



The limits of short refitted sequences in detecting knapping skills from a Middle Palaeolithic assemblage[☆]

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ABSTRACT

Refitting is a key-tool for researchers to understand past knapping behaviours, technological strategies, and decision-making processes. The longer the reconstructed lithic reduction sequences, the more complete the understanding of knapping behaviour becomes. Yet, due to taphonomic constraints that often affect the archaeological record, not all sites yield the same quantity of lithic refits, therefore the completeness of the information can vary significantly.

In this paper we present lithic refitting conducted on a primarily Quina lithic assemblage from the Middle Palaeolithic site of De Nadale cave. The goal was to assess potential variability in knapping skill levels within the assemblage. However, the limited number of refits recovered, and the brevity of reduction sequences posed significant challenges to our analysis.

Nonetheless, we maximized the information by running comparative analyses with experimental Quina assemblages produced by knappers of varying skill levels. Outcomes indicate that short refitting sequences may not provide reliable insights into individual knapping skills or knapper variability, underscoring the limitations of this approach in contexts with fragmentary refit data.

1. Introduction

Lithic refitting has always been regarded as one of the most solid archaeological tools to understand intra-site dynamics, post-depositional processes and stone tool production strategies. Specifically, it provides information about the presence of activity areas (Vaquero et al., 2012) and single knapping events that occurred on-site (Romagnoli and Vaquero, 2019). It also relates temporal dimension to activities (Turq et al., 2013), validating the integrity of human occupation and the archaeological stratigraphy (Deschamps and Zilhão, 2018; Takakura, 2018). Together with the technological analysis of lithic assemblages, it may reinforce the assumption of transportation of tools through the identification of “ghost” artefacts (Delpiano and Peresani, 2017; Turq et al., 2013). Another interesting advantage of lithic refits is that, in the most fortuitous cases, they allow us to shift the

focus from site dynamics to knappers’ behaviour and, notably, to follow individual movements within the site (Foulds, 2010).

As a matter of fact, identifying skill levels through refitting lithic assemblages has enriched our knowledge about technical behaviour, knappers’ decisions during the exploitation, and about the “biography” of a single tool or block of chert (Turq et al., 2013). A specific branch of this behavioural research is the use of lithic refits to detect knapping skills within a lithic assemblage (Bamforth and Finlay, 2008), thus providing further information about group social composition and organization within the site. Pioneer studies using lithic refits to detect knapping skills variability were first documented Upper Palaeolithic sites of France and Denmark in the late Eighties (Fischer 1990b; Karlin 1991; Olive 1988; Pigeot 1987; Ploux 1988).

To underline the key role of refitting in this kind of studies, it is enough to recall that the first evidence of the diversity of knapping skills

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and learning (Bodu et al., 1990; Fischer, 1990b) were presented at the Big Puzzle symposium in Monrepos, the first international workshop about lithic refits (Cziesla et al., 1990) and which largely contributed to confirm the multiple applications of refits to archaeological assemblages. Like other pioneering studies, these relate the identification of knapping skill levels and – in a broader sense – knapping apprenticeship through the interaction of expert and novice knappers (Fischer, 1990a) and the spatial organization of their activity areas (Pigeot, 1987, 1990).

Through the years, more research focusing on lithic refits found a disparity of knapping skills from Upper Palaeolithic and Mesolithic sites (Bordes and Bachellerie, 2018; Cunhar, 2015; Roberts and Barton, 2021; Simonet, 2018; Takakura, 2013; Taylor et al., 2018, amongst others). For instance, a high resolution of past hominins' behaviour was reached at the Shirataki sites, where a single core reduction sequence was passed and reused from expert to novice knappers (Takakura, 2019). Furthermore, in cases of extensive blade refits and good preservation of the lithic assemblages, assumptions about age groups and status of the individuals have been proposed (Audouze and Cattin, 2011; Dugstad, 2010; Grimm, 2000).

The just-mentioned studies only consider research where skill differences were identified through lithic refitting. However, examples of differences in knapping skills defined through a flake-by-flake approach, recording deviation from classical norms and presence/absence of accidents on cores, tools and lithic products, are abundant. These studies come from all around the world and encompass different Palaeolithic periods (amongst others: Anderson, 2018; Assaf et al., 2016; Baena et al., 2019; Cattabriga & Peresani, 2024; Hovers, 2009; Profitt et al., 2022).

In this light, we present the case study of the lithic assemblage found at De Nadale Cave, a Middle Palaeolithic site in north-eastern Italy. The choice was primarily determined by the chronology of the site – only a handful of studies focuses on identifying skill levels in Middle Palaeolithic assemblages (Baena et al., 2019; Centi et al., 2023; Torres and Preysler, 2020) – and the finding of a Neanderthal deciduous tooth, suggesting the occupation of De Nadale Cave by a heterogeneous group of Neanderthals. The aim of our research was to try to identify knapping skill levels within De Nadale lithic assemblage through lithic refitting. Another key-goal was to provide a method to determine the presence of knapping skill by analysing lithic refits without relying only on observation but also with a more objective approach, notably with the aid of multivariate analysis. To do so, we combined a flake-by-flake approach and refitting, thus bringing together technological attributes from the refitted pieces to expand the analytical basis for evaluating individual reduction sequences. We compared results with experimental material produced during Quina-like core reduction sessions with participants with different knapping backgrounds and skills. Aside from the difficulty to find refitted reduction sequences long enough to gain insight on Neanderthals who inhabited the site, we address the issue of drawing inferences about variability of knapping skills from short refitted reduction sequences.

2. De Nadale cave: presentation of the archaeological context

De Nadale cave is located in the southern slope of the Berici Hills, a karst plateau in the subalpine region of northern Italy. Eight excavation campaigns from 2014 until 2022 exposed a short stratigraphic sequence, including one single Mousterian layer (Unit 7) embedded in archaeologically sterile deposit and dated to $70.2 \pm 1/-0.9$ ka as a minimum age (Jéquier et al., 2015). Unit 7 was investigated for a total of 20 m² and yielded thousands of fragmented bones, flint implements, few tiny fragments of charcoal, and a Neanderthal deciduous tooth (Arnaud et al., 2017). The zooarchaeological assemblage is of an anthropogenic nature, including mainly remains of red deer (*Cervus elaphus*), giant deer (*Megaloceros giganteus*) and bovids (*Bison priscus* and *Bos primigenius*) (Livraghi et al., 2021; Terlatto et al., 2019). This faunal association, coupled with small mammal assemblage, and the anthracological spectra of charred wood, provides evidence for paleoenvironmental and

paleoclimatic reconstruction, indicate a cold climate phase characterized by a landscape presenting open woodland formations and open dry meadows (López-García et al., 2018; Vidal-Matutano et al., 2022). Taking into account the chronology of the site, this has been associated with the very beginning of MIS 4.

