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Anne Delagnes, Michel Brenet, Brad Gravina, Frédéric Santos. Exploring the relative influence of raw materials, percussion techniques, and hominin skill levels on the diversity of the early Oldowan assemblages: Insights from the Shungura Formation, Lower Omo Valley, Ethiopia. PLoS ONE, 2023, 18 (4), pp.e0283250. 10.1371/journal.pone.0283250 . hal-03851230

HAL Id: hal-03851230

<https://hal.science/hal-03851230v1>

Submitted on 14 Nov 2022

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PLOS ONE

Exploring the relative influence of raw materials, percussion techniques, and hominin skill levels on the diversity of the early Oldowan assemblages: Insights from the Shungura Formation, Lower Omo Valley, Ethiopia

--Manuscript Draft--

Manuscript Number:	
Article Type:	Research Article
Full Title:	Exploring the relative influence of raw materials, percussion techniques, and hominin skill levels on the diversity of the early Oldowan assemblages: Insights from the Shungura Formation, Lower Omo Valley, Ethiopia
Short Title:	influence of raw materials, percussion techniques, and hominin skill levels on the early Oldowan assemblages
Corresponding Author:	Anne Delagnes, Ph.D CNRS: Centre National de la Recherche Scientifique Pessac, FRANCE
Keywords:	Archaeology; Oldowan; Experimental studies; lithic technology; Eastern Africa
Abstract:	The eastern African Oldowan has been documented in multiple raw material contexts and physical environments and displays considerable differences in terms of technological complexity. The relative influence of percussion techniques and raw material quality are central to debates concerning hominin skill levels as a potential driver of change during the period between 2.6 and 2 Ma. The early Oldowan assemblages from the Shugura Formation play a key role in these debates due to a number of distinctive features, including the small size of the artefacts and little or poorly controlled flaking. Here we mobilize quantified and replicable experimental data in order to (a) assess the significance of the bipolar technique in the Omo archaeological assemblages and (b) discriminate the respective impact of raw materials, technical choices and knapper skill levels on the unique character of these assemblages. By combining descriptive statistics with regression tree models, our analysis demonstrates knapper skill level to be of minimal importance in this context for the production of sharp-edged flakes. The absence of a link between skill and knapping success reflects the combined effect of raw material constraints, the frequent use of the bipolar technique, and relatively simple technical objectives. Our analysis confirms the key role played by local environmental conditions in the unique appearance of the Shungura assemblages, a relationship which has been frequently suggested but never demonstrated. Beyond the operational and sensorimotor skills considered in most studies, we suggest that the diversity of early Oldowan assemblages should be better sought in the cognitive traits developed by early toolmakers as a response to landscape learning and use, two elements of early human evolution that remain largely unexplored.
Order of Authors:	Anne Delagnes, Ph.D Michel Brenet Brad Gravina Frédéric Santos
Opposed Reviewers:	
Additional Information:	
Question	Response
Financial Disclosure Enter a financial disclosure statement that describes the sources of funding for the work included in this submission. Review	This work is supported by a public grant from by the French National Research Agency - ANR-OLD N°16-CE27-0009-01 to AD, and by a grant from the Nouvelle Aquitaine Region - ECCE OMO N°2017-1R40219) to J.R. Boisserie and AD. It is part of the 'Grand Programme de Recherche' Human Past (University of Bordeaux). The funders had no role in study design, data collection and analysis, decision to publish, or

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Pessac, 20 July 2022

Anne DELAGNES
Director of Research at CNRS

PlosOne Editorial Board

Dear Editors,

We are pleased to submit an original article entitled “Exploring the relative influence of raw materials, percussion techniques, and hominin skill levels on the diversity of the early Oldowan assemblages: Insights from the Shungura Formation, Lower Omo Valley, Ethiopia” for consideration for publication to *PlosOne*. This article tackles a long-debated issue concerning the stability or “stasis” of the Oldowan techno-complex by contrast with the variable complexity by several works. Here we propose an alternative approach that differs considerably from previous empirical analyses in that we use quantitative replicable data based on descriptive statistics combined with regression tree models. The data derive from a context specific experimental assemblage and several archaeological assemblages from Member F of the Shungura Formation. The time range, ca. 2.3 Ma, is pivotal for assessing potential technological shifts in lithic production insofar as it is intermediate between the oldest early Oldowan industries from Gona and Ledi Geraru dated to ca. 2.6 Ma, and the more “classic” Oldowan industries which multiply from 2 Ma onwards.

The main interests of this paper are the (1) use of multivariate statistical analyses that remain uncommon despite their importance for addressing multi-causal relationships, (2) the confirmation of the heavy influence of both raw materials and percussion technique on the success of Oldowan knapping sequences and, more generally, the strong impact of the environmental conditions on the nature of these early lithic assemblages. This results are of significant interest for the community of scientists working on human origins - archaeologists, paleoanthropologists, paleontologists and environmentalists. All details of the statistical protocol and experimental data are available in Supplementary Information and online.

We hope our research meets the high standards of your journal and its readers.

Sincerely,

Anne Delagnes.

1 **Exploring the relative influence of raw materials,**
2 **percussion techniques, and hominin skill levels on the**
3 **diversity of the early Oldowan assemblages: Insights from**
4 **the Shungura Formation, Lower Omo Valley, Ethiopia**

5
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15

16 **Abstract**

17 The eastern African Oldowan has been documented in multiple raw material
18 contexts and physical environments and displays considerable differences in terms of
19 technological complexity. The relative influence of percussion techniques and raw material
20 quality are central to debates concerning hominin skill levels as a potential driver of change
21 during the period between 2.6 and 2 Ma. The early Oldowan assemblages from the Shugura
22 Formation play a key role in these debates due to a number of distinctive features, including
23 the small size of the artefacts and little or poorly controlled flaking. Here we mobilize
24 quantified and replicable experimental data in order to (a) assess the significance of the
25 bipolar technique in the Omo archaeological assemblages and (b) discriminate the
26 respective impact of raw materials, technical choices and knapper skill levels on the unique
27 character of these assemblages. By combining descriptive statistics with regression tree
28 models, our analysis demonstrates knapper skill level to be of minimal importance in this
29 context for the production of sharp-edged flakes. The absence of a link between skill and
30 knapping success reflects the combined effect of raw material constraints, the frequent use
31 of the bipolar technique, and relatively simple technical objectives. Our analysis confirms
32 the key role played by local environmental conditions in the unique appearance of the
33 Shungura assemblages, a relationship which has been frequently suggested but never
34 demonstrated. Beyond the operational and sensorimotor skills considered in most studies,
35 we suggest that the diversity of early Oldowan assemblages should be better sought in the

36 cognitive traits developed by early toolmakers as a response to landscape learning and use,
37 two elements of early human evolution that remain largely unexplored.

