Flake productivity in the Levallois recurrent centripetal and discoid technologies: New insights from experimental and archaeological lithic series

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ABSTRACT

During the Middle Paleolithic, hunter-gatherers were flexible in their use of lithic technologies and sometimes applied one knapping strategy, exploited different methods simultaneously or combined them in ramified operative chains. The Levallois recurrent centripetal method and the bifacial discoid method were two of the flaking strategies most frequently used by Neanderthals, but understanding of their changeover in the archaeological record is still discussed. This paper aims to add new data to the current debate investigating the aspects of productivity of the Levallois recurrent centripetal and bifacial discoid technologies with an experimental series and an archaeological lithic series. The results reveal that these two knapping strategies not only share similarities in blank morphologies but also could have similar values in flake production. Productivity is strongly influenced by the knapper's goals and by the maintenance of low values of flake thickness during the reduction sequence. Although the bifacial discoid is a more flexible and simpler method, the exclusive use of the Levallois recurrent centripetal modality during the Middle Paleolithic might be related to the features of the Levallois products that were more advantageous during longer foraging movements.

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1. Introduction

An issue debated in Paleolithic archaeology is the understanding of the causes that promoted variations in technical behaviors among hunter-gatherers. Within the study of the processes that favored technological innovations (Powell et al., 2009; Schiffer, 1992; Shennan, 2001), the availability of raw materials, stone flaking properties and mobility patterns have been considered the main variables that influenced the hominins’ technological organization (Andrefsky, 1994; Bamforth, 1986; Binford, 1979; Bousman, 1993; Kelly, 1983; Kuhn, 1992; Surovell, 2009; Torrence, 1983). During the Middle Paleolithic, Neanderthals applied several lithic technologies and varied between methods that had rigid core shaping (preferential Levallois, unibipolar recurrent Levallois, laminar) and a lower degree of blank predetermination (Levallois recurrent centripetal, discoid, Quina, handaxe façonnage; Boëda et al., 1990; Delagnes and Meignen, 2006). This variability in flake production has generated a long ongoing debate about the significance of and the possible reasons that encouraged utilization of these methods (Binford and Binford, 1966; Bordes, 1961; Delagnes and Meignen, 2006; Delagnes and Rendu, 2011; Dibble and Rolland, 1992; Discamps et al., 2011; Mellars, 1965; Turq, 1992). Neanderthals were flexible in their use of lithic technologies and sometimes applied only one knapping strategy, exploited different methods simultaneously or combined the methods in ramified operative chains (Bourguignon et al., 2004; Delagnes and Meignen, 2006; Picin, 2014). In this perspective, some flaking strategies might have been considered more productive than others in terms of outcrop distributions, territorial physiography or tasks to perform (Binford, 1973, 1979; Delagnes and Rendu, 2011; Geneste, 1988b; Kuhn, 1992; Picin and Carbonell, 2016).

An interesting aspect of the debate about the Mousterian technological variability concerns the changeover between the Levallois method and the bifacial discoid method (Chacón et al., 2013; Delagnes and Meignen, 2006; Delagnes and Rendu, 2011; Mourre, 2003; Picin, 2014; Picin and Carbonell, 2016). Geneste (1988a) proposed that the Neanderthals’ adoption of a particular technology might have been influenced by the quality of the raw material. In this manner, nodules with good flaking properties were used to produce Levallois flakes and scrapers whereas mediocre ones were mainly utilized for expedient reductions (e.g., discoid) and the manufacture of denticulates (Bar-Yosef et al., 1992; Geneste, 1988a; Meignen et al., 2007; Moncel et al., 2008; Otte, 1991; Wengler, 1990). This hypothesis was also supported by Delagnes and Rendu (2011) in a recent synthesis of the Middle...
Paleolithic Mousterian settlements of Western France. The Levallois technology was found to be more dependent on high-grade chert nodules whereas the discoid method was associated with different types of stones. Although these studies might be valid for some regions, the complexity of European physiography requires an in-depth analysis of other cumulative factors that might have been critical in the choice of a knapping strategy. In territories where chert outcrops are mainly scattered throughout the landscape or the properties of chert cobbles are mediocre, Neanderthals might have balanced the use of the Levallois method or the discoid method in terms of flake productivity or the number of blanks with certain characteristics.

