability of flake reduction systems within Upper Palaeolithic levels.

Abric Romani (Fig. 12)

Abric Romani has a long sequence with several Middle Palaeolithic levels. The studied material derives from the first excavations (Vaquero 1997) and does not yield the extraordinary stratigraphical resolution of the recent excavation. Nevertheless, this assemblage separated in three Middle Palaeolithic levels

lithic reduction system		predetermined	predetermined & predetermining	predetermining	total negatives	total cores
AR-F		%	%	%	N	N
Bladelet	unidirectional	-	*84*	*16*	29	5
total (mean)		**-**	***84***	***16***	**29**	**5**
AR-G		%	%	%	N	N
Bladelet	unidirectional	-	*79*	*21*	19	3
Le Pucheuil-type	unidirectional	*24*	*48*	*29*	10	2
Levallois recurrent	centripetal	-	*100*	-	10	2
total (mean)		***7***	***76***	***17***	**39**	**7**

Fig. 11. Efficiency of different reduction strategies in Arbreda.

Abb. 11. *Effizienz der verschiedenen Strategien der Grundformgewinnung in Arbreda.*

lithic reduction system		predetermined	predetermined & predetermining	predetermining	total negatives	total cores
RO-FG		%	%	%	N	N
Le Pucheuil-type	unidirectional	-	*100*	-	3	1
Discoidal	with flat base	-	*89*	*11*	10	3
	without flat base	-	*65*	*35*	17	1
Levallois recurrent	centripetal	-	*65*	*35*	11	2
	unidirectional	*33*	-	*67*	6	1
total (mean)		***4***	***70***	***26***	**47**	**8**
RO-E		%	%	%	N	N
Le Pucheuil-type	unidirectional	*29*	*29*	*43*	7	1
Discoidal	with flat base	-	*67*	*33*	9	1
	without flat base	-	*75*	*25*	20	2
Levallois recurrent	centripetal	-	*80*	*20*	49	9
	unidirectional	*30*	-	*70*	18	2
total (mean)		***6***	***64***	***30***	**103**	**15**
RO-BCD		%	%	%	N	N
Le Pucheuil-type	unidirectional	*27*	*63*	*10*	17	3
Discoidal	with flat base	-	*59*	*41*	16	2
Levallois recurrent	centripetal	-	*77*	*23*	71	11
Levallois preferential	unidirectional	*16*	-	*85*	30	3
total (mean)		***7***	***61***	***33***	**134**	**19**

Fig. 12. Efficiency of different reduction strategies in Abric Romani.

Abb. 12. *Effizienz der verschiedenen Strategien der Grundformgewinnung im Abric Romani.*

– RO-BCD, RO-E and RO-FG – was integrated in the case study. 42 cores with 284 the reduction surfaces covering negatives were analysed. In all levels the lithic reduction systems are nearly identical: Le Pucheuil-type, discoidal and Levallois recurrent methods constitute the technological repertoire.

Salzgitter-Lebenstedt (see Fig. 5)

The late Middle Palaeolithic archaeological material from Salzgitter-Lebenstedt was embedded in different geological units but probably results from one single occupation. 59 cores with 622 negatives on the reduction surfaces were analysed. It is remarkable, that mostly different Levallois recurrent as well as preferential methods are present. The Working Stage Analysis demonstrates clearly the different proportions of negatives of preparational flakes that provide convexity (predetermining), end-products that profit from the convexity (predetermined) and end-products that establish convexity (predetermined and predetermining).

Balver Höhle (Fig. 13)

The cores of the five late Middle Palaeolithic levels – BA-I, BA-II, BA-II/III, BA-III and BA-IV –have been analysed with the Working Stage Analysis. In total 163 cores with 1'069 reduction surfaces covering negatives were counted. Except Balve I with only three cores, the different assemblages yield a broad spectrum of different reduction strategies, including the unidirectional bladelet method.

To summarise, in every studied level, the distribution of the different negative-types on the reduction surfaces are in line with the expected core configuration concepts. Concerning their definitions, Levallois preferential methods need for example more preparation than unidirectional bladelet methods. But variations of core configurations within every single reduction system are obvious which we interpret as different technological behavioural efficiency, or core configuration efficiency.