The lithic industry exhibits distinct features compared to the Levallois-dominated assemblages of the Berici area (Peresani, 1995-96, 2015; Peresani and Porraz, 2004). Nonetheless, the technological and typological features of the De Nadale lithic assemblage showed marked differences with the Mousterian of the rest of northern Italy. By combining technological and use-wear analyses in the reconstruction of lithic core-reduction, tool-reduction, and tool use, we indicated that the flexible core reduction strategies identified at De Nadale can be ascribed to a scheme showing some similarities with the Quina knapping method (Delpiano et al., 2022), in addition to the adoption of centripetal methods on single surfaces. Quina cores, products and tools were also identified at Grotta di Fumane (Peresani et al., 2023) and at Grotta della Ghiacciaia (Bertola et al., 1999; Peresani et al., 2022). Variations of this scheme have been identified at De Nadale, include the exploitation of lateral and narrow fronts addressed to the production of elongated blanks. A parallel, ramified reduction is applied to *limace*-cores and Quina or demi-Quina scrapers having diversified purpose (mixed matrix). These blanks are exploited as tools and cores-on-flakes tools from which thinner, usable flakes or bladelets are detached. The use-wear identified on both scrapers and *reaffutage* flakes further confirms this behavior, demonstrating the use of both blanks, although for different tasks (i.e., scraping and cutting). The high frequency of retouched tools and Quina or demi-Quina scrapers seems to accompany the highly mobile human groups associated with this techno-complex and their seasonally organized subsistence strategies (Delpiano et al., 2022). In addition to lithic tools, it is important to emphasize the presence of over 300 retouchers made from the bones of large cervids and bovids (Martellotta et al., 2021).

3. Materials and methods

For the current study, we analysed the whole lithic assemblage found at De Nadale Cave ($n = 1,318$) and material ($n = 477$) produced during a pilot experiment which took place in 2022 at Iphes-CERCA (Institut Català de Paleoeologia Humana i Evolució Social) in Tarragona, Spain. The experimental material consisted of eight lithic assemblages produced by knappers of different skill levels: K1 has never knapped before; K2 had practiced knapping only a few times during his studies; K3 has few years of practice and mainly specialized in blade technology; K4 is an expert knapper with over twenty years of knapping experience. Their knapping abilities were deduced by a questionnaire they were asked to fill about their familiarity with knapping and the Quina method. Novice knappers (K1, K2, K3) attempted to produce Quina-like blanks first imitating (Exp1) the expert knapper (K4) and then, freely interacting and listening to his explanations (Exp2) – i.e. active teaching. Their main goal was to obtain thick and asymmetrical flakes following the Quina reduction system, which translates in an alternated exploitation of sub-parallel and secant surfaces (Bourguignon 1996). Given the fact that De Nadale lithic assemblage is mainly made of good-quality chert, we provided participants with Norfolk chert (England), a rather homogeneous raw material.

The archaeological assemblage consisted of cores, flakes and bladelets (Delpiano et al., 2022). For both the archaeological and experimental assemblages (see Table 1) we set the threshold size of 20 mm.

To analyse the experimental assemblages, attributes used for lithic technological analysis (Inizian et al., 1995; Andrefsky, 2007) and to identify knapping skill levels (amongst others: Anderson, 2018; Assaf et al., 2016; Hogberg, 2008; Klaric, 2018; Milne, 2013; Pigeot, 1990; Simonet, 2012; Takahashi and Nishiaki, 2019; Takakura, 2013) were recorded. For the archaeological material we added skill-related attributes used in these studies to the technological analysis previously made

Table 1

Material considered for our study.

Lithic assemblage	Total pieces	Flakes	Proximal flake fragments	Flake fragments	Cores
De Nadale	1318	680	166	398	74
K1_1	23	5	0	17	1
K2_1	97	55	11	31	1
K3_1	82	29	15	37	1
K4_1	84	68	0	15	1
K1_2	44	25	3	15	1
K2_2	48	26	6	14	1
K3_2	52	34	5	12	1
K4_2	42	35	0	7	1

by Delpiano et al. (2022) on the archaeological assemblage of De Nadale Cave. Then, attempts for refitting of the archaeological and experimental lithic assemblages were carried on. To streamline the procedure, the archaeological assemblage was mainly divided into raw material units and all possible combinations between lithic elements were systematically tested. Overall, approximately 250 h were dedicated to the refitting of the archaeological material and 90 h to the experimental assemblages (see Table 2 for a list of the sets of refits). Refits were extensively documented through photos and videos of the refitted reduction sequences (see OR Table 1 for a short description of the archaeological refits).

Once lithic refitting was completed, we compared archaeological and experimental data by first applying descriptive, and then multivariate statistical analysis, through RStudio software (Baxter and Cool, 2010).

Table 2

List of lithic refitting considered for this study. “DN” set of refits are from De Nadale Cave. K1_1, K2_1, K3_1, K4_1, are from novice (K1 to K3) and expert (K4) knappers in Experiment 1 (Learning Quina by imitation). K1_2, K2_2, K3_2, K4_2 are from novice (K1 to K3) and expert (K4) knappers in Experiment 2 (Learning Quina with verbal advice).

Set of refit	N of refitted pieces
DN1	2
DN2	2
DN3	2
DN4	2
DN5	2
DN6	2
DN7	2
DN8	2
DN9	2
DN10	2
DN12	3
DN13	3
DN14	2
DN15	2
DN17	2
DN18	2
DN19	2
DN20	2
DN21	2
DN22	2
DN23	4
DN24	4
DN25	4
DN26	2
K1_1	17
K2_1	57
K3_1	66
K4_1	62
K1_2	39
K2_2	38
K3_2	44
K4_2	31

For descriptive analysis we considered all lithic elements whereas for multivariate analysis we only included data from the sets of refits. Specifically, we used multivariate statistical analysis to test the following hypotheses:

- Can a variability of knapping skill level be detected with short reduction sequences?
- What is the acceptable range of the number of refitted lithic elements that can provide information about knapping skills?