The Levallois method is considered the technological innovation that marked the beginning of the Middle Paleolithic in Eurasia (Adler et al., 2014; Picin et al., 2013; Scott and Ashton, 2011). Although the earliest reports of Levallois artifacts dated back to the end of the XIX century (Mortillet, 1883; Perthes, 1857), the description of its technological features was accomplished only a century later with the identification of six discriminating criteria (Boëda, 1993, 1994) (Table 1). Levallois technology is characterized by a hierarchical division of the core volume and by preparing the flaking surface which made it possible to predetermine the shape of the final morphology. The Levallois method comprehends different modalities discriminated by a preferential or recurrent character (Boëda, 1993, 1994). The Levallois preferential method is distinguished by the production of a single blank and the reconfiguration of the core convexities before the successive removal. Conversely, the recurrent modalities allow the knapper to a continuous production avoiding the stages of flaking surface reconfigurations with the detachments of core-edge flakes and pseudo-Levallois points (also called core-edge dos limité flakes). In Levallois recurrent uni- or bi-directional methods a single or two opposed striking platforms are used whereas in Levallois recurrent centripetal, the whole striking platform is employed. In the preferential modality, the shape of the Levallois flake is influenced by the lateral and distal convexity whereas in the recurrent methods, the position of the previous detachments acts as a guide in shaping the outline of the following flakes (Boëda, 1994; Van Peer et al., 2010). Thus, managing the number and the position of the ridges on the core surface and controlling the platform thickness, the knapper could influence the dimension and the morphologies of the pursued products (Van Peer et al., 2010). Brantingham and Kuhn (2001) pointed out quantitatively that Levallois technology is an efficient method of reducing raw material waste and increasing the number of flakes produced. Although their mathematical model does not consider the stages of core reconfiguration and the possible knapping errors that could substantially alter the results, the economic costs of mass loss could be stabilized during the Levallois reduction making this flaking strategy convenient overall for Paleolithic hunter-gatherers (Lycett and Eren, 2013). Moreover, Levallois flakes are artifacts with moderated thickness distributed across the cross-section of the blank and with greater general symmetry in comparison with other types of flakes (Eren and Lycett, 2012). These features of robustness and balance of weight distribution might have been appealing during different tasks and retouching events (Eren and Lycett, 2012; Kuhn, 1994).

Discoid technology is considered to be a more simplistic method which was common since the Lower Paleolithic (Stout et al., 2010; Vaquero and Carbonell, 2003). The discoid strategy shares with Levallois four of the six fundamental criteria described by Boëda (1993) (Table 1). The differences include the unihierarchical relation of the surfaces and the direction of production that is secant in comparison with the plane of intersection of the two surfaces. These characteristics allow a less rigid configuration of the core volume and a more flexibility in the flaking reduction. In discoid strategy are distinguished the modality sensu lato, in which the objectives are varied, or sensu stricto, in which the sequence is focused on the production of pseudo-Levallois points and core-edge removal flakes (Mourre, 2003).

The centripetal exploitation of the core volume and the similarities in intermediary and final flake morphology (Boëda, 1993; Lenoir and Turq, 1995; Picin et al., 2014) induce some authors to claim a strict similarity between Levallois recurrent centripetal and discoid supporting the hypothesis that discoid strategy retain a high degree of predetermination (Boëda, 1993; Locht and Swinnen, 1994; Mourre, 2003). On the contrary, others corroborate that the similarities are based on byproducts (pseudo-Levallois points and core-edge removal flakes) that are only used to maintain the core convexity (Martí et al., 2009; Picin et al., 2014; Vaquero et al., 2012). This debate generates also a series of opinions on the productivity of the two flaking strategies that are not supported by quantitative estimates. The un-hierarchical relation of the surfaces have been argued to favor the discoid method that could count on two knapping surfaces that could be alternatively used for flake production. Conversely, the direction of production would benefit the Levallois method because the parallel exploitation permits increased control of the management of the flaking surface and of the size of the flakes produced (Boëda, 1993; Lenoir and Turq, 1995; Locht and Swinnen, 1994).