Efficiency of core configuration

To get an insight into the efficiency of core configuration, the sample of cores is firstly separated according to the ten observed, well-defined reduction strategies regardless of their chronology, site or regional origin:

Surface conceptions:

- Levallois recurrent methods (centripetal, bidirectional, unidirectional)
- Levallois preferential methods (divergent, bidirectional, unidirectional)

Volumetric conceptions:

- Discoidal methods (with flat base, without flat base)
- Le Pucheuil-type flake method (unidirectional)
- Bladelet method (unidirectional)

In a second step we calculate the relative ratio of negatives of preparational flakes that provide convexity (predetermining), end-products that profit from the convexity (predetermined) and end-products that establish convexity (predetermined and predetermining).

This procedure achieved reasonable results in a former study on a small scale (Pastoors & Tafelmaier 2010). The calculation of the relative frequency of negatives profiting from the convexity on the reduction surface serves as a major tool. For the calculation, a minimum number of three cores per level and reduction strategy are required. Therefore, from 601 studied cores, 533 were included within our analysis.

The relative frequency of blanks profiting from surface convexity varies considerably within the analysed cores and ranges from 91 % (unidirectional bladelet method) to 14 % (Levallois preferential unidirectional method; Figs. 14 & 15). It becomes apparent that methods of surface conceptions compared to volumetric conceptions display a lower degree of efficiency, due to the high effort that has to be invested in the preparation of the reduction surfaces.

The Levallois recurrent methods are placed between the volumetric concepts (unidirectional bladelet, unidirectional Le Pucheuil-type flake method and discoidal) and the Levallois preferential method. The discoidal method reaches high efficiency and can be seen as a proof for the effectiveness of Middle Palaeolithic technological conceptions.

Efficiency of lithic technological behaviour

The efficiency of lithic technological behaviour was analysed by cumulating results of all conceptual cores of the respective level; opportunistic methods were excluded from the analysis. For each level, efficiency of core configuration is expressed by the arithmetic mean of negatives from all cores profiting from convexity notwithstanding the reduction system (Figs. 16 & 17). In the studied levels, the amount varies between 38 % negatives of all kind of predetermined end-products (Salzgitter-Lebenstedt) as the lower class limit and 97 % (El Castillo level 18) as the upper class limit. The two extremities explicitly reflect the antagonism of lithic technological behaviour efficiency observed in our sample: The lowest degree of core configuration efficiency in Salzgitter-Lebenstedt and the highest degree in El Castillo level 18. Between these class limits, all 22 studied levels are classified following the rule of Freedman and Diaconis (Freedman & Diaconis 1981), with an interquartile range of 15.24, and a class width of 10.88 (rounded up 11). The compilation shows a clear trend towards an amount of negatives profiting from convexity below 44 %: A prevalence of classes 1-4 (Fig. 18), with class 1 including the assemblages showing a high efficiency of core configuration. Within this framework, nearly 70 %

lithic reduction system		predetermined	predetermined & predetermining	predetermining	total negatives	total cores
BA-I		%	%	%	N	N
Bladelet	unidirectional	-	40	60	5	1
Levallois recurrent	unidirectional	44	13	44	16	2
total (mean)		**29**	**22**	**49**	**21**	**3**
BA-II		%	%	%	N	N
Bladelet	unidirectional	12	87	1	55	13
Blade	bidirectional	-	100	-	2	1
Le Pucheuil-type	unidirectional	-	83	17	6	1
Discoidal	without flat base	-	72	28	193	14
Levallois recurrent	centripetal	-	52	48	106	11
	bidirectional	22	51	27	16	2
	unidirectional	18	34	46	79	10
Levallois preferential	unidirectional	16	-	85	54	7
total (mean)		**8**	**56**	**35**	**511**	**60**
BA-II/III		%	%	%	N	N
Bladelet	unidirectional	8	79	14	28	8
Le Pucheuil-type	unidirectional	61	6	33	13	2
Discoidal	without flat base	-	82	18	24	3
Levallois recurrent	centripetal	-	64	36	47	7
Levallois preferential	unidirectional	17	67	17	6	1
total (mean)		**9**	**67**	**24**	**118**	**21**
BA-III		%	%	%	N	N
Bladelet	unidirectional	17	69	15	31	7
Discoidal	without flat base	-	84	16	33	5
Levallois recurrent	centripetal	-	62	39	81	10
	bidirectional	13	50	38	8	1
	unidirectional	59	4	38	16	3
total (mean)		**12**	**61**	**28**	**169**	**26**
BA-IV		%	%	%	N	N
Bladelet	unidirectional	4	85	11	93	23
	bidirectional	25	50	25	4	1
Blade	bidirectional	-	60	40	5	1
Le Pucheuil-type	unidirectional	28	55	17	12	3
Discoidal	with flat base	-	89	11	24	4
	without flat base	19	66	15	30	4
Levallois recurrent	centripetal	-	75	25	53	10
	unidirectional	35	65	-	18	5
Levallois preferential	orthogonal	40	-	60	5	1
	unidirectional	17	-	83	6	1
total (mean)		**10**	**74**	**16**	**250**	**53**