38 **Introduction**

39 The Oldowan (ca. 2.6 to 1.7 Ma) lithic assemblages of eastern Africa share a simple
40 yet effective core-flake technology for the production of what are generally unmodified
41 sharp-edged flakes [1-4]. These assemblages nevertheless display some diversity in terms
42 of complexity, the origin of which has long been the matter of debate [2, 3, 5-12]. This issue
43 is particularly relevant for the archaeological record of the Shungura Formation in the Lower
44 Omo Valley, Ethiopia (Member F, 2.32 to 2.23 Ma) [13, 14]. Its distinctive features include
45 the small size of the artefacts and little or poorly controlled flaking, resulting in high
46 proportions of angular fragments and flake fragments, with correlatively low proportions
47 of complete sharp-edged flakes [15-20]. Diverse causal mechanisms have been advanced to
48 explain the unique appearance of the Shungura assemblages, alternatively invoking
49 environmental factors, such as the small size of the quartz pebbles available in the Lower
50 Omo Valley [16-19, 21], technical choices [18], and/or knapper skill level [22, 23]. Here we
51 mobilize quantified and replicable experimental data in order to (a) assess the significance
52 of the bipolar technique in the Omo archaeological assemblages and (b) discriminate the
53 respective impact of raw materials, technical choices and knapper skill levels on the unique
54 character of these assemblages based on replicates. In order to overcome limitations
55 inherent in empirical approaches for addressing complex multi-causal issues, we assess the

56 role of each of these three factors both independently and in combination through the use
57 of descriptive statistics combined with regression trees.

58 Raw material constraints are the main factor held to explain the singularity of the
59 Shungura assemblages [16-20]. All modern knappers agree that quartz is one of the most
60 difficult to work raw material due to its tendency to fracture randomly, following multiple
61 fracture planes in three dimensions from the impact point [24, 25]. This relatively
62 uncontrollable fracturing results in high proportions of angular fragments [17] and “split”
63 flake fragments [16] in the Shungura assemblages. However, the respective impact of
64 quartz on flake fragmentation in relation to other factors remains to be established. In the
65 context of the Lower Omo Valley, the highly variable knapping quality of quartz pebbles
66 must be integrated in such a consideration. The small size of the quartz pebbles available in
67 the Lower Omo Valley, with a mean maximum length of between 3.3 and 4.2 cm (excluding
68 pebbles > 2cm) [26], accounts for the diminutive size of the assemblages, as already pointed
69 by Merrick [19].

70 The use of bipolar percussion in the Shungura assemblages was first noted by
71 Chavaillon for a core fragment from Omo 123 [15], and equally noted by de la Torre for a
72 chert core from the same site [16]. On the other hand, the predominant if not exclusive use
73 of the bipolar technique was suggested by Ludwig, based on his own experimentally-derived
74 observations and reanalysis of assemblages from Merrick’s excavations (FtJi1, FtJi2, FtJi5
75 sites) [18]. This technical choice was interpreted by the same author as the only possible
76 choice available to knappers in order to split the water-rounded quartz pebbles available in

77 the Lower Omo Valley. Bipolar flaking is strongly linked to the exploitation of quartz at a
78 number of eastern African ESA sites [27-31]. Experimental studies repeatedly highlight the
79 benefits of this technique when applied to quartz, such as facilitating core reduction [28,
80 32], reducing fragmentation [33], or efficiently producing cutting edges [28, 34, 35]. On the
81 other hand, the relative importance of bipolar percussion with regard to freehand
82 percussion has never been assessed for the Shungura assemblages.

83 Inferences regarding the degree of technical skill and dexterity of the Shungura
84 toolmakers are even more controversial. The exploitation of minuscule cores and flakes has
85 been interpreted as reflecting an advanced degree of grip precision and manual dexterity
86 [18, 36]. The Shungura flaking methods have also been described as simple but efficient and
87 readily adapted to the mediocre quality of the raw material [16, 18, 36]. On the other hand,
88 the prevailing image of an expedient technology limited to "the intensive smashing of small
89 quartz lumps and pebbles", as emphasized by Merrick [19, 20], has led several authors to
90 question the degree of elaboration of the Shungura assemblages [37]. Subsequently, it was
91 suggested that the Shungura assemblages were indistinguishable from those produced by
92 non-human primates [38]. This echoes with previous descriptions of the Shungura
93 assemblages as reflecting a "pre-Oldowan stage" characterized by poor technological skills,
94 evident in the lack of control over the basic stone knapping principles and poor
95 management of lithic resources [23, 39]. These views fueled an "ape's view" of the Oldowan
96 as a whole, with these industries seen as a stage of hominin cognitive evolution that shares
97 many of the tool-based practices with extant apes [40, 41]. Although views on the earliest

98 Oldowan assemblages have evolved significantly over the past decades [4], particularly
99 since the stunning evidence of elaborate reduction sequences recovered from Lokalalei 2c
100 [12] and Gona [6], the dominant perception of the Shungura assemblages remains that of
101 poorly elaborated industries.

102 In sum, each of the factors advanced to explain the unique character of the Shungura
103 assemblages continues to be the subject of diverging interpretations. These contrasting
104 views are deeply rooted in research paradigms and fostered by a drastic lack of solid
105 analytical data. The diminutive size of the Shungura assemblages is clearly related to the
106 small size of the available pebbles in the Lower Omo Valley, which, combined with the
107 variable quality of the pebbles, required adaptive solutions from the toolmakers. One of the
108 most common solutions is the use of bipolar percussion, extensively documented in quartz
109 assemblages around the world and from all periods of prehistory [29]. However, its role in
110 the Shungura assemblages remains to be determined. Insofar, as the impact of each of
111 these factors, raw material, technical choices and knapping skill, has not been clearly
112 established, their respective influence in accounting for the simple technical objectives of
113 the Shungura toolmakers remains impossible to accurately evaluate, a problem
114 compounded by the fact that these factors likely interacted to some extent. Here we
115 present an alternative quantitative approach based on experimental data designed to
116 identify interactions between these different factors and thus provide new insights for
117 discussing the mechanisms contributing to unique appearance of the Shungura
118 assemblages and the diversity of the Oldowan techno-complex more generally.

119

120 **Materials and methods**

121 **Knapper skill levels, raw material quality, and technical choices**

122 The question of knapper skill level is addressed based on experimental reduction
123 sequences produced by modern knappers with highly contrasting experience, in order to
124 derive more reliable interpretations. “Skill” is a generic term that encompasses a large
125 variety of distinct notions. For the present analysis, we make a distinction between (a)
126 cognitive skills, i.e. knowledge, (b) operational skills, i.e. know-how, and (c) sensorimotor
127 skills, including precision grip, striking accuracy, and control of percussive force [42-44]. We
128 focus on operational and sensorimotor skills, grouped together under the generic term of
129 “technical skill”, and exclude notions of knapper cognition which cannot be easily addressed
130 through experiments carried out by modern knappers.