To address these issues:

- First, we tested the experimental material to observe how it grouped together according to the variability of participants' knapping skills. To do this, we employed chi-square tests to verify the strength of the association of the recorded attributes; hierarchical clustering to measure the weight of each variable and to select the most influential ones; correspondence analysis (CA) to observe the distribution of the assemblages according to selected variables (Baxter, 1994).
- We then combined groups of De Nadale refits divided by the number of refitted items – i.e. two (DN1, DN2, DN3, DN4, DN5, DN6, DN8, DN14, DN15, DN17, DN19, DN20, DN21, DN22, DN26), three (DN12, DN13) and four (DN23, DN24, DN25) refitted pieces – with experimental refits into several CAs to analyse how archaeological material spread and whether it grouped around refits produced by modern knappers.
- We tested the reliability of De Nadale refits and the strength of CAs on short reduction sequences. The aim of this test was to assess the reliability of short refitted sequences in terms of knapping skills levels. To do this, we applied CA to the experimental material to verify the validity of short refitted sequences on a reference sample. We considered the three lithic assemblages produced by less experienced knappers during Exp2 as stable elements, while progressively decreasing the number of the expert's set of refits. We chose this latter because it was knappers' best attempt, and the most complete sequence of core exploitation produced with the Quina reduction system. Regarding this last point, the test started with a complete set of 30 refitted items produced by the expert knapper. The following tests involved 20, 15, 10, 5, and lastly 4, 3, 2 pieces (see OR Fig. 2 and 3). Since in the CA carried out with 20 refitted pieces, the pieces that supposedly belonged to the decortication phase and preparation of the core had already been removed, we ran six more CAs selecting random short sequences of refitted pieces to ensure full of the reduction sequence of core reduction. If CAs with 4, 3, 2 pieces were not statistically reliable to identify skill levels, it might be challenging to get precise information about knapping dexterity from De Nadale short refitted sequence. For this reason, we run the test only on the experimental assemblages.
- Finally, we decided to test whether the representation of the lithic assemblage changed according to the phases of the operational chain. In other words, we wanted to verify whether our criteria were better represented – and thus more accurately reflective – by a certain phase of the reduction sequence. To do this, we ran CAs for the decortication and full production stages for each of the experiments.

Regarding the experimental material, the entire assemblages produced by knappers in Exp1 and Exp2 were used for phase a), b), d) because although not all the pieces were refitted together, we identified whose assemblage belonged to each knapper. For phase c), instead, we included only sets of refits from Exp2 since the focus of this stage was to investigate short sequences of lithic refits.

To test the representation of the selected criteria throughout the reduction sequence (phase d), the experimental material was allocated

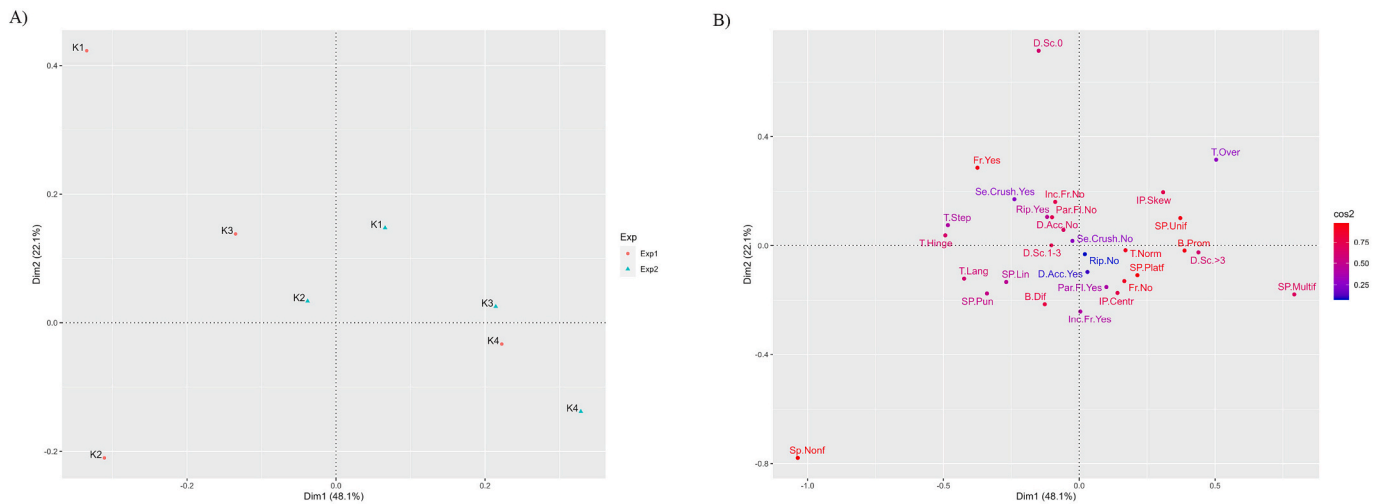


Fig. 1. A) Correspondence Analysis of Exp1 and Exp2; B) Contribution of row (cos2) to the Correspondence Analysis of Exp1 and Exp2.