In lithic studies, discussion on productivity have been blurred by using interchangeably the term efficiency although they have different meanings (Bamforth, 1986; Cole, 2009; Eren et al., 2008; Jennings et al., 2010; Jeske, 1992; Lin et al., 2013; Pasda, 1998; Prasciunas, 2007; Uthmeier, 2004). Efficiency is a measurable concept, quantitatively determined by ratios of useful output to total input. It is a measure of the extent to which input is well used for an intended task or function (output). Conversely, productivity is computed by dividing the amount of output per unit of input. In Paleolithic Archaeology, the distinction between efficiency and productivity has been distorted due to the absence in the archaeological record of critical variables, such as the weight of the nodules, the energy/time employed by the knapper to reduce a core and the exact number of flakes produced from a core unit. Therefore, the terms productivity and efficiency have been interpreted as the maximum utility derived from flakes and cores that may reduce the requirement of stone tools, decrease the size and weight of the transported toolkit or prolong the period between quarry visits (Binford, 1977; Kuhn, 1992, 1994).

Flake productivity was first explored by Leroi-Gourhan (1955), who investigated the relation between the weight and the length perimeter of the blanks’ outline. In his model, named statue économique, he pointed out that, during the Paleolithic, the use of raw materials became increasingly economical and efficient. This new approach to considering the lithic industries was based on the hypothesis of a linear evolution of the technological progress but without quantitative estimates. The introduction of replicative experiments permitted a more computable understanding of prehistoric knapping methods that promoted broader comparisons with experimental and/or archaeological materials (Bamforth, 1986; Eren et al., 2008; Jennings et al., 2010; Jeske, 1992; Prasciunas, 2007).

About Middle Paleolithic technical behaviors, many works focused on Levallois technology (Baumler, 1988; Boëda, 1994; Bradley, 1977;
Table 2
Raw count of the discoid and Levallois recurrent centripetal knapping experiments including the nodule weight (g), the number of complete flakes (N'), the ratio of nodule weight by the number of complete flakes (W/N'), and the amount of flakes by 1 kg of chert (N' by 1 kg).

<table>
<thead>
<tr>
<th>Experiment</th>
<th>Raw material</th>
<th>Weight</th>
<th>N'</th>
<th>Ratio W/N'</th>
<th>N' by 1 kg</th>
<th>Reference</th>
</tr>
</thead>
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<td></td>
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<tr>
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<td>Norfolk</td>
<td>5020</td>
<td>144</td>
<td>35</td>
<td>29</td>
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</tr>
<tr>
<td>D2</td>
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<td>101</td>
<td>50</td>
<td>20</td>
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</tr>
<tr>
<td>D3</td>
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<td>62</td>
<td>34</td>
<td>29</td>
<td>This study</td>
</tr>
<tr>
<td>D4</td>
<td>Norfolk</td>
<td>3030</td>
<td>72</td>
<td>42</td>
<td>24</td>
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</tr>
<tr>
<td>Br24</td>
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<td>481</td>
<td>32</td>
<td>15</td>
<td>67</td>
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<tr>
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<td>427</td>
<td>31</td>
<td>14</td>
<td>73</td>
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<td>12</td>
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</tr>
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<tr>
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<tr>
<td>Br29</td>
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<td>1052</td>
<td>53</td>
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<td>50</td>
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</tr>
<tr>
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<td>21</td>
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<tr>
<td>Tu2</td>
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<td>32</td>
<td>31</td>
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</tr>
<tr>
<td>LEVALLOIS REC. CENTR.</td>
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<tr>
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<td>38</td>
<td>26</td>
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</tr>
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<td>41</td>
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<tr>
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<tr>
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<td>91</td>
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</tr>
<tr>
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<td>1810</td>
<td>82</td>
<td>22</td>
<td>45</td>
<td>Brenet (2011)</td>
</tr>
<tr>
<td>Bo1</td>
<td>Bergerac</td>
<td>3034</td>
<td>83</td>
<td>37</td>
<td>27</td>
<td>Brenet (2011)</td>
</tr>
<tr>
<td>Bo2</td>
<td>Bergerac</td>
<td>3750</td>
<td>114</td>
<td>33</td>
<td>30</td>
<td>Brenet (2011)</td>
</tr>
</tbody>
</table>