131 The majority of raw materials exploited by the Shungura toolmakers are vein quartz
132 pebbles [26] that derive from sources east of the Shungura Formation, in the Precambrian
133 basement of the Hamar Range (Fig 1a). Its petrographic diversity includes quartz, quartz-
134 rich gneiss and quartz feldspar, gathered here under the generic term “quartz”. For the
135 purposes of this analysis, we focus uniquely on the knapping quality of the pebbles,
136 designated as good or medium to low. Good quality quartz pebbles correspond to
137 homogeneous, usually fine-grained quartz that permits relatively good control over the
138 detachment of flakes. Medium to low quality quartz pebbles are more often coarse-grained,

139 and/or with internal cleavage planes or inclusions that make the detachment of flakes
140 considerably more difficult to control (Fig 1b). Knapping quality of each pebble was
141 recorded before each experimental reduction sequence and, if erroneous (i.e. appearance
142 of cleavage plans, coarse rather than fine-grained matrix), was corrected at the end of the
143 experiment.

144 **Fig 1. a. Selection of archaeological quartz pebbles from FtJi5 occurrence** [17, 20]. This
145 occurrence is found in a conglomerate at the bottom of Member F and provides a unique
146 abundance of unmodified quartz pebbles in archaeological context at the Shungura
147 formation scale; **b. experimental quartz pebbles from the Lower Omo Valley.** 1 to 4:
148 medium to low quality quartz pebbles due to internal cracks (1), coarse grain structure (2
149 and 3), or heterogeneous matrix (4), 5 to 8: good quality quartz pebbles.

150 Two technical choices are considered in our analysis: free-hand and bipolar
151 knapping, two percussion techniques implying radically distinct motions and implements
152 (Fig 2). The free-hand technique involves a hand-held mobile hammerstone used to strike a
153 core held in the other hand, with platform angle $< 80^\circ$ (Fig 2a). Bipolar knapping involves a
154 mobile hammerstone and a passive stone or anvil. The core is placed on the anvil and struck
155 vertically, or with a slightly oblique blows, from an opposite platform [45] forming an angle
156 of up to 90° (Fig 2b). The counterblow on the extremity in contact with the anvil produces
157 impact damage (e.g. crushing, cracks, split fractures...), similar to those developed on the
158 opposite platform. The most diagnostic features, which are exclusive to this technique, are
159 thus cores and flakes with opposed impact scars, developed uniaxially or multifacially.

160 Diagnostic cores are rare, as in their final stage of reduction cores are most often
161 indistinguishable from angular fragments, in particular in contexts involving quartz and
162 where cores have been reduced until exhaustion. Diagnostic flakes are also rare, limited to
163 invasive flakes which have overshot the distal edge of the core. All other features described
164 from experimental studies, e.g. a cubic core shape, unidirectional removals, shattered
165 platforms, high proportions of angular fragments, etc., are not exclusive to the bipolar
166 technique and can therefore not be directly extrapolated to archaeological assemblages for
167 identifying bipolar products. Furthermore, most experimental studies show that
168 discriminating both techniques in quartz assemblages is highly challenging [46-50], and the
169 Shungura assemblages are no exception. However, assessing the relative significance of the
170 bipolar technique in the Shungura assemblages appears essential for testing its relevance
171 as a factor that might have potentially impacted knapping success.

172 **Fig 2. a. Free-hand percussion technique performed by a novice knapper; b. Bipolar**
173 **technique performed by a novice knapper.**

174 **Selected variables**

175 The Shungura lithic assemblages are the result of the reduction until exhaustion of
176 small unprepared quartz pebbles for the production of sharp-edged flakes that did not
177 require modification prior to use. Considering the simplicity of these objectives, applying a
178 wide range of morphometric or technological attributes is inappropriate. For this reason,
179 we selected three independent variables which are directly relevant for assessing the
180 success of the knapping sequence – the proportions of angular fragments per knapped

181 pebble, the proportions of sharp-edged flakes per knapped pebble, and the length of cutting
182 edges on the sharp-edged flakes. Our analysis considers three independent variables: ratio
183 of angular fragments, proportions of sharp-edged flakes and cutting edge extension as
184 measure of knapping success. Angular fragments are by-products devoid of sharp edges,
185 lack a platform, and bear no identifiable ventral or dorsal surface indicative of a controlled
186 detachment. Sharp-edged products include all flakes and broken flakes with usable sharp
187 edges, defined here as an edge angle $\leq 70^\circ$, and maximum length > 2 cm. The length of the
188 cutting edges is calculated as the ratio cutting edge length (mm) to overall circumference
189 of the piece (mm). This ratio is preferred to other values, such as length of cutting edge
190 alone [18] or flake edge (cm) / flake mass (g) [51, 52], which can be affected by external
191 variables, including raw material size or matrix.

192 **Archaeological assemblages**

193 The presence and significance of the bipolar technique is estimated in five archaeological
194 assemblages from Member F, dated to between 2.324 ± 0.020 and 2.271 ± 0.041 Ma [13, 14].
195 These assemblages, namely OMO FtJi2 – A2, OMO 123 – A13, OMO 79 - A43, OMO 79 – A82 and
196 OMO 371N – A167, were chosen because of their richness (Table 1) and good degree of integrity
197 in relation to the preservation of artefacts in primary *in situ* position. The first two assemblages
198 derive from excavations carried out in the 70s by the IORE team [15, 19, 20], completed by
199 smaller portion of the OMO 123 – A13 assemblage recovered from a test trench and surface
200 surveys as part of the OGRE team in 2008. The last three assemblages come from excavations
201 and test trenches carried out as part of the OGRE in 2018 at OMO 79 and in 2019 at OMO 371N,

202 both of which being newly documented site complexes. The diagnostic features of the bipolar
 203 percussion were established on all complete and broken flakes with intact proximal and distal
 204 edges. The significance of this technique in the archaeological assemblages was assessed by
 205 comparing the proportions of the bipolar diagnostic flakes in the archaeological and
 206 experimental assemblages. After an omnibus Fisher exact test comparing the proportions of
 207 diagnostic flakes among all assemblages, five additional Fisher exact tests were performed as a
 208 post-hoc analysis. Each of these tests includes only the experimental assemblage and one given
 209 archaeological assemblage – a process commonly referred to as ransacking [53].