Fig. 13. Efficiency of different reduction strategies in Balver Höhle.
Abb. 13. *Effizienz der verschiedenen Strategien der Grundformgewinnung in der Balver Höhle.*

of all levels are placed in classes 2 and 3 with an amount of negatives profiting from convexity between 11 % and 33 %.

Interestingly, the 22 levels are not clearly sorted by the calculated classification according to their techno-complex attribution: Middle Palaeolithic levels spread from class 2 up to class 6 with a concentration in class 3, while Upper Palaeolithic assemblages are recorded from class 1 to class 3. Beside the two extremities of El Castillo on the one hand (level 18 and

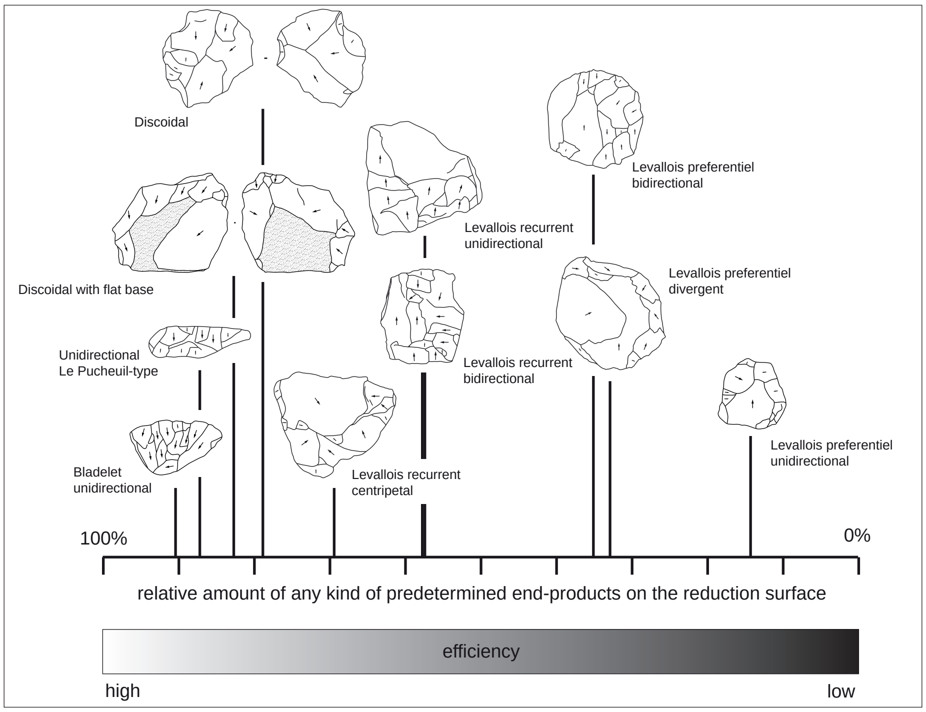

Fig. 14. Efficiency of core configuration of ten Middle and early Upper Palaeolithic core reduction strategies (data base: 533 cores).

Abb. 14. *Effizienz der Kernkonfiguration von zehn mittel- und jungpaläolithischen Strategien der Grundformgewinnung (Datengrundlage: 533 Kerne).*

level 16) and Salzgitter-Lebenstedt on the other hand, Middle and Upper Palaeolithic assemblages overlap in classes 2 and 3. Cueva Morín level 9, attributed to the Aurignacian, is the only exception as it ranges among the majority of Middle Palaeolithic levels. On the other hand, three Middle Palaeolithic levels, Cueva Morín level 12, Cueva Morín level 10 and Balver Höhle level IV are placed in between the more recent levels with a high degree of lithic technological behavioural efficiency.