2.1. Experimental materials

The materials produced by experimental knapping are the results of four Levallois recurrent centripetal and four bifacial discoid (sensu latu) core reductions performed by two expert knappers at the Institut Català de Paleoecologia Humana i Evolució Social (IPHES) (Tarragona, Spain) (Figs. 2–3). The first modern knapper is associated with the experiments D1, D2, LR1 and LR2 whereas the second knapper is correlated with the lithic series D3, D4, LR3 and LR4. The raw material used for the experiments was a high-quality chert, gathered from the Cromer Chalk geological formation located in Norfolk (United Kingdom). The main assumption of the utilization of a foreign raw material, from those used at Abric Romani, is to test from an ideal perspective the flake productivity of the Levallois recurrent centripetal and bifacial discoid technologies by the core unit. The nodules used for the experiments have similar sizes, and the absence of impurities or fissures allowed the complete and uninterrupted reduction of the cores until they were exhausted (Table 2). The cores were reduced using quartzite pebbles as hammerstones. During the experiments, all knapped products (flakes, cores, fragments, chips and chunks) were subsequently collected and analyzed (Table SM1). In order to make a broader comparison of productivity in the analysis, data from Brenet’s (2011) knapping experiments, in which three expert knappers (Br, Tu, Bo) were involved in the replicative tests, were added (Table 2). The discoid cores were reduced using the modality sensu stricto. The comparison of the analyses of the flaking sequences, performed by skilled knappers with different experience and learning backgrounds, is critical for understanding the technical variability in prehistoric flake technologies.

2.2. Abric Romani rock shelter

The Abric Romani rock shelter is located near the town of Capellades (Barcelona province, Spain) in the travertine cliff called Cinglera del Capelló at 280 m ASL (Fig. 1). The stratigraphic sequence consists of 15 archaeological levels and has been dated by U-series and radiocarbon methods as between 40 and 110 ka BP (Bischoff et al., 1988; Sharp et al., 2016; Vallverdú-Poch et al., 2012). Level A is ascribed to the Middle Paleolithic (Vallverdú-Poch et al., 2012). The most frequently used raw material...
is chert, and the other stones selected included limestone and quartz, which are found close to the site (Chacón et al., 2013). Previous studies of the varieties of chert in level J have demonstrated the use of outcrops from Sant Martí de Tous (≥12–15 km), Valldeperes (≥20–25 km) and Panadella-Montemaneu (≥25–28 km) (Vaquero et al., 2012). In levels O and M, patination affected the surface of the flakes, limiting the information available for the procurement strategies (Picin and Carbonell, 2016). Macroscopic discrimination of the Panadella-Montemaneu lithological type was less difficult, because the patination turned the raw material light brown, which is very different from the light and dark grey-blues tones of the Sant Martí de Tous and Valldeperes outcrops (Vaquero et al., 2012). Thus, in the analysis of the lithic assemblages (considered here), only the chert variety Panadella-Montemaneu (PAN) was considered whereas the others are clustered in general groups named O and M (Table 4).