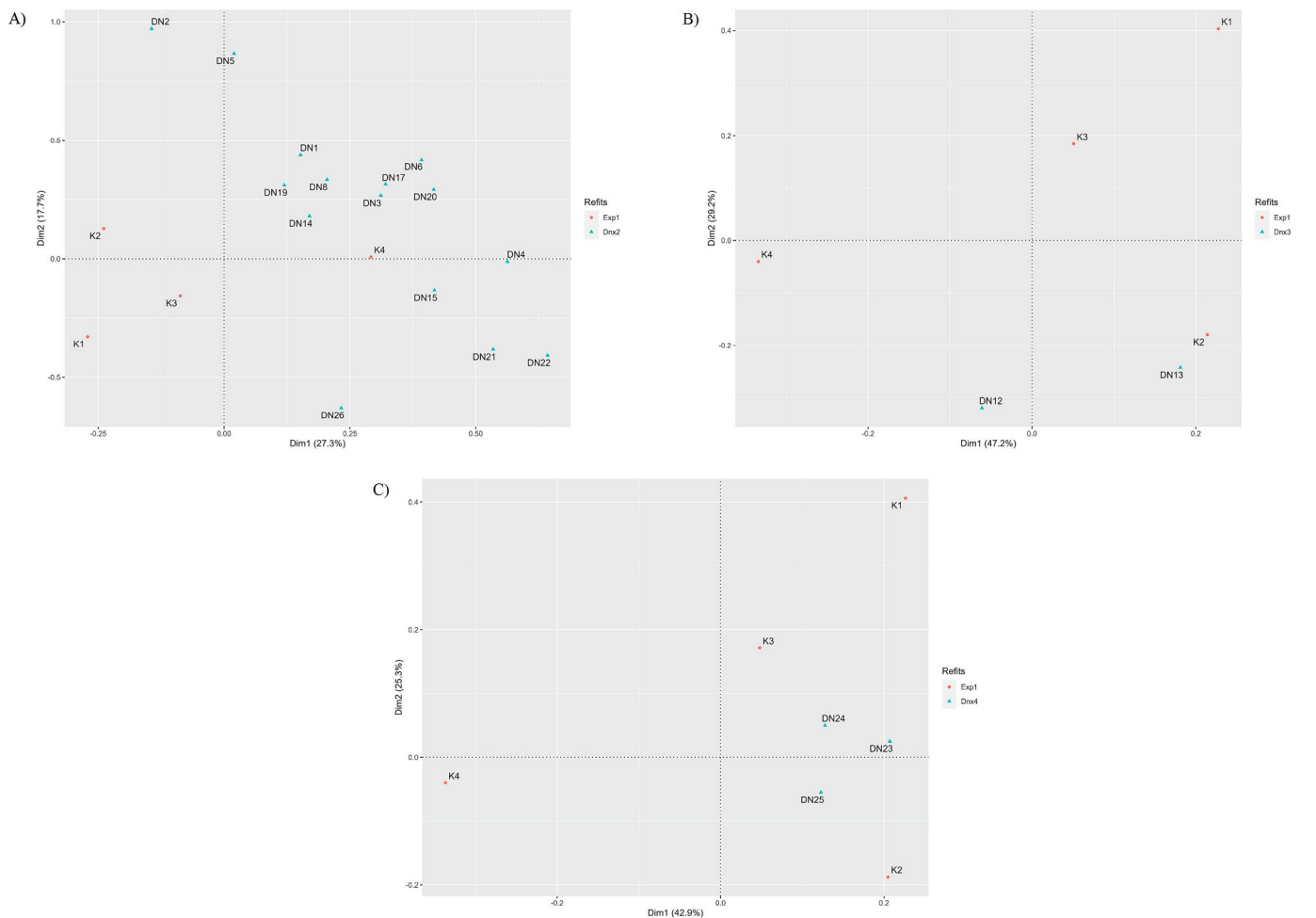


Fig. 2. A) Correspondence Analysis of Exp1 with De Nadale two-pieces refits set; B) Correspondence Analysis of Exp1 with De Nadale three-pieces refits set; C) Correspondence Analysis of Exp1 with De Nadale four-pieces refits set.

only to decortication and full production stages, without including maintenance or core preparation. We opted for this choice because our novices did not consider, were unaware of, or were unable to prepare surfaces and/or maintain the convexities of the core. In fact, these stages were evident only in the expert's assemblages. A similar behaviour has

also been observed in the lithic assemblages of Etiolles, Tercis and Tuto-la-Camalhot (Anderson 2018, Pigeot 1990, Simonet 2012), where the action of novices was suggested by refits or cores showing, amongst other things, a poor management of the convexities. Indeed, the lack of maintenance and core preparation stages due to inexperience should be