Only the Balver Höhle shows a steady increase of the here defined efficiency ratio from bottom to top. All other multilevel sites display a variable pattern. The degree of efficiency measured by our approach in Cueva Morín, El Castillo, Arbreda and Abric Romani seems to be randomly distributed.

Method		**predetermined**	**predetermined & predetermining**	**predetermining**	**total**
		%	*%*	*%*	n
Bladelet	unidirectional	*6*	*84*	*10*	161
Le Pucheuil-type	unidirectional	*24*	*63*	*13*	34
Discoidal	with flat base	*1*	*81*	*18*	13
	without flat base	*2*	*77*	*21*	38
Levallois recurrent	centripetal	*1*	*68*	*31*	193
	bidirectional	*21*	*37*	*42*	5
	unidirectional	*27*	*31*	*42*	51
Levallois preferential	divergent	*30*	*5*	*65*	10
	bidirectional	*31*	*2*	*67*	6
	unidirectional	*14*	*1*	*85*	22
total					**533**

Fig. 15. Efficiency of ten different Middle and early Upper Palaeolithic reduction strategies.

Abb. 15. *Effizienz der Kernkonfiguration von zehn mittel- und jungpaläolithischen Strategien der Grundformgewinnung.*

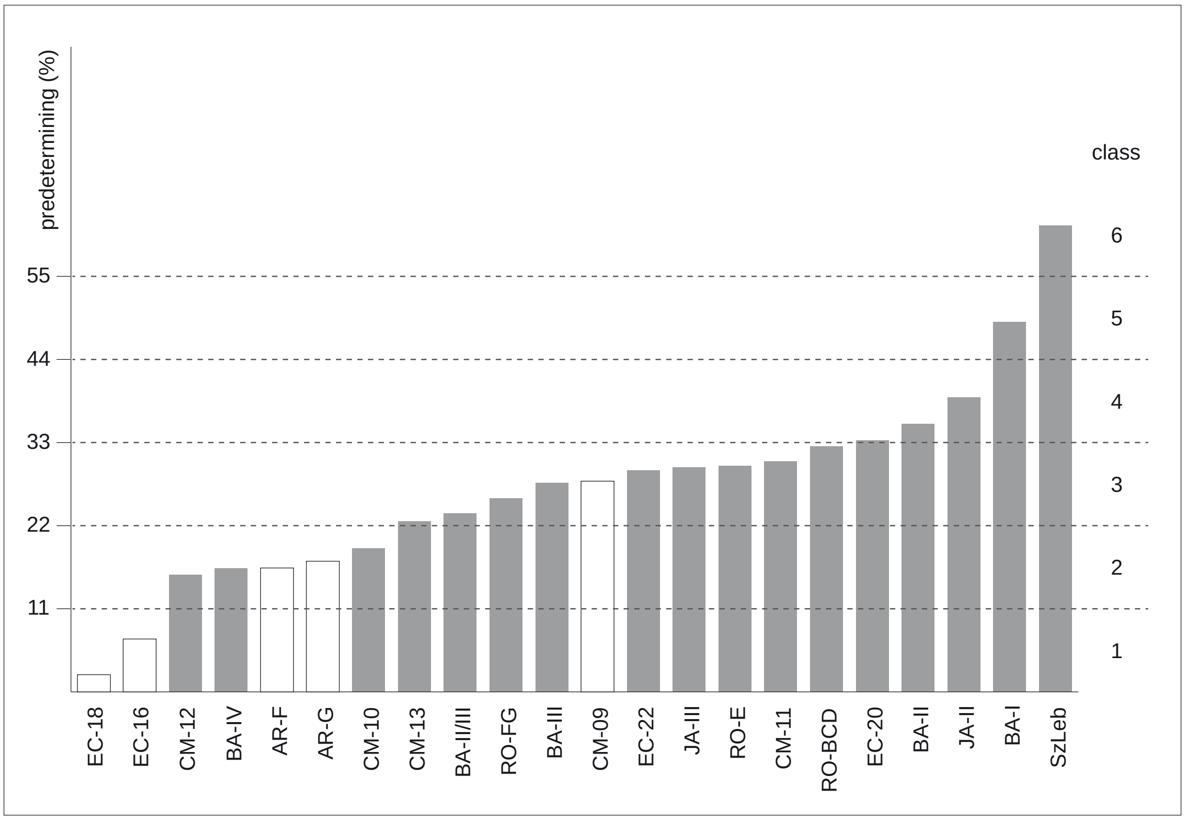

Fig. 16. Efficiency of lithic technological behaviour in different sites (grey – Middle Palaeolithic level; white – transitional and early Upper Palaeolithic level).