210 **Table 1. Technological composition of the five archaeological assemblages from Member F**
 211 **(Shungura Formation) and experimental assemblage** (NB. “Cores” includes whole and broken
 212 cores, “Pebbles” includes whole and broken pebbles).

	FtJi2-A2		OMO 123 – A13		OMO 79 – A43		OMO 79 – A82		OMO 371N – A167		Exp.	
	N	%	N	%	N	%	N	%	N	%	N	%
Flakes	26	9,3	114	20,9	23	15,4	39	13,5	64	16,9	437	27,3
Broken Flakes	125	44,8	186	34,1	54	36,2	81	28,0	145	38,3	477	29,8
Flake fragments	62	22,2	132	24,2	48	32,2	94	32,5	105	27,8	181	11,3
Angular fragments	66	23,7	110	20,2	20	13,4	66	22,8	58	15,3	451	28,2
Cores	0	0	3	0,6	4	2,7	9	3,1	6	1,7	52	3,3
TOTAL > 1 cm	279	-	545	-	149	-	289	-	378	-	1598	-
Pebbles	8	2,9	0	0	4	2,7	0	0	3	0,6	-	-
Chips (≤1 cm)	77	21,2	423	43,7	93	37,8	29	9,1	124	24,6	-	-
TOTAL	364	-	968	-	246	-	319	-	505	-	-	-

213

214 **Experimental dataset analysis**

215 The replication of stone-tool assemblages for addressing issues related to quartz
216 and/or bipolar knapping [25, 27, 28, 34, 35, 46-50], or directly focused on the Shungura
217 assemblages [18], provide an informative empirical dataset for establishing uncausal
218 relationships between technical choices and the specific features of knapping products.
219 Multi-causal relationships are, however, much more difficult to test and require joint
220 multivariate statistics. Our approach uses context specific experimental data which are a
221 prerequisite for technological studies tightly linked to contextual data, especially when
222 dealing with raw materials such as quartz, which are highly variable between contexts. In
223 order to limit the inherent biases induced by comparative actualistic studies carried out by
224 modern stone knappers with cognitive capacities and goals that are far removed from those
225 of the Plio-Pleistocene hominins [54, 55], our experimental data was generated by knappers
226 with contrasting skills.

227 The experimental assemblage was produced during two working sessions, in the field in
228 2010 and in France (Pôle Mixte de Recherche de Campagne) in 2011. They involved four novice
229 knappers, i.e. experimenters who had never practiced stone knapping before, and one
230 experienced knapper (MB), who has routinely reproduced stone tool technologies for over
231 twenty years and masters all Early Stone Age technologies. The novices were given basic training
232 before they started, including the mechanical constraints and principles for the detachment of
233 flakes with both bipolar and free-hand techniques. Each pebble was reduced using a single
234 technique, either bipolar or free-hand, and for the sole purpose of obtaining as many sharp-
235 edged products as possible, until the core was exhausted. The raw materials were quartz pebbles

236 collected in the Lower Omo Valley (Fig 1b). A total of 37 quartz pebbles were knapped, resulting
 237 in 1598 products > 1cm, for a mean ratio of 43 products per core (min. 14, max. 86) (Table 2).
 238 The entire experimental assemblage was analyzed following the same technological and
 239 morphometric attributes as those used for the archaeological assemblages. The date file for the
 240 experimental assemblage is publicly available on Nakala (<https://doi.org/10.34847/nkl.3e292r29>).

241 The isolated influence of each of the three factors (raw material knapping quality,
 242 knapping technique, and skill level) was considered in the experimental dataset for each of the
 243 three quantitative variables described above. Since the first two variables (proportion of angular
 244 fragments, proportion of sharp-edged flakes) only make sense at the pebble-level, Wilcoxon-
 245 Mann-Whitney *U* tests were performed to assess the impact of each factor on these variables for
 246 the 37 knapping sets presented in Table 2. By contrast, the third variable (extension of the cutting
 247 edges) is relevant at the product-level, which allowed a hierarchical linear model (55) to be built
 248 for the whole sample (n = 1598), where the response variable is the ratio length/circumference,
 249 the predictor is one of the three explanatory factors, and a random intercept is defined to take
 250 into account the pebble from which each flake was produced.

251 **Table 2. Experimental data: computation of useful variables for each pebble.**

Pebble ID	Number of products	Knapping skills	Raw material quality	Technique	Prop. of angular fragments	Prop. of sharp-edged flakes	Ratio length / circum.
5	55	Expert	Med_Low	Free-hand	0.273	0.342	0.507
6	42	Expert	Good	Free-hand	0.19	0.375	0.522
7	75	Novice	Good	Free-hand	0.173	0.458	0.455
8	32	Novice	Good	Free-hand	0.219	0.542	0.49
10	28	Novice	Good	Free-hand	0.071	0.48	0.465
11	32	Novice	Good	Free-hand	0.25	0.478	0.496

Pebble ID	Number of products	Knapping skills	Raw material quality	Technique	Prop. of angular fragments	Prop. of sharp-edged flakes	Ratio length / circum.
12	61	Expert	Good	Free-hand	0.066	0.345	0.514
13	86	Novice	Good	Free-hand	0.314	0.316	0.454
14	37	Novice	Med_Low	Free-hand	0.108	0.375	0.415
16	36	Expert	Med_Low	Bipolar	0.194	0.25	0.371
17	22	Novice	Med_Low	Bipolar	0.273	0.462	0.207
18	44	Novice	Good	Bipolar	0.136	0.189	0.413
19	41	Expert	Med_Low	Bipolar	0.341	0.28	0.441
20	60	Novice	Good	Bipolar	0.117	0.327	0.37
21	77	Novice	Good	Bipolar	0.221	0.5	0.451
22	51	Expert	Med_Low	Bipolar	0.471	0.154	0.291
23	50	Novice	Good	Bipolar	0.4	0.241	0.537
24	48	Novice	Good	Bipolar	0.521	0.429	0.4
25	27	Expert	Good	Bipolar	0.296	0.222	0.484
26	26	Novice	Good	Free-hand	0.231	0.316	0.437
27	39	Novice	Good	Free-hand	0.179	0.29	0.484
28	32	Novice	Good	Free-hand	0.375	0.444	0.466
29	48	Novice	Good	Free-hand	0.5	0.136	0.372
30	46	Novice	Good	Free-hand	0.109	0.231	0.406
31	48	Novice	Med_Low	Bipolar	0.375	0.103	0.346
32	59	Novice	Good	Bipolar	0.458	0.323	0.546
33	52	Novice	Good	Bipolar	0.231	0.385	0.413
34	66	Novice	Med_Low	Bipolar	0.742	0.188	0.316
35	20	Expert	Good	Bipolar	0.15	0.562	0.555
36	33	Expert	Med_Low	Free-hand	0.424	0.222	0.406
37	39	Expert	Good	Free-hand	0.128	0.152	0.574
38	14	Expert	Good	Free-hand	0.071	0.455	0.518
40	26	Expert	Med_Low	Bipolar	0.308	0.412	0.448
41	31	Expert	Med_Low	Free-hand	0.29	0.048	0.579
42	49	Expert	Good	Free-hand	0.041	0.13	0.522
43	41	Expert	Med_Low	Free-hand	0.317	0.154	0.57
44	25	Expert	Good	Bipolar	0.56	0.091	0.221