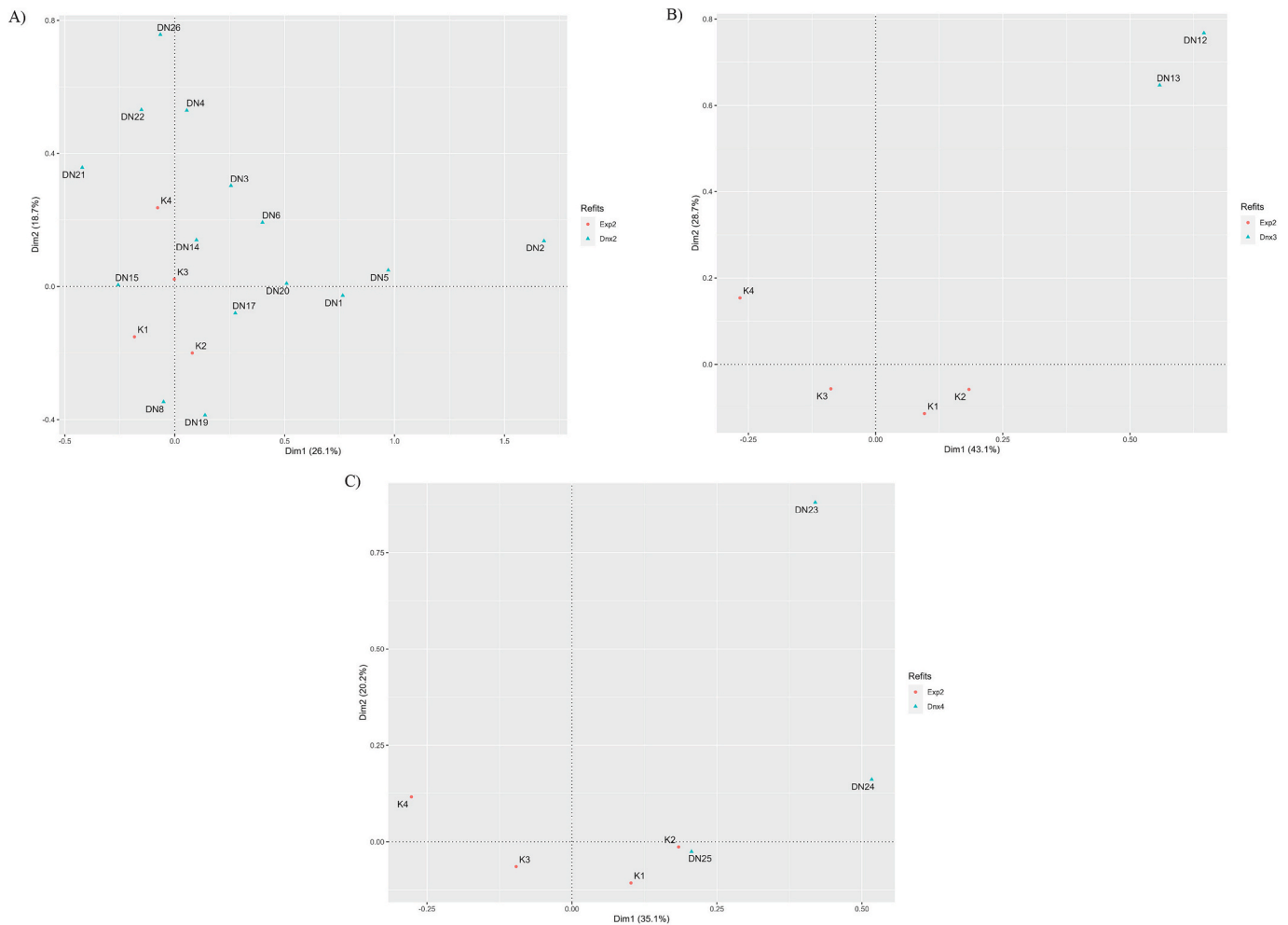


Fig. 3. A) Correspondence Analysis of Exp2 with De Nadale two-pieces refits set; B) Correspondence Analysis of Exp2 with De Nadale three-pieces refits set; C) Correspondence Analysis of Exp2 with De Nadale four-pieces refits set.

considered a criterion to identify novices itself.

Regarding the archaeological material, we considered as part of the decortication group every set of refits with at least one cortical or semi-cortical item (DN 6, DN8, DN17, DN19, DN22, DN23, DN24, DN25, DN26). Under the full production group, in addition to full production sets of refits with non-cortical pieces (DN1, DN2, DN3, DN4, DN5, DN12, DN13, DN14, DN15, DN16, DN20, DN21), also lithic items refitting with cores were included (DN7, DN9, DN10, DN18).

4. Results

4.1. Testing the experimental material

Since knappers participating in the experiment differed in knapping skills, we tested their assemblages to see if they grouped according to their skill categories; ideally, novices would cluster closely together but remain distant from the expert knapper. The analysis followed these steps:

1. The application of hierarchical clustering (Manhattan distance with average linking method) was aimed to observe how subcategories ($n = 84$; A complete list of subcategories can be found in OR Table 2) grouped together according to frequency in order to identify the most influential attributes. The purpose was to create a list of technological attributes common to the experimental assemblages

produced during Exp2. For this stage we considered only qualitative attributes.

2. Among this selection, we chose the general attributes that are usually associated with knapping skill level (these first steps are summarized in OR Fig. 1). For instance, if “D_Acc.Steps” as subcategory was common to all knappers, we considered “Dorsal Accidents” as a general attribute to be included in the Correspondence Analysis (CA).
3. The table derived by this last selection recorded the presence/absence and/or type of 12 general attributes usually associated with knapping skill level and common to the lithic assemblages produced during the experiment (See Table 3).
4. We ran the Chi-square test on the final contingency table to verify the association between variables. Results showed that variables are independent (See Table 4).
5. We ran the Wilcoxon signed-rank test on the frequency of the production of each knapper for Exp1 and Exp2 to confirm that the two experiments were two different populations (K1 p-value = $5.698e-05$; K2 p-value = $1.314e-05$; K3 p-value = 0.001633 ; K4 p-value = $8.774e-06$). Given the results, we treated the experiments separately.

The CA resulting from the comparison of the experimental material (see Fig. 1) shows a high percentage of the total inertia and a good representation of the total data (70 percent). The first two dimensions are mainly driven by presence of fractures, uni-faceted striking platform and pronounced bulb. Whereas this latter might be indicative of the use

Table 3

List of criteria and subcategories used for the analysis.

N. Criteria	Technological attribute	Subcategory	Legend
1	Bulb morphology	Diffuse Bulb	B.Dif
		Prominent Bulb	B.Prom
2	Dorsal Accidents	Presence	D.Acc.Yes
		Absence	D.Acc.No
3	Dorsal Scars	None	D.Sc.0
		Few	D.Sc.1–3
		Numerous	D.Sc. > 3
4	Fractures	Presence	Fr.Yes
		Absence	Fr.No
5	Position of the impact point	Central	I.Centr
		On the sides	I.Skew
6	Incipient Fractures	Presence	Inc.Fr.Yes
		Absence	Inc.Fr.No
7	Parasitical flakes	Presence	Par.Fl.Yes
		Absence	Par.Fl.No
8	Ripples	Presence	Rip.Yes
		Absence	Rip.No
9	Crushed striking edge	Presence	Se.Crush. Yes
		Absence	Se.Crush.No
10	Striking platform morphology	Platform	SP.Plattf
		Linear	SP.Lin
		Puntiform	SP.Punt
11	Striking platform preparation	Non-faceted	Sp.Nonf
		Uni-faceted	SP.Unif
		Multi-faceted	SP.Multif
12	Termination	Feather	T.Feather
		Hinged termination	T.Hinge
		Languette	T.Lang
		Step	T.Step
		Overshot	T.Over

Table 4

Contingency table of Experiment 2 with chi-square result.

Variable	K1_2	K2_2	K3_2	K4_2
B.Dif	14	25	16	20
B.Prom	19	10	23	20
D.Acc.Yes	2	11	10	8
D.Acc.No	45	35	42	33
D.Sc.0	8	4	2	1
D.Sc.1–3	35	33	32	27
D.Sc. > 3	3	9	18	13
Fr.Yes	19	21	17	7
Fr.No	28	25	35	34
IP.Centr	16	16	22	30
IP.Skew	10	8	11	5
Inc.Fr.Yes	10	11	13	10
Inc.Fr.No	37	35	39	31
Par.Fl.Yes	12	16	21	20
Par.Fl.No	35	30	31	21
Rip.Yes	19	29	27	15
Rip.No	28	17	25	26
Se.Crush.Yes	5	8	2	0
Se.Crush.No	42	38	50	41
SP.Plattf	27	22	33	37
SP.Lin	4	5	4	1
SP.Pun	5	8	6	1
Sp.Nonf	2	4	1	0
SP.Unif	28	19	28	24
SP.Multif	1	1	2	7
T.Norm	34	32	36	36
T.Hinge	7	5	1	2
T.Step	3	3	4	2
T.Lang	0	3	3	1
T.Over	3	3	8	0
Chi square	p-value = 0.00432			

of hard hammerstone, fractures and a simple preparation of the striking platform may suggest the action of novices. As a matter of fact, they tend to produce more fragmented pieces and they struggle with a proper preparation of the striking platform, due to the lack of control of

knapping rules involved in the reduction process (Shelley, 1990). In both experiments, the expert's assemblages (K4) were grouped together with high values for a lack of knapping accidents and the presence of well-preserved striking platforms. On the other hand, especially in Exp1, novice knappers (K1, K2) show a negative relationship with K4, placing themselves at the opposite part of the plot, while the intermediate knapper (K3) is located between the two groups. There appears to exist a positive trend in knappers' production between Exp1 and Exp2, suggesting an overall improvement of their capabilities. However, this impression must still be confirmed by further tests and comparison with more experimental material.