Abb. 16. *Effizienz technologischen Verhaltens bei der Grundformgewinnung in verschiedenen Fundstellen (grau – Mittelpaläolithikum; weiß – frühes Jungpaläolithikum).*

Discussion

The compilation of the existing estimation methods for technological behaviour efficiency shows that five different kinds of efficient behaviour can be distinguished: blank usability, blank portability, distance attrition, nodule size, and cutting edge length. All these methods make use of blanks as resource-input and as product-output, the maximum number of specific blank-types as subset of the resource-input. The relations and therefore the amount of these specific blank-types are highly dependent on external factors such as excavation area, activity zone, blank export and preservation.

The methodological approach presented here focuses on the efficiency of the working processes of core configuration, documented by different connected working stages on the reduction surfaces of cores. Within this approach cores are regarded as chronological finite analytical units. Their surfaces display a well-defined and well detectable micro biography. All steps of this biography are directly linked to human behaviour in general and to the immediate cognitive choices of individual knappers. Negatives covering the reduction surface of cores are understood as resource-input. Consequentially our approach estimates the efficiency of core configuration.

In contrast to the blank based approaches summarized above, cores as analytical units are independent from the excavated area or preserved excavation section. All the required technological information to reconstruct the last applied reduction method is preserved within one single artefact. During excavation, cores have a high visibility and a high probability of discovery, even in old excavations with low standards of excavation technique. Sampling bias is therefore lower than for blanks.

The described analytical process is time-saving and easy to apply: It is itself a very efficient method of lithic analysis (Fig. 19). Within a reasonable period of time, data can be collected that are replicable, representative and comparable at an inter-site as well as at an intra-site level. In contrast to that, blank based methods require a vast amount of time depending admittedly on the assemblage size. However, a large sample of the lithic remains is taken into account, which is of course due to the fact that blanks usually make up the major part of lithic assemblages. Nevertheless, this fact does not consequently lead to a higher representativity of the thereby acquired results. Additional problems, such as the adscription of often undiagnostic artefacts to specific reduction concepts, have to be faced. In addition to the undiagnostic nature of the artefacts, comparability and reproducibility are further complicated by the

level	predetermined	predetermined & predetermining	predetermining	class	techno-complexe	total number of cores
	%	%	%			N
EC-18	*1*	*96*	*3*	1	TRANS	64
EC-16	*1*	*92*	*7*	1	AUR	14
CM-12	*59*	*25*	*16*	2	MP	6
BA-IV	*10*	*74*	*16*	2	MP	53
AR-F	-	*84*	*16*	2	GRA	5
AR-G	*7*	*76*	*17*	2	AUR	7
CM-10	*6*	*75*	*19*	2	CHA	52
CM-13	*21*	*56*	*23*	3	MP	5
BA-II/III	*10*	*67*	*23*	3	MP	21
RO-FG	*4*	*70*	*26*	3	MP	8
BA-III	*12*	*61*	*27*	3	MP	26
CM-09	*2*	*70*	*28*	3	AUR	28
EC-22	*11*	*59*	*30*	3	MP	68
JA-III	*6*	*65*	*29*	3	MP	31
RO-E	*6*	*64*	*30*	3	MP	15
CM-11	*24*	*46*	*30*	3	MP	6
RO-BCD	*7*	*61*	*32*	3	MP	19
EC-20	*2*	*65*	*33*	4	MP	48
BA-II	*8*	*56*	*36*	4	MP	60
JA-II	*8*	*53*	*39*	4	MP	4
BA-I	*29*	*22*	*49*	5	MP	3
SzLeb	*23*	*15*	*62*	6	MP	59
total						**602**

Fig. 17. Relative amount (as arithmetic mean) of relevant working stages for the core configuration; degree of efficiency = arithmetic mean of preparation for establishing the required convexity.

Abb. 17. *Relativer Anteil (Mittelwert) der für die Kernkonfiguration relevanten Arbeitsschritte; Effizienzgrad = Mittelwert der Präparation zur Einrichtung der notwendigen Konvexitäten.*

subjective interpretation of the archaeologists collecting the data.