252

253 In a second step, regression trees [56], a special kind of decision tree when the response
254 variable is quantitative, were built in order to explore the combined effects of the three
255 explanatory factors on each variable, thus allowing for the (conditional) interaction of the three

256 factors to be presented in easily readable and interpretable form. Regression trees are based on
257 an algorithm of recursive partitioning of the data and aim to model the relationship between one
258 quantitative variable and a set of predictors by defining a sequence of splits from the initial
259 dataset. Each split (i.e., each node of the tree) basically consists in a yes/no question relative to
260 one of the predictors, defined in such a way that it creates two subsets of individuals which
261 maximally differ in terms of the response variable. By iterating this process, the tree grows from
262 its initial root (i.e. the whole sample) to terminal leaves containing homogeneous subsets of
263 individuals. Regression trees can grow until they reach a given stopping criterion. Here, as the
264 regression trees were mainly used as exploratory tools, they were allowed to grow as long as
265 their nodes contained more than five cases. All statistical analyses were performed with R 4.2.1
266 package [57]. Full details concerning the R packages used, along with the whole R code used to
267 produce the results of the present study, can be found as Supporting Information (SI1).

268 **Results**

269 **Identifying the bipolar technique in the Shungura assemblages**

270 The only pattern which is exclusive to the bipolar technique is the production of
271 flakes and broken flakes with double impact points produced simultaneous during flake
272 detachment from the struck platform, and by a counterblow from the opposite edge of the
273 core placed on the anvil (Fig 3). Although far from being systematic, these traits are specific
274 to flakes obtained by bipolar percussion. When comparing their mean frequency with that
275 observed in the five main lithic assemblages of Member F in the Shungura Formation, the

276 results are strongly contrasted (Table 3). In two assemblages (OMO 371 – A167, OMO 79 -
 277 A43), the diagnostic products appear in similar or even higher proportions than those
 278 observed in the experimental bipolar series, suggesting a predominant if not exclusive use
 279 of the bipolar technique. In two other assemblages (FtJi2 – A2, OMO 123k – A13), the
 280 proportions of diagnostic flakes are significantly lower ($p < 0.001$ at Fisher exact test in both
 281 cases), which can be attributed to the predominant use of the free-hand technique, while
 282 the last series (OMO 79 – A82) has an intermediate value which may reflect a more balanced
 283 mix of both techniques.

284 **Fig 3. Archaeological and Experimental diagnostic bipolar flakes.** 1 to 7: archaeological
 285 bipolar flakes from OMO 371N – A167; 8 to 12: experimental bipolar flakes. The black
 286 triangles indicate the impact points.

287 **Table 3. Amount and proportions of bipolar diagnostic flakes in the archaeological and**
 288 **experimental assemblages.** (NB. only whole flakes and broken flakes preserving both their
 289 proximal and distal extremities are considered).

	FtJi2-A2	OMO123 - A13	OMO79- A43	OMO79- A82	OMO371N- A167	Exp.
N diag.	1	8	9	4	18	32
% diag .	0,7	1,9	11,7	3,4	8,7	8,3
N Total	151	432	77	119	207	387

290
 291 These strong contrasts in the use of the bipolar technique undermine the idea that
 292 the Shungura toomakers did not have any other technical choice to reduce the rounded

293 quartz pebbles in the Lower Omo Valley, as suggested by Ludwig [18]. Furthermore, the
294 quartz pebbles in the Shungura Formation are not highly rounded as a result of prolonged
295 water transport but are in the form of angular pebbles with abraded edges (Fig 1), which
296 can easily be flaked without an initial stage of bipolar splitting for producing suitable
297 platform angles. Nonetheless, the small size of the quartz pebbles available in the Lower
298 Omo Valley [26] might have favored the bipolar technique as it does not require a full hand
299 grip like the free-hand technique. The production of flakes with parallel lateral edges that
300 are more elongated than those produced with the free-hand technique may have also been
301 one of the advantages of the bipolar technique. By contrast, the greater loss of mass typical
302 of the bipolar technique can be seen as a disadvantage in this context of poor mineral
303 resources [19, 26]. Finally, during our experiments, novice knappers did not have any
304 particular difficulty with either technique, suggesting that skill was not a critical factor in
305 the use of the bipolar technique.

306 **Assessing the relative impact of raw material quality, knapping** 307 **techniques and knapper skills**

308 In order to assess the relative impact of raw material quality, knapping technique
309 and skill levels on the selected variables, each factor was successively explored via
310 descriptive statistics, complemented by the information provided by regression trees.

311 **Proportions of angular fragments in the experimental series**

312 The boxplots presented in Fig 4a show the proportion of angular fragments to be
313 substantially higher for the low-quality pebbles, or when using a bipolar flaking technique.
314 Wilcoxon-Mann-Whitney's U tests provide some evidence against the null hypotheses of no
315 impact of raw material quality and knapping technique on the proportion of angular fragments
316 ($p \approx 0.051$ and $p \approx 0.021$ respectively). Conversely, knapping skill appears to have no influence on
317 the proportion of angular fragments ($p \approx 0.771$). Accordingly, percussion technique appears to
318 be the most discriminating factor for the proportion of angular fragments in the regression tree
319 (Fig 4b), with the quality of the raw material playing a consistent secondary role regardless of the
320 technique used. Not surprisingly, low-quality pebbles are associated with a substantial increase
321 in the proportion of angular fragments. Combining the bipolar technique with the use of low to
322 medium-quality pebbles results in even higher rate of angular fragments (about 39%).
323 Conversely, the free-hand technique on high-quality pebbles produces the lowest proportion of
324 angular fragments, this trend being even more pronounced when performed by the experienced
325 knapper (about 10%). Expertise therefore only plays a role when combined with the other two
326 factors (free-hand technique and high-quality pebble).

Fig 4. a. Boxplots and stripcharts for the impact of each factor on the proportion of angular fragments; b. Regression tree for the proportion of angular fragments, with knapping technique, raw material quality and knapping expertise as covariates. (In each node, the upper value is the empirical proportion observed for a given combination of factors; the "%" value indicates the percentage of the total sample size in this node).