4.2. Application to De Nadale refits

We then added the archaeological data to the Correspondence Analyses (CAs) of Exp1 (see Fig. 2) and Exp2 (see Fig. 3). To do this, we considered only archaeological refitted flakes, but we excluded flake-to-core refits. First, we recorded the frequency of the attributes selected from the experimental material, and then we completed a series of CAs. Thus, we added De Nadale refit sets (see Fig. 4) according to the number of refitted pieces (two-, three- and four-piece refits) to the CAs of Exp1 and Exp2.

Overall, a gradual decrease of the percentage of representation of the assemblages from four to two refitted pieces can be observed (see Fig. 2 and 3). Especially with two-refitted pieces the representation of the assemblage dropped below 50%. In addition, despite the apparent proximity of some sets of refits clustering around modern knappers' productions, the high number of outliers present in all CAs should be taken into consideration when interpreting the results.

In order to explain such a high presence of outliers and the low percentage of representation of the assemblage with two-piece refits, we questioned the reliability of this type of analysis with short reduction sequences.

4.3. Testing the reliability of short reduction sequences

To test the accuracy of CA with very short reduction sequences, we simulated a series of CAs (see Fig. 5. For the complete CAs, see OR Fig. 3 and OR Fig. 4) where we gradually decreased the number of refitted pieces of a varying element (K4 in Exp2), while the sets of refits of the other three elements (K1, K2, K3 in Exp5) remained stable. Another aim was to verify whether, below a certain threshold of refitted items, the results of the CA remained solid, or they varied significantly.

The initial situation shown by the first CA represents the entire set of refits (30 pieces in total) of K4 positively associated with K3 although they do not cluster together. Instead, K1 and K2 are negatively associated with K3 and K4. We consider this CA as representative of the status of participants' knapping capabilities during Exp2.

While decreasing the number of refitted pieces, it can be noticed that the total inertia remains rather stable until 10 refitted pieces (around 83%). After this number of refitted items, although the overall representation of the data remains high, a change in the total inertia occurs, notably below five pieces. In addition, K4's behaviour increasingly resembles that of the outliers (a summary of the main CA is shown in Fig. 5). This situation arises especially with very short reduction sequences, and it is confirmed by the bootstrap analysis. Specifically, while the configuration from the 30-piece matrix remains highly stable ($SD \sim 0.22 / 0.10$), the configurations derived from the matrices with 4, 3 and 2 pieces show increasing instability (SDs ranging from ~ 0.43 to 0.61). This indicates a gradual loss of reliability in the CA structure with reduced sample size. Furthermore, as shown in the "Random" test (see OR Fig. 4), this pattern persists regardless of the stages of the reduction sequence in which pieces were produced. For these reasons, our results suggest that when fewer than five refitted pieces are available, caution may be warranted when drawing inferences about knapping skill levels.



Fig. 4. Sets of refits found at De Nadale Cave.