Although a subjective approach affects the interpretation of cores as well, methodological problems are seen as negligible as reduction concepts can be most easily identified on cores. Even though the analysed reduction surfaces of the cores represent only one single stage within the complete reduction process, the cores can be directly linked to the prehistoric manufacturer. To the contrary, single blanks represent static, single events that have firstly to be reconstructed to an operational sequence, thereby being prone to misinterpretations. The influence of import and export activities is high in blank based approaches as, e.g., in cases where complete reduction stages of the whole process are missing due to their evacuation. The export of cores simply leads to their ignorance in the analysis. When technological issues are concerned, experiments play an important role. The whole production process can be documented and comprehended easily. However, skills of the manufacturers can vary considerably and the collection of a sufficient database containing numerous cores is time-consuming and material-intensive. Thus experiments can only serve as subsidiary information. The results outlined by

predetermining	class	level	
%		N	%
< 11	1	2	*9*
11.1-22	2	5	*23*
22.1-33	3	10	*45*
33.1-44	4	3	*14*
44.1-55	5	1	*4.5*
> 55.1	6	1	*4.5*
total		**22**	***100***

Fig. 18. Results of the classification of lithic technological behaviour.

Abb. 18. *Klassifikation technologischen Verhaltens bei der Grundformgewinnung.*

		core configuration	blank production	experiment
material		core	blank	complete nodule
representativity		+ / - depends on the excavation section	+ / - depends on the excavation section	+ subsidiary
reproducibility		+ + good	- problematic	+ satisfactory
comparability		+ + good	+ satisfactory	+ satisfactory
assignment of artefacts to reduction concept		+ + good	- problematic	+ + good
reconstruction of the reduction process		+ partially complete	- incomplete	+ + complete
work effort:	time	+ + low	- high	+ medium
	documentation	+ + low	- high	- high
	experience	+ medium	+ medium	- high
influence of import and export activities		+ medium	- high	+ + nonexistent
advantages		1) With minimum effort reproducible, comparable and representative data can be collected. 2) No mixture of different reduction processes is possible as cores represent chronological finite events.	1) A large sample of the assemblage is recorded.	1) The whole reduction process is recorded
disadvantages		1) Only the last stadium of core reduction can be reconstructed. 2) The representativity is influenced by the size of the excavation section.	1) Time-consuming data collection process. 2) Assignment of blanks to specific reduction concept is problematic due to the undiagnostic nature of many blanks. 3) Isolation of chronologically different working processes difficult (except refittings and raw material units).	1) Experiments can only function as subsidiary information. 2) Individual skills are different.

Fig. 19. Advantages and disadvantages of core based and blank based methods for estimation of technological behavioural efficiency.
Abb. 19. *Vor- und Nachteile der unterschiedlichen Methoden zur Bewertung der Effizienz technologischen Verhaltens bei der Grundformgewinnung.*

averaging calculation (arithmetic mean) can be used for diachronic as well as for isochronic analysis of the core reduction strategies.

For the analysis of lithic production systems, it seems precarious to choose the appropriate analytical corpus because the relevant input and output factors are unknown. Almost every archaeological level represents an accumulation of different occupational events. These occupational events may have differed in terms of purpose, length and intensity, each leaving behind a complex set of archaeological remains. The isolation of these occupational events is difficult and mostly even impossible. A sorting to raw material units (Weißmüller 1995; Richter 1997; Uthmeier 2004; Bataille 2006) allows isolating chronological events but is often hampered by the scarce macroscopic variability of the considered raw material or the patination of the artefacts. In addition to that, an archaeological level is not a static preservation of lithic production sequences but is highly affected by import and export activities. Therefore, the preference of blanks for the evaluation of efficiency of lithic production systems seems to be problematic. It has to be considered that 1) every analysed sample reflects only an unpredictable part of the excavated archaeological remains; 2) the assignment of blanks to a specific reduction concept is difficult as not all blanks are technologically diagnostic and 3) especially the Upper Palaeolithic end-products are likely to be taken away or to be transformed.

Due to these uncertainties, we decided to ignore blanks and abstain from counting absolute numbers of blanks or calculating the length of cutting edges. Our approach intends to reconstruct human behaviour by reconstructing the decision making. In our opinion, the tenor of lithic raw material processing reflects the degree of efficiency. Both individuals as well as the society they belong to are reflected in lithic processing. Society provides the individual with a set of technological solutions to produce the intended end-products and the individual is able to choose between different concepts belonging to his/her concept reservoir (Weißmüller 1995). Both, the chosen reduction concept and the individual technological behaviour are preserved in the core. Therefore the method presented here meets the desideratum referred to by Brantingham and Kuhn (2001), as it allows to reconstruct the dynamic decisions made by the individual knappers during the reduction process.