327 **Proportion of sharp-edged flakes**

328 As regards the proportion of sharp-edged flakes, the boxplots (Fig 5a) show quite similar
329 outcomes for both knapping techniques. On the other hand, slightly higher proportions can be
330 seen in the case of high-quality quartz pebbles, and among flakes produced by novice knappers.
331 However, Wilcoxon-Mann-Whitney's U tests did not provide any strong evidence against the null
332 hypotheses of no influence of these factors ($p \approx 0.095$ and $p \approx 0.075$ respectively). The
333 predominant influence of the raw material quality on the proportion of sharp-edged flakes is also
334 illustrated by the regression tree (Fig 5b), where knapper skill has an impact only when associated
335 with good quality pebbles, and novice knappers produce an unexpected slightly higher
336 proportion of sharp-edged flakes. Knapping technique, which was found to have no overall
337 influence, is absent from the regression tree, thus demonstrating this factor to have no
338 detectable influence on the proportion of sharp-edged flakes, when associated with a given raw
339 material quality or knapping expertise. This unexpected outcome in terms of knapper skill level
340 is not supported by a Wilcoxon Mann-Whitney test ($p \approx 0.31$). All statistical data point to a weak
341 impact of all three factors on the proportion of flakes with cutting edges. This likely results from
342 either insufficient sample size, in particular for the free-hand reduction sequences on low-quality
343 pebbles, or the unpredictability inherent in quartz pebbles from the Lower Omo Valley for
344 detaching sharp-edged flakes, independent of technique and knapper skill.

345 **Fig 5. a. Boxplots and stripcharts for the impact of each factor on the proportion of sharp-**
346 **edged flakes; b. Regression tree for the proportion of sharp-edged flakes, with knapping**
347 **technique, raw material quality and knapping expertise as covariates.** (In each node, the upper

348 value is the empirical proportion observed for a given combination of experimental conditions;
349 the "%" value indicates the percentage of the total sample size in this node).

350 **Extension of cutting edges**

351 The extension of cutting edges is analyzed at the product-level (Fig 6a). The free-hand
352 technique produces flakes and broken flakes with more extensive cutting edges, a trend which is
353 even more evident among flakes produced from high-quality pebbles or by expert knappers.
354 Although of a moderate magnitude, these associations are confirmed by the hierarchical linear
355 models ($p \approx 0.023$, $p \approx 0.031$ and $p \approx 0.011$ respectively; see S11 for full details). Similarly, the
356 regression tree (Fig 6b) reflects the prevailing impact of the free-hand technique on the extension
357 of cutting edges, which are slightly increased when combined with higher skill level, while for the
358 bipolar technique the best results are obtained when this technique is combined with good
359 quality quartz pebbles, regardless knapper skill level.

360 **Fig 6. a. Boxplots and stripcharts for the impact of each factor on the extension of**
361 **cutting edge; b. Regression tree for the extension of cutting edges, with knapping**
362 **technique, raw material quality and knapping expertise as covariates.** (In each node, the
363 upper value is the empirical proportion observed for a given combination of experimental
364 conditions; the "%" value indicates the percentage of the total sample size in this node.)

365 **Discussion**

366 When all variables are taken into account, knapper skill level impacts successful
367 reduction sequences only in combination with one or both of the other factors, and always
368 to a lesser degree. The combination free-hand technique / good quality pebbles / high skill

369 level is most efficient in minimizing the proportion of angular fragments, while free-hand
370 technique / high skill level is the best combination for more extensive cutting edges. The
371 unexpectedly higher ratio of sharp-edged flakes produced by the novice knappers tend to
372 confirm the non-decisive character of knapper experience when considered alone. By
373 contrast, knapping technique appears to be the most determining factor for successful
374 reduction sequences, with a marked advantage for free-hand over bipolar technique. This
375 raises questions concerning the potential advantages of the bipolar technique for the
376 Shungura toolmakers.

377 Unlike previously descriptions of the Shungura Member F assemblages as
378 technologically uniform [16, 18, 19], our analyses confirm the frequent, although highly
379 variable, use of the bipolar technique. To what extent the use of the bipolar technique
380 reflects choices and/or technical constraints cannot be precisely established in this context.
381 However, we assume that size constraints played a key role in the use of this technique,
382 following a pattern which is recurrent in all contexts and all periods of prehistory [29, 58].
383 These constraints might have outweighed the disadvantages of this technique, notably a
384 reduced efficiency for the production of cutting edges and a significant loss of mass, as
385 shown by our experimental data.

386 Given that the bipolar technique is often found in association with the free-hand
387 technique in the Shungura archaeological assemblages, and sometimes even in lower
388 proportions, the bipolar technique may have been an alternative or complement to the
389 free-hand technique. The most parsimonious explanation is that bipolar percussion was

390 used for quartz cores that were too small to be struck in the hand, either from the beginning
391 of the knapping sequence or at an advanced stage of core reduction, as evidenced in other
392 contexts [59]. Technique and raw material are two highly interdependent factors in this
393 context, with choice of percussion technique appearing as an adaptive response to the
394 nature of the raw material. This interpretation is consistent with the idea that raw material
395 would be a key factor in the diversity of the Oldowan assemblages at both inter- and intra-
396 assemblage levels [1, 19, 60, 61].

397 Raw material quality is an aspect largely neglected in studies dedicated to the
398 characterization of Oldowan raw materials, which mainly focus on raw material sourcing
399 and selectivity [62-67]. This factor deserves to be explored in greater depth, beyond the
400 simple categorization of raw material knapping qualities applied in our study. Which raw
401 material properties were best adapted to knapping objectives, to what extent raw material
402 quality was understood by Oldowan toolmakers and integrated in their procurement
403 strategies are still pending issues.

404 The prevalent role of raw material and/or technique overshadows the relative
405 impact of knapper skill level. This low visibility is due to the limited technical skills required
406 for producing sharp-edged products following a simple core-flake technology without any
407 structured method. Minimal oral instructions coupled with a very basic demonstration were
408 sufficient for the novice knappers involved in our experiments to fulfil the defined
409 objectives almost as well as the experienced knapper. It has also been stressed that not all
410 raw materials have the same potential for identifying knapper skill levels [61]. This pattern

411 challenges the most commonly used quantitative attributes for assessing early hominin
412 technical skills, e.g. size, proportions of end-products vs. waste products, fragmentation
413 rates, cutting edge extension, in their comparative potential.