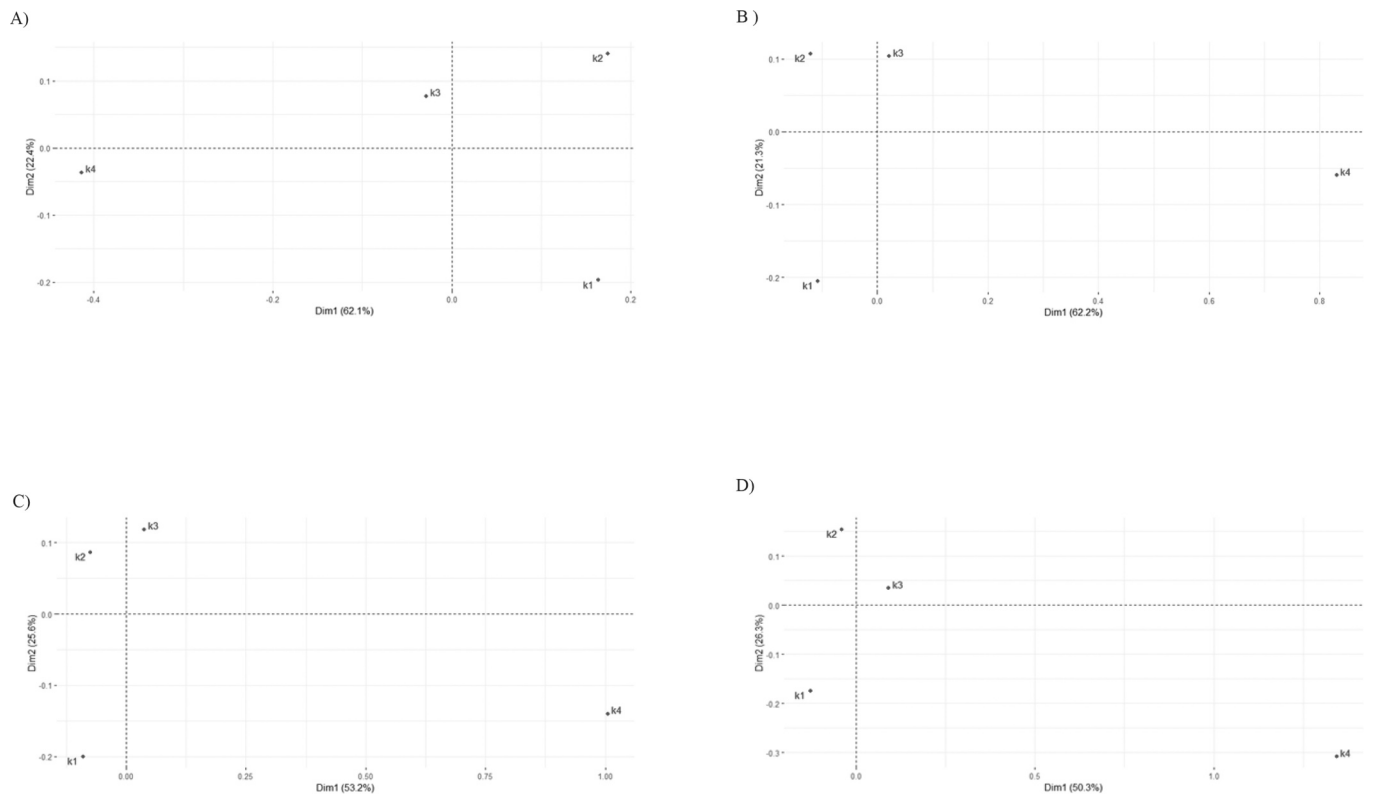


Fig. 5. Results from reliability test on Exp2, with K1, K2, K3 as fixed elements and K4 as variable. A) Correspondence Analysis with the entire refitted set (30 pieces); B) Correspondence Analysis with ten refitted pieces; C) Correspondence Analysis with five refitted pieces; D) Correspondence Analysis with two refitted pieces.

4.4. Does reliability change between phases of the reduction sequence?

Further tests were run to determine whether our results depended on the phase of the reduction sequences. In other words, we verified to what extent the selected criteria were more explanatory of the full production or the decortication phase – we did not consider other stages of the production sequence for the reasons described in the previous section. As specified in the previous section, the set of refits considered for this analysis were not the same as phase b.

We were able to apply CA only to Exp1 (see Fig. 6) because the chi-square test of Exp2 resulted in $p\text{-value} > 0.05$. This result asserts the independence of the variables and a no significant association between

rows and columns of this dataset. For this reason, Exp 2 was not included in this last analysis (see OR Tables 3 and 4). Concerning the decortication phase of Exp1 and De Nadale refits, the inertia of variables is mainly represented by crushed striking edge and crushed striking platform, hinges, unprepared butts and fractures. For the full production phase, the presence of fractures, accidents (failed terminations) and unprepared platforms mainly influenced the two first dimensions. In comparison with the decortication, the full production phase once again shows higher values for the total inertia. These outcomes are consistent with the assumption that most of the selected criteria are representative of the full production stage, whereas those related to the decortication phase appear to be less influential, at least in the assemblages

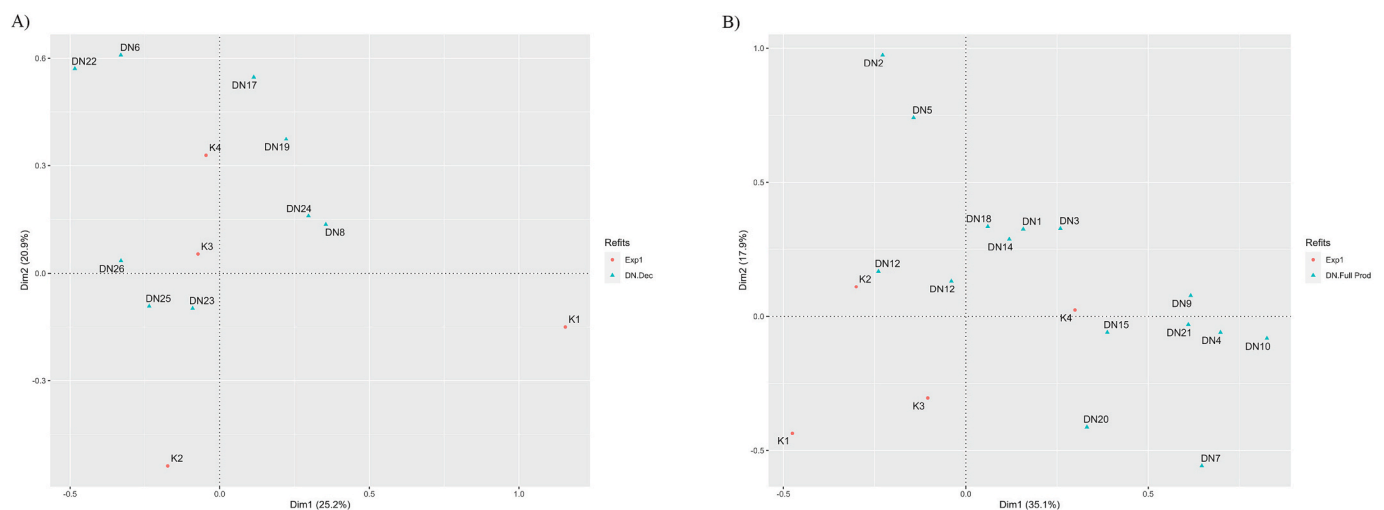


Fig. 6. Correspondence Analysis of Exp1 and De Nadale. A) Chart with De Nadale with cortical and semi-cortical set of refits; B) Chart with De Nadale set of refits with full production set of refits.

considered.

5. Discussion

Throughout this paper, we test the validity of identified knapping skill levels through multivariate analysis of lithic refitting. The first step was to check whether the action of modern knappers with different knapping backgrounds could be detected by observing lithic refits and recording technological and skill-related attributes. The criteria employed in this study were statistically selected through chi-square analysis from an experimental Quina replication dataset. Although they are therefore grounded in a Quina-specific experimental framework, their cross-method validity is currently being assessed through ongoing experimental programs focused on other reduction systems. Furthermore, not all selected attributes necessarily reflect Quina-specific conceptual features. Several of them relate to general aspects of core reduction and motor control. These dimensions are widely discussed in the technological literature as components of knapping competence that transcend specific reduction systems. For this reason, in the present study these criteria are interpreted as provisional indicators of variability in skill expression rather than as method-diagnostic markers or features exclusive to Quina production. The aim was not to define technological affiliation, but to test whether variability structured by these experimentally derived attributes can be detected within an assemblage characterized by technological flexibility. Outcomes showed that this procedure is effective when assemblages yield abundant sets of lithic refits. At De Nadale Cave, lithic refits were, unfortunately, not abundant and, most importantly, not representative of long reduction sequences. With this kind of situation, our quest for individuals had to be reoriented, as when lacking extensive refits, we can only achieve a snapshot of individual knapping exploitation strategies and behaviour. Consequently, we preferred to remain cautious about making inferences on the identification of knapping skills and decision-making within this specific archaeological assemblage. Specifically, concerning statistical results, although several sets of archaeological refits seem to cluster around the behaviour of some modern knappers, results from the CAs should not be considered valid due to the low amount of information usually provided by short refitted sequences. A clear warning emerges when comparing plots C (four-pieces set of refits) in Fig. 2 and 3. In the first case, DN 23, DN24 and DN25 seem to group between K2 and K3, thus giving the impression that these sets of refits were likely produced by novices. However, when comparing this situation with Exp2, results differ significantly: despite the proximity of DN25 to K2, DN23 and DN24 behave as outliers. Given the inconsistency of the two situations, we consider these results unreliable. The same occurs when analysing plots B (three-pieces set of refits) in Fig. 2 and 3. On the other hand, comparing plots A (two-pieces sets of refits), some patterns appear to remain stable between Exp1 and Exp2, especially when considering refits that are statistical outliers and those that do not. Another promising element is the clustering of most refits around K4. This can be explained by the fact that, in this case, two-piece refits show a lower presence of heavy accidents or criteria generally associated with novices. However, once again, results should be interpreted with caution due to the low percentage of inertia, which suggests that they are not sufficient to represent the entire dataset. Another argument against the reliability of the information provided by short, refitted reduction sequences is that in such small assemblages, even a minimal change can shift results from one extreme to the other.