Level O was dated by a weighted mean to about 55 ky BP and has yielded a copious assemblage of fauna and lithic remains together with wood imprints and combustion structures (Chacón et al., 2013; Vallverdú-Poch et al., 2012). The fauna assemblage documents the presence of red deer (Cervus elaphus), horses (Equus ferus) and aurochs (Bos primigenius) with some occasional prey species such as rhino (Stephanorhinus hemitoechus), wild cat (Felis silvestris), hare (Oryctolagus cuniculus), bear (Ursus sp.) and goat (Capra aegagrus) (Gabucio et al., 2012; Gabucio et al., 2014). The lithic assemblage is still being studied, and only products from an area of about 20 square meters (lines 57–62) in the western part of the rock shelter were considered. This area yielded the richest amount of archaeological finds (Bargalló et al., in press). The lithic material is characterized by the use of the Levallois in the preferential and recurrent centripetal methods (Figs. 4–5), whereas secondary operative chains include a small amount of hierarchized centripetal, centripetal cores, core-on-flakes and simple cores. The retouched artifacts are composed mainly of denticulates, notched tools and few scrapers (Chacón et al., 2013; Picin, 2014; Picin and Carbonell, 2016; Picin et al., 2011; Picin et al., 2014).

Archaeological level M has been dated to between 54.9 ± 1.7 and 51.8 ± 1.4 ka BP and has yielded abundant faunal and lithic remains, wood imprints and combustion structures (Fernández-Laso et al., 2011; Picin, 2014; Picin et al., 2014). The zooarchaeological analysis documented the presence of red deer, horses and aurochs, with low frequencies of hare and lynx (Lynx sp.) (Fernández-Laso et al., 2010). Seasonal studies have been performed on the teeth of the herbivores, and these studies placed the hunts between autumn and early winter (Fernández-Laso et al., 2010). The lithic assemblage is characterized by the use of the discoid bifacial method (Figs. 4–5) whereas secondary
chaînes opératoires document few hierarchized centripetal cores, centripetal cores, orthogonal cores and core-on-flakes. The group of retouched tools is composed of a small number of denticulates and notched tools (Chacón et al., 2013; Picin, 2014; Picin and Carbonell, 2016; Picin et al., 2011; Picin et al., 2014).

3. Results

From a volumetric perspective, the important variable for determining the productivity of a knapping method is the relation between the weight and the number of flakes detached by the core unit. In the experimental materials, performed at IPHES, a Mann-Whitney test indicated that there were no differences between the mean values of the weights of the nodules used (p = 1.0) and the weights of complete flakes (p = 0.8691). Conversely, in the data published by Brenet (2011), a Mann-Whitney test showed significant differences between the nodules’ weights (p = 0.0003).

In the experiments performed for this study, the analysis showed similar values for flake productivity in both technologies (Table 2). Conversely, Brenet’s (2011) knapping experiments showed higher flake production in the discoid method. Although the standard deviations and coefficients of variation were lower in the Levallois experiments, the discoid technology produced more flakes by 1 kg of chert (Table 3). Moreover, the ratios between the nodules’ weights by the number of flakes indicated the production of lighter blanks in comparison to those of the Levallois recurrent centripetal method (Table 3).

The flake productivity of the Abric Romani archaeological material was also analyzed (Table 4). First, an unpaired t-test between the weight values of the lithic assemblages of levels M and O by different raw material units was performed. The results revealed that between the clustered raw materials M and O, significant differences were recorded between the total weight values (t = 4.895, df = 3514, p ≤ 0.0001) and between the weight of complete flakes (t = 4.181, df = 1775, p ≤ 0.0001). Conversely in PAN, the weight mean values was not significantly different (t = 0.3442, df = 317, p = 0.7309; t = 0.1729, df = 180, p = 0.8629). The analysis showed that the Levallois recurrent centripetal technology of level O was more productive because it produced a higher number of flakes by kilos of chert than the discoidal technologies of level M (Table 4). These results show significantly higher productivity rates in the Levallois assemblage of level O that were not recorded during the experiments. Conversely, in level M the productivity values were similar to those found by Brenet (Table 3). In raw material Panadella, the discoid technology was more productive, but the few flakes recovered in level M led us to interpret this result cautiously (Table 4).

4. Discussion

The study of flake productivity showed that in the experimental assemblages, the bifacial discoid technology was more productive than the Levallois recurrent centripetal technology (Tables 2–3). The null hypothesis that the two methods produce a similar number of flakes was rejected in favor of the alternative hypothesis (unpaired t-test on N° by 1 kg in Table 1: p = 0.0144, t = 2.668, df = 21). The bifacial exploitation of the discoid cores reduced the raw material more efficiently with an increase in the number of flakes.