414 The low potential of the Shungura assemblages for assessing knapper technical skills
415 should thus be seen as the combined effect of raw material constraints, a frequent use of
416 the bipolar technique and basic technical objectives. Therefore, direct comparisons derived
417 from technological data between the Shungura assemblages and pene-contemporaneous
418 Oldowan assemblages are unlikely to reveal distinct skill levels. This does not mean that
419 such differences did not exist, but rather that they are impossible to identify. This contrast
420 is particularly evident with Lokalalei 2c, which is only about 100 km to the south in the
421 Nachukui Formation and characterized by the controlled detachment of flakes by means of
422 a unifacial free-hand flaking method [12, 66, 68]. It remains possible, although
423 indemonstrable, that the same human groups were responsible for these very unequally
424 elaborated lithic productions. Like all other early Oldowan industries, the Shungura
425 assemblages are based on targeted knapping sequences with the goal of producing sharp-
426 edged flakes adapted to the processing soft materials. The Shungura toolmakers managed
427 to produce usable flakes despite the difficulties inherent to the quartz material. In
428 agreement with de la Torre [16], we suggest that this reflects a cognitive stage far more
429 advanced than that of any material culture known to date for non-human primates.

430 The mechanisms underlying the diversity of the early Oldowan assemblages
431 therefore appear to be more linked to the cognitive skills of the toolmakers, cognitive skills

432 which we dissociate from the technical skills considered in this study. These include a set of
433 techno-economic behaviors based on environmental knowledge, including patterns of land-
434 use, group mobility, raw material procurement and processing, problem-solving abilities
435 and tool-using activities. Such aspects have remain under-explored in the Shungura
436 Formation [26, 69] and present promising avenues for future research. The stable
437 environmental conditions prevailing during the formation of Members F and Lower G [17,
438 70], i.e. from ca. 2.3 to 2.0 Ma, present an ideal context for inter-site diachronic
439 comparisons in the Shungura Formation. Comparative analyses with younger Oldowan
440 assemblages from the Fejej Formation [71], will potentially allow regional patterns of
441 change to be explored, as both contexts share the common use of vein quartz from the
442 Hamar Range.

443 Several conclusions can be drawn from our analyses of the Shungura early Oldowan
444 archaeological and experimental assemblages.

- 445 - The combination of descriptive statistics and regression trees provides a powerful
446 tool for disentangling the relative impact of the main factors influencing the nature
447 and composition of prehistoric lithic technologies. Applied here to the question of
448 the factors involved in the diversity of the early Oldowan, this approach might be
449 highly relevant in all studies involving multi-causal relationships;
- 450 - The sensorimotor and operative skills reflected in the early Oldowan assemblages
451 from the Shungura Formation cannot be directly assessed based on standard
452 quantitative proxies, which are highly raw material and technique dependent. This,

453 of course, directly questions most implicit or explicit assumptions suggested in
454 previous works regarding the skill level of the Shungura toolmakers;
455 - Environmental constraints, i.e. poor and small-sized mineral resources, that are
456 specific to the Lower Omo Valley play a key role in the technical elaboration of the
457 Shungura assemblages. The strong impact of these environmental settings suggests
458 that patterns of diversity in hominin behavioral skills should rather be sought in
459 landscape knowledge and use.

460 **Acknowledgments**

461 This study would not have been possible without the involvement of several of our
462 Ethiopian collaborators: Wogeno Amerga, Kochito Kero, Dawit Seifu, and Daniel Kaï, who,
463 despite a few cuts to their fingers, enthusiastically participated to the experimental
464 program; we warmly thank them. Our work benefits from the unfailing support of the
465 ARCCH (Authority for Research and Conversation of the Cultural Heritage, Ministry of
466 Culture and Tourism, Ethiopia) which grants the OGRE project a research permit, and CFEE
467 (Centre Français des Etudes Ethiopiennes, Addis Abeba) which provides administrative and
468 logistical support to the project. The TGIR Huma-Num has contributed to the online
469 publication of the experimental data through the FAIR data service Nakala.

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640 **Supporting information captions**

641 SI1. R code and statistical analyses

Figure1

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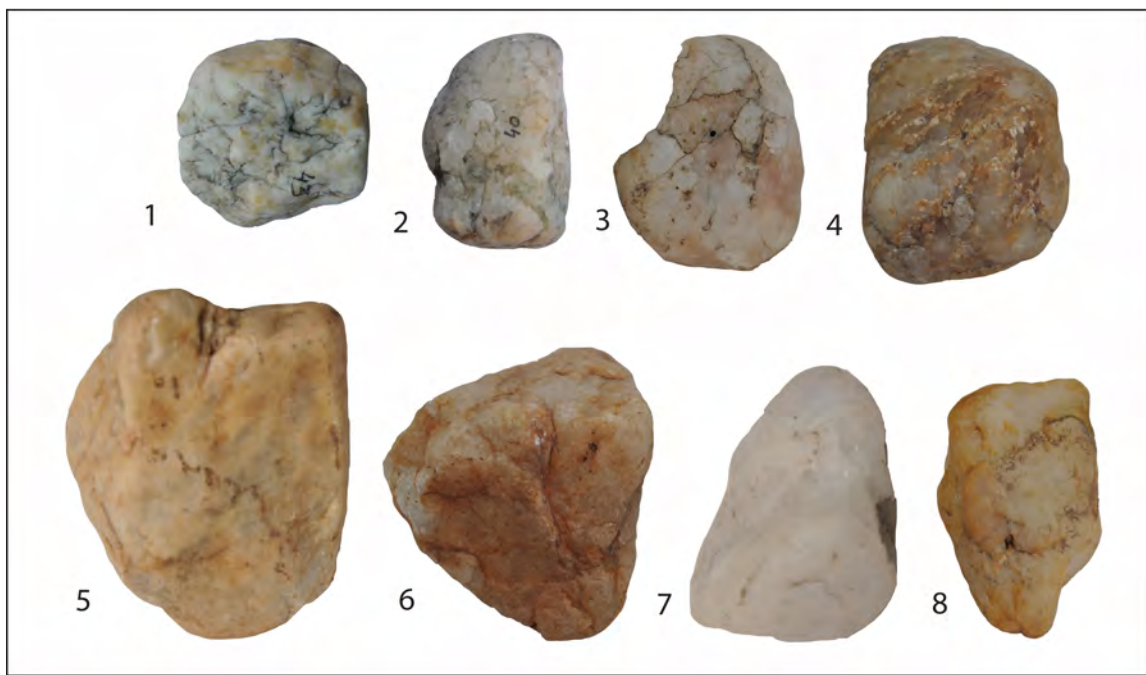


Figure2

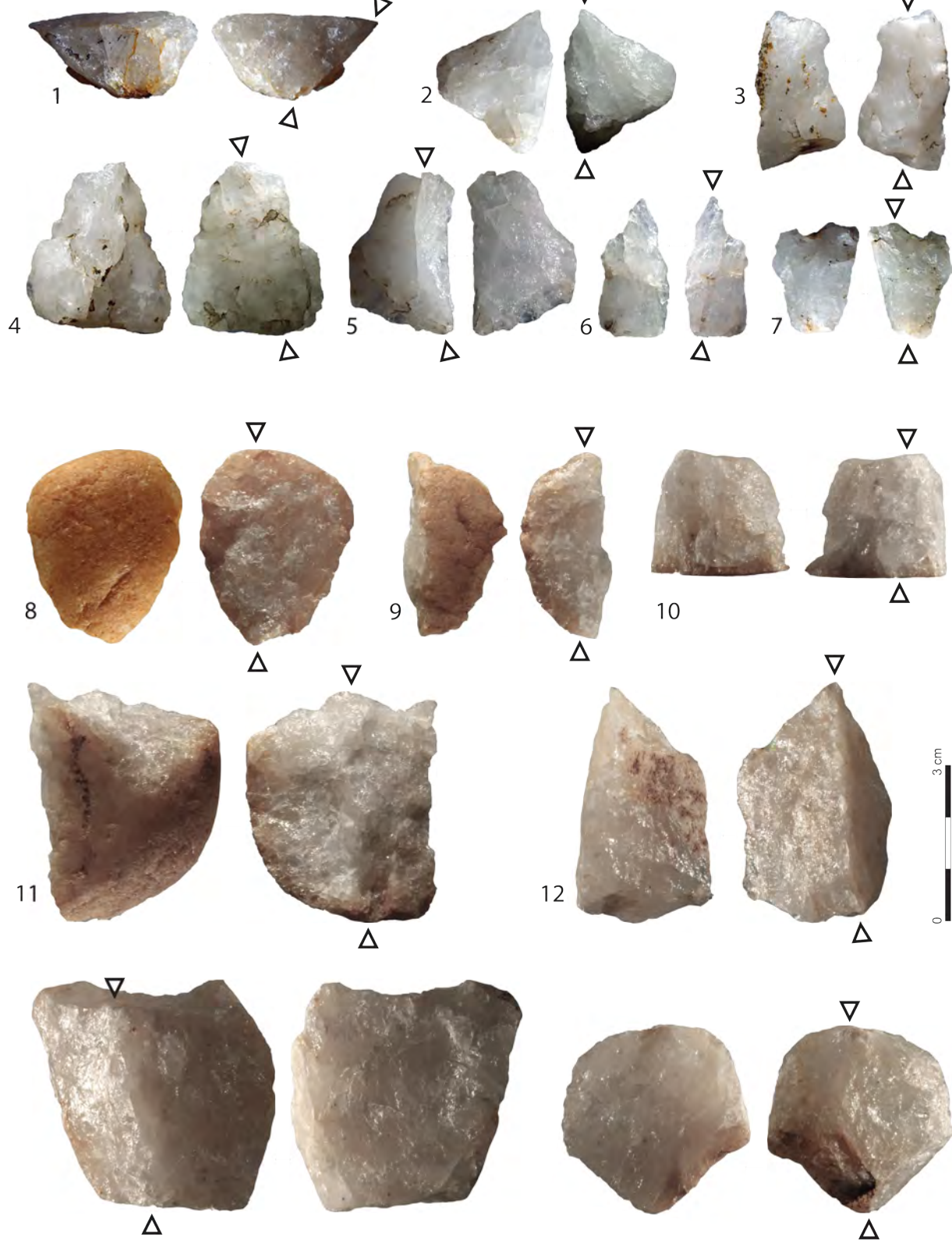
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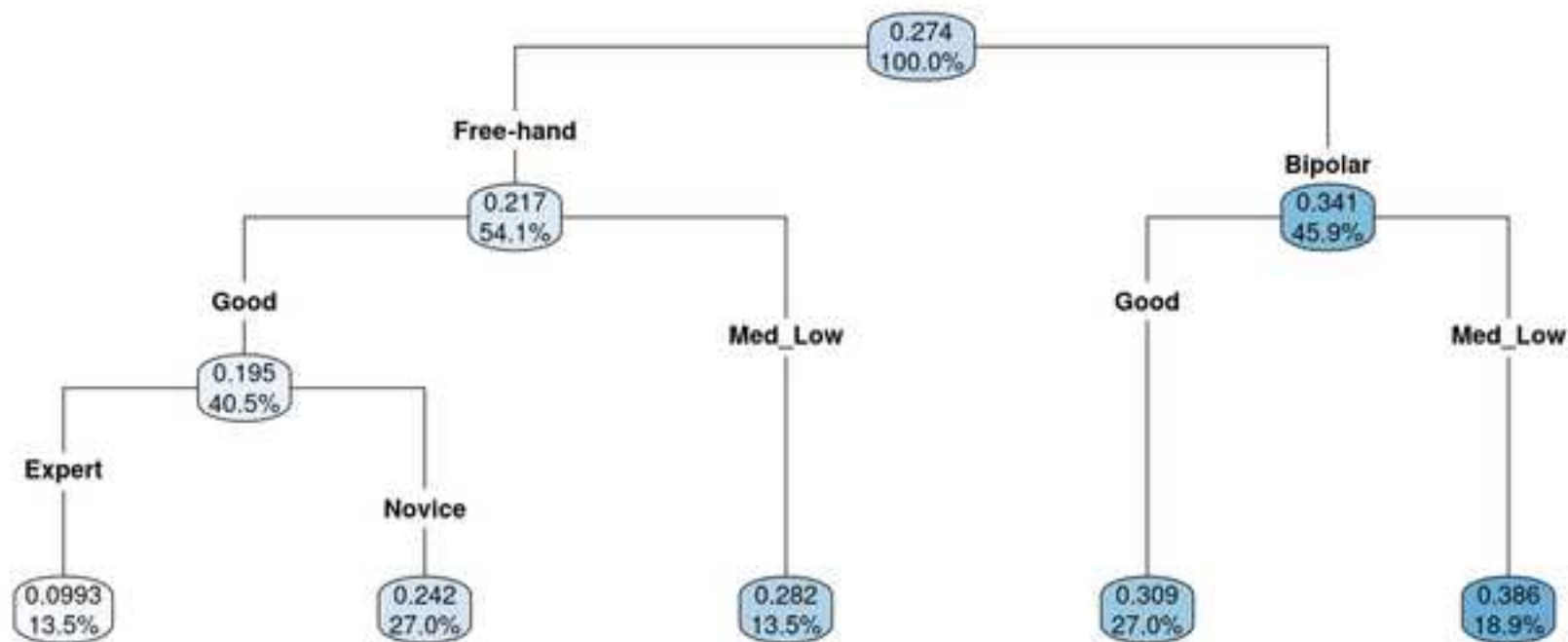