As already mentioned, efficiency can be described as a cost-benefit ratio: "Measuring efficiency involves assessing the benefits accrued as a function of cost or resources invested." (Vallée-Tourangeau 2012: 1061) This ratio is applied to different aspects of life such as economy, psychology, physiology and several others. Our approach focuses on core configuration efficiency, which we do not classify solely as economic efficiency. Core configuration is directly influenced by different factors of the adaptive culture as for instance the current lithic concept reservoir or mobility patterns resulting from the practised land use system, natural environment including the availability of resources as well as individual abilities. Some of these factors, as e.g. the applied reduction concept, the utilized raw material or the individual decision making processes in reducing the raw volume, are conserved on every core as a complex information puzzle.

Our study presents a ranking of the efficiency of core configuration of ten different Middle and early Upper Palaeolithic reduction strategies based on the analysis of 533 cores. This data corpus filled a gap of empirical data for the evaluation of efficiency of different lithic reduction strategies which Jennings referred to in 2010 (Jennings et al. 2010: 2155). Thanks to this broad approach, the results embrace the already published singular comparisons and confirm their ranking (Prasciunas 2007: 346; Eren et al. 2008). For the first time a comprehensive efficiency ranking of the most important Middle and early Upper Palaeolithic lithic reduction strategies is available, which is based on the quantification of core configuration, observable on the reduction surfaces of cores, and the subsequent calculation of an efficiency ratio.

"Did hunter-gatherers become more efficient throughout the Pleistocene, leading to a zenith of efficiency in the Upper Paleolithic?" (Cole 2009: 128) This notion, discussed by Cole, is still remarkable in prehistoric research and public media. Focussing on lithic technology, the problem can be reduced to volumetric versus surface conceptions. Volumetric conceptions represent blade and bladelet production with a high degree of efficiency, and are commonly associated with modern humans; surface conceptions, or Levallois conceptions, represent flake production with a high amount of preparation and therefore a low degree of efficiency commonly associated with Neanderthals. Nowadays, it is well established in the scientific community that this simple picture does not match archaeological reality. It is obvious that volumetric conceptions are part of Middle Palaeolithic strategies and vice versa, surface conceptions are integrated in Upper Palaeolithic strategies (Cazals et al. 2005; Chiotti 2002; Pastoors & Tafelmaier 2010, 2012, 2013; Pastoors 2009; Pastoors & Peresani 2012; Tafelmaier 2011).

An increase of efficiency from the Middle to the Upper Palaeolithic as an evolutionary shift is not documented. Therefore claims about evolutionary differences in economic behaviour of late Neanderthals and modern humans at the time of the transition cannot be supported here.

The obtained results of either the different reduction strategies or the lithic technological behaviour open new venues to analyse their diachronic variability. The technological choice is surely influenced by the shape and quality of the available raw material (Andrefsky 1994), but also by other factors of subsistence strategies (Delagnes & Rendu 2011). Therefore, efficient or less efficient treatment of resources should also be visible apart from lithic technology. The generous handling of available lithic resources, e.g., in Salzgitter-Lebenstedt (Pastoors 2001; Pastoors 2009) finds its counterpart in the treatment of hunted animals. According to Gaudzinski, the faunal remains of reindeer most probably represent one or more successive hunting events, in which a part of the population was killed on their migration routes. Subsequent exploitation of the kills was restricted to a systematic use of high-quality resources only. Primarily young animals remained unexploited. Maybe these animals were killed because of their hide (Gaudzinski 1998: 197).The interesting hypothesis of a link between the exploitation of high-quality parts of animal carcasses and generous handling of available raw material resources, as can be observed in the core configuration of Salzgitter-Lebenstedt, needs an extensive analysis and a critical discussion.