Fig. 2. Experimental Levallois recurrent centripetal cores (1–4) and discoid cores (5–8).
by the size of the chert nodules (Fig. 6). Conversely, in the Levallois recurrent centripetal method, the stricter configuration processes of the core convexity could influence the number of flakes detached, and nodules with different weights could produce similar frequencies of blanks (Fig. 6).

The different replicative experiments also showed a variability in the productivity rates between the different methods. In the experiments performed for this study, the productivity values of number of flakes by kilos of chert were similar to (Mann-Whitney test: $p = 0.5614$) but smaller in comparison with those of Brenet (2011) (Mann-Whitney test: Levallois recurrent centripetal method, $p = 0.0424$; discoid method, $p = 0.0084$). Although the knappers are experts in replicating Mousterian technologies, the variation in the flake amounts could be related to the different distributions of the weight during the flaking sequences. In the discoid experiments performed at IPHES, a higher amount of weight was wasted during the decortication phases (Fig. 7). Conversely, in Brenet’s (2011) Levallois experiments, the bigger percentage of weight recorded in the decortication category was balanced by bigger rates in the production phase (Fig. 7). Conversely, in Brenet’s (2011) Levallois experiments, the bigger percentage of weight recorded in the decortication category was balanced by bigger rates in the production phase (Fig. 7). Thus, from a volumetric perspective, the detachment of thick blanks during the first phase of core reduction influenced the productivity values of the IPHES experiments leaving smaller quantities of chert to be exploited in comparison with the others. Unfortunately, the values of weight of the different reduction phases of Brenet’s (2011) discoid experiments are not available, and the higher productivity rates documented could also be related to the balanced distribution of the chert weight in the diverse technological categories.

Another aspect highlighted in the study is the different frequency of flake categories in the two technologies (Fig. 8). In the discoid experiments, lighter nodules had increasing values in the decortication phases with small changes in the production phase. This aspect is probably related to the size of the nodules. Small artifacts could be handled better by the knapper, allowing a more careful decortication of the chert cobbles with the detachment of several small flakes. Conversely, in larger nodules the decortication phase was carried out with the detachment of fewer and bigger flakes. In the Levallois recurrent centripetal method, the differences in the nodule sizes affected the frequency of the cortical flakes to a lesser extent, and more variability was documented during the core management phase (Fig. 8). This result reflects the different preparations of the core convexities that in the discoid bifacial method is more flexible than the Levallois method since discoid cores could be configured in several ways.

These results show that the foremost difference in productivity between the two flaking strategies depends on the knappers’ approach in preparing, maintaining and reducing the core volume. The detachment of several weighty flakes during the early stages of decortication or core preparation could decrease the core volume excessively and change the number of products significantly. Moreover, some variability exists between knappers in the application of the same technology due to different learning experiences, practices and objectives. This latter
feature was more evident in the discoid method because the reduction could be carried out with different goals changing between the modalities *sensu lato* or *sensu stricto*. Bourguignon et al. (2011) related the recurrent production of pseudo-Levallois points as an index for determining the skillfulness of a knapper. However, discoid cores could be reduced correctly by detaching only core-edge removal flakes without showing any differences in the production frequency (Fig. 8) or in the morphology of the by-products and cores (Picin et al., 2014). Therefore, the discoid method is not only flexible because it can be applied during any stage of the reduction sequence, but its production can also be influenced by the knapper's aim or skill.

In the Levallois context, the criteria for configuring the core are more rigid, and the recurrent detachment of Levallois flakes imposes a lesser use of core-edge removal flakes and pseudo-Levallois points (also called core-edge *dos limité* flakes) that are used only to maintain the core convexity. This feature is reflected in the experimental and level O assemblages in which the frequencies of these items are very similar (Fig. 9). However, some differences have been detected in the frequency of Levallois flakes that in level O is lower in comparison with the experimental material (Fig. 9). This discrepancy could be explained as a pattern of recurrent transport of Levallois items outside the rock shelter or, more probably, was caused by the mediocre quality of some chert nodules, which meant the flaking surfaces were reconfigured more frequently. This latter hypothesis may explain the higher frequency of blanks related to the core configuration/maintenance (Fig. 9).