The simulation performed on Exp2, where only the assemblage of K4 changed (Fig. 5), led to the same conclusion – that results appear to be more solid starting from about ten-pieces refits, whereas below five-pieces refits, they are weaker. Relating these outcomes to broader interpretations of past individuals, this threshold becomes even more important to consider before drawing inferences about knapping skills. In other words, relying on short refitted sequences to define knapping skills might be problematic. Indeed, a small number of refitted pieces

provides only limited information about the knappers' strategies; consequently, the identification of knapping expertise becomes less precise.

Furthermore, concerning the technological attributes used to identify knapping skills, it appeared that, within De Nadale assemblage, criteria related to cortex coverage and preparation of the core are less indicative of knapping skills than those associated with the full production phase. In other words, attributes related to these stages of core exploitation contribute less to identifying skill levels than the attributes typically observed during full reduction. Conversely, the absence of these stages in archaeological lithic assemblages has often been interpreted as evidence of novice activity due to their limited ability to prepare and manage core convexities. For instance, refit analysis from Upper Palaeolithic French sites shows that the main difference between intermediate and expert knappers is the general management of convexities (Pigeot, 1990). This is because to prepare the core and maintain convexities, knappers must have a good knowledge and know-how of basic knapping dynamics and rules to remove successful flakes without irremediably ruining cores. When a “sharing” of cores is recognized in the archaeological record, it was usually reported that a well-made preparation of the core (supposedly made by experts) and then, an exploitation characterised by accidents, multiple and chaotic impact points, ruined striking edges and so on, suggesting the action of novices (Assaf, 2019; Takakura, 2019).

Returning to the “De Nadale situation”, the major consideration that can be indicated is that not all assemblages are suitable for the identification of knapping skill levels. Although several studies approached this issue without lithic refits – thanks to the abundance of accidents, the variability of core reduction or artefact morphology (Assaf et al., 2016; Anderson, 2018; Cattabriga & Peresani, 2024; Simonet, 2012, amongst others) – it was not possible to follow this path at De Nadale Cave because cores are not statistically abundant at the site and the research about tracing novices in the production of retouched tools is still at its initial stage (Rots, 2005). Therefore, in our case the most solid evidence to identify knapping skill levels had to come from lithic refits. The lack of this latter is likely due to the following reasons:

- Cemento chronology and dental tooth analyses, combined with the analysis of lithic industry, suggested repeated short-term occupations of small groups of Neanderthal likely occurred during winter (Livraghi et al., 2021; Delpiano et al., 2022). However, a higher resolution of single events cannot be distinguished because the De Nadale Cave deposit is a palimpsest of occupations (Livraghi et al., 2022).
- De Nadale lithic assemblage is extremely reduced with a rather abundant rate of retouched tools (Delpiano et al., 2022). These highly reduced volumes imply a higher percentage of non-complete negatives on dorsal and core surfaces. In addition, retouch actions for their natural shape and modify the edge of lithic items, and when particularly invasive – as with Quina scrapers (Bordes, 1984) – contribute to hide the original shape of flakes and past negatives, thus making the search for lithic refits more complex. Moreover, the industry is characterized by the branching of reduction sequences, with the common presence of ‘mixed matrices’, namely blanks used both as cores and tools, and the manufacturing of tools on scrapers’ resharpening flakes. This has profound implications on the spatial fragmentation of the chaîne opératoire, further lowering the probability of finding refits.

Although the abundance of accidents and the presence of a deciduous tooth in the anthropic layer suggest a small and heterogeneous group (Jéquier et al., 2015), further inferences about the social context and individuals' choices are for now masked by the palimpsest and the nature of the lithic assemblage.

6. Conclusion

In our research, we tried to identify knapping skill levels through a comparison between experimental and Middle Palaeolithic lithic refits using multivariate analysis. The lack of an abundant set of archaeological refits and, more importantly, the complexity of reconstructing long reduction sequences due to the nature of the lithic assemblage, obscured individuals' behaviour at the site. However, some inferences can be drawn at both the experimental and archaeological levels. First of all, we isolated a list of technological attributes, mainly representative of the full production phase, to distinguish varying levels of knapping skill based on experimental refits. Indeed, the application of these attributes to other assemblages can be adjusted to specific situations. In addition, our results suggest a threshold below which information derived from lithic refits may be insufficient for confidently identifying knapping skills and should therefore be interpreted with caution. Although these results might seem to be shaped by our specific case study – a primarily Quina Middle Palaeolithic site – they can be a starting point to conduct further assessments of the reliability of lithic refits in identifying skill levels. A more in-depth analysis of refits and spatial analysis can provide more knowledge about the organization of activity areas and transportation of tools.

CRediT authorship contribution statement

Gloria Cattabriga: Writing – original draft, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Amelia Bargalló:** Writing – review & editing, Validation, Supervision, Conceptualization. **Davide Delpiano:** Writing – review & editing, Validation, Supervision, Conceptualization. **Alessandra Livraghi:** Writing – review & editing, Validation, Conceptualization. **Marco Peresani:** Writing – review & editing, Validation, Supervision, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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