Following Kuhn, this kind of direct connection seems unrealistic because the "economic connections between technology and subsistence are indirect, and not easily generalized across cases." (Kuhn 1998: 217) Moreover, Kuhn argued that "raw material economies are organized around subsistence requirements." (1998: 217) According to Fowler and Turner, this view seems too pessimistic. They noticed that indigenous people have developed many strategies to maintain and enhance their resources. Some of these strategies "are obvious and direct; others are deeply encoded in narratives, ceremonies, and religious teachings." (Fowler & Turner 1999: 421). In their study of the Neandertal mobility strategies, Delagnes and Rendu used two behavioural patterns in combination: lithic production systems and large game hunting strategies (Delagnes & Rendu 2011: 1772). They conclude that "the Levallois and laminar technologies, which prevailed during the early stages of the Middle Palaeolithic, prior to OIS4, were related to a forager-related mobility system with no selective hunting strategies. By contrast, they relied on a demanding raw material supply, both in terms of size and quality of the knapped nodules. [...] At the end of the Middle Palaeolithic, the development of selective and seasonally scheduled hunting strategies focused on migratory prey (reindeer and bison) is correlated with the emergence of adapted technologies, specifically the Quina and discoidal-denticulate systems. They both relied on flexible and easily segmentable reduction sequences designed for the production of multi-purpose blanks, which may have been alternatively used as tools or cores." (Delagnes & Rendu 2011: 1779)

This little excursus shows clearly the potential of the combination of different behavioural patterns, e.g. human efficient behaviour, but it also reveals an associated intensive theoretical debate about the probability of these behavioural patterns. A database comprising a sufficient set of statistically relevant data of the lithic as well as the faunal remains and corresponding climate data is needed to elaborate further on that issue. Nevertheless, the compilation of such a copious data corpus presented in this article opens the possibility to correlate the results of the efficiency analysis with palaeo-ecological data in order to analyse the interaction between subsistence strategies and the economisation of working processes.

Conclusions

In the present article an already established method, the Working Stage Analysis (Pastoors & Schäfer 1999; Pastoors 2001; Richter 1997), has been applied to measure the efficiency of core configuration within different late Middle Palaeolithic and early Upper Palaeolithic assemblages of Central and South-Western Europe. Prior to the presentation of the analysed data an effort has been made to clarify the terminology within research on behavioural technological efficiency. Different methods have been compared with regard to the parameters used to measure the resource-input on the one hand and the resource-output on the other hand. Thereby, a better understanding of what kind of efficiency is addressed by the varying methods could be achieved.

In contrast to other methodological approaches, focus in the current analysis has been put on the reduction surfaces of cores. From a theoretical point of view the preference of cores brought with it two main advantages. Firstly, cores reflect a dynamic reduction process which could be reconstructed with the help of the Working Stage Analysis in a comprehensible and replicable way. Secondly, cores and the reduction processes stored therein are understood as finite analytical units. The reduction surfaces of cores allow to cast a direct glance on the Prehistoric manufacturer and are much less susceptible to import and export activities one has to face when working with blanks to estimate technological efficiency.

Our study shows that the long-held view of significant differences in Neanderthal and modern human behaviour at the time of the transition from the Middle to the Upper Palaeolithic is inappropriate. No simple diachronic evolution from a less efficient processing of resources in the Middle Palaeolithic towards a highly efficient treatment of raw material in the Early Upper Palaeolithic can be attested. Undeniably a moderate trend towards a more efficient production of (laminar) blanks in the Upper Palaeolithic can be observed. This is mainly due to the fact that volumetric reduction concepts, prevailing in Upper Palaeolithic assemblages, proved a higher efficiency because the amount of exclusively predetermining blanks is significantly lower than in surface conceptions. This aspect is illustrated within figure 14 where different reduction concepts have been depicted according to the relative amount of predetermined end-products. In further studies a combined analysis of experimentally reduced cores and archaeological data will probably yield interesting insights.

The picture arising from the presented analysis is a complex one. Several late Middle Palaeolithic assemblages have proven to be more efficient with respect to the technological behaviour than different Upper Palaeolithic inventories (Fig. 16). Therefore, to the authors it seems possible that specific ecological circumstances may force people to process resources more efficiently rather than postulating that cognitive differences between late Pleistocene hominin species are responsible for diverging treatment of resources. A similar statement has been made by Eren and Lycett that "cognitive capacities in different species of Middle-Late Pleistocene hominins are not as sharply differentiated as previous generations of scholars postulated". (Eren & Lycett 2012: 9). The study presented here emphasizes this view: Middle Palaeolithic hunter-gatherers did not per se apply less efficient core configuration concepts than their Upper Palaeolithic counterparts.

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