The discrepancy between the productivity values in the experimental and archaeological assemblages might also be explained in terms of the aims of the reduction sequences. During the experiments, modern knappers attempted to produce an uninterrupted series of flakes whereas, in the archaeological record, Neanderthals applied more economic management of the chert nodules. This more careful approach used by Neanderthals in core reduction was probably influenced by the distribution of chert outcrops located in a radius of between 12 and 28 km from Abric Romani rock shelter (Fig. 1; Picin and Carbonell, 2016). The technological analysis of level O documents the broader territoriality of Neanderthals who foraged near the Panadella-Montemaneu area more frequently. Conversely, in level M, Neanderthals decreased their foraging territory and visited the Panadella-Montemaneu area more sporadically, shifting their attention to other areas close to Valldeperes and Sant Martí de Tous, or toward the hinge zones between the Prelitoral Range and the Vallès-Penedès depression (Picin and Carbonell, 2016).

In the high mobility context, the longer use life of the Levallois flakes was economically more convenient for hunter-gatherers than the shorter and thicker discoid blanks with more limited re-sharpening.

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**Fig. 4.** Levallois preferential cores (1–3) and Levallois recurrent centripetal cores (2–4) of level O; discoid cores (5–8) of level M (drawings S. Alonso).
events. Moreover, level O Neanderthals maintained smaller flake thicknesses in comparison with those of level M, which increased the productivity of the core units. An unpaired t-test performed on the IPHES experimental assemblages showed that there was no significant mean difference between the thicknesses of the experimental unbroken flakes ($t = 0.9566$, $df = 731$, $p = 0.3391$) whereas it is very significant between the complete flakes of levels M and O ($t = 10.9$, $df = 1897$, $p \leq 0.0001$). Thus, the more costly configuration of the Levallois cores in level O was balanced by several characteristics that were more advantageous during longer displacements into interior territories where raw material outcrops were more scattered. Conversely, in the reduced foraging radius, the smaller flake production of the discoid technology was lessened by the possibility of gathering chert nodules more frequently. Furthermore, the production of thicker blanks in the discoid context allowed the reuse of these flakes as cores for the production of small items when urgent needs arose. This recycling practice was common in level M (Vaquero et al., 2015) where core-on-flakes and kombewa flakes were abundant (Picin and Carbonell, 2016). In level O, the use of Levallois technology on poorer nodules emphasizes that it was the technology guiding the strategy for procuring raw materials and not the flaking properties of the nodules. This feature is important because show other technical behaviors in comparison with the evidences recorded by Geneste (1988a) in southwestern France.

However, these differences between the Levallois and discoid contexts should also consider the effects of artifact transport in the ratio between the weight and number of flakes. In some levels of Abric Romaní characterized by the dominance of discoidal knapping, such as levels J and M (Vaquero et al., 2012; Vaquero et al., 2015), a clear distinction has been found between the artifacts produced on the spot and the artifacts brought to the site as single items. The former were mainly small flakes, whereas the later tended to be large artifacts. Therefore, if the frequency of the transported artifacts increased, the productivity index would decrease. Since a comparison of the frequencies of transported blanks between levels M and O remains to be made, we do not know whether this factor also

![Fig. 5. Levallois flakes (1–6) of level O; discoid centripetal flakes (7–9) and discoid pseudo-Levallois points (10–12) of level M (drawings S. Alonso).](image-url)
contributed to the differences in the productivity ratio. Nonetheless, the role of artifact transport in the Levallois and discoid contexts constitutes an interesting avenue for future research.

5. Conclusion

This study about the productivity of the Levallois recurrent centripetal method and the bifacial discoid method revealed that these two methods share not only technical similarities in blank morphology but could have also similar amounts of flake production. The size of the starting nodule plays an important role in discoid technology because the size affects the number of cortical flakes. Conversely, in the Levallois recurrent centripetal method, the stricter configuration processes led to similar frequencies of artifacts in nodules of different dimensions. The use of the modality *sensu stricto* in the discoid method aims to increase the number of pseudo-Levallois points, but in terms of overall production, the frequency values were similar to those of the cores reduced *sensu lato*.

In conclusion, the productivity of the Levallois recurrent centripetal method and the bifacial discoid method is strongly influenced by the knapper’s goals and experience and by the maintenance of low flake thicknesses. Although it has been suggested that in Levallois reduction the blanks are thinner than in other technologies, the use of small and medium nodules with the bifacial discoid method also leads to small thick flakes, which increases productivity. Thus, the Levallois recurrent centripetal technology and the bifacial discoid technology could share similarities not only in the morphology of the byproducts but also in the production rates. Even if the bifacial discoid is a more flexible and simpler method, the exclusive use of Levallois recurrent centripetal modality during the Middle Paleolithic might be related to the features of the Levallois products (Eren and Lycett, 2012; Kuhn, 1994) that were more appealing during longer foraging movements.

![Graph showing the relation between weight and flake production](image1)

**Fig. 6.** Plot of the relation between the weight of the nodules, used for the replicative experiments, and the amount of flakes produced with 1 kg of chert in Levallois recurrent centripetal and bifacial discoid.

![Bar chart showing weight distribution](image2)

**Fig. 7.** Bar chart of comparison between the frequencies of weight distribution in the different blanks technological categories.
Increasing use of the experimental materials as a term of comparison with the archaeological collections and further investigations of the productivity patterns with different raw materials will be critical for understanding the different aspects of the technological organization in prehistoric hunter-gatherers.

Acknowledgments

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![Flake Frequency](image)

**Fig. 8.** Bar chart of comparison between the flake frequencies in the different technological categories.

![Comparison between the frequencies of the different technological categories in the experimental materials, performed at IPHES, and in the archaeological material of level O and M.](image)

**Fig. 9.** Comparison between the frequencies of the different technological categories in the experimental materials, performed at IPHES, and in the archaeological material of level O and M.

### Table 3

Summary table of the productivity of discoid and Levallois recurrent centripetal technology in experimental and archaeological materials including the nodule weight (g), the number of flakes (N°), the ratio between the weight and the number of flakes (NW/N°), the values of standard deviation (S.D.), coefficient of variation (C.V.) and number of flake by 1 kg of chert (N° by 1 g).

<table>
<thead>
<tr>
<th>Experiment</th>
<th>N° experiment</th>
<th>Raw material</th>
<th>Nodule weight</th>
<th>N°</th>
<th>NW/N°</th>
<th>S.D.</th>
<th>C.V.</th>
<th>Flakes by 1 kg</th>
<th>Reference</th>
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<tr>
<td>DISCOID</td>
<td>D1-2</td>
<td>Norfolk chert</td>
<td>10,020</td>
<td>245</td>
<td>40.9</td>
<td>10.3</td>
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<td>24</td>
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<td></td>
<td>D3-4</td>
<td>Norfolk chert</td>
<td>5170</td>
<td>134</td>
<td>38.6</td>
<td>5.3</td>
<td>14</td>
<td>26</td>
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<td></td>
<td>Br</td>
<td>Sénonien chert</td>
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<td>208</td>
<td>17.4</td>
<td>4.3</td>
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</tr>
<tr>
<td></td>
<td>Tu</td>
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<tr>
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<td>AR</td>
<td>M</td>
<td>M + PAN</td>
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<td>988</td>
<td>18.5</td>
<td>54</td>
<td></td>
<td></td>
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</tr>
<tr>
<td></td>
<td>O</td>
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<td>12,035</td>
<td>954</td>
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<td>79</td>
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<td>This study</td>
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Table 4

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<th>N°</th>
<th>NW/N°</th>
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<tr>
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<td>PAN</td>
<td>1613.2</td>
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<td>95</td>
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Appendix A. Supplementary data

Supplementary data to this article can be found online at http://dx.doi.org/10.1016/j.jasrep.2016.05.062.

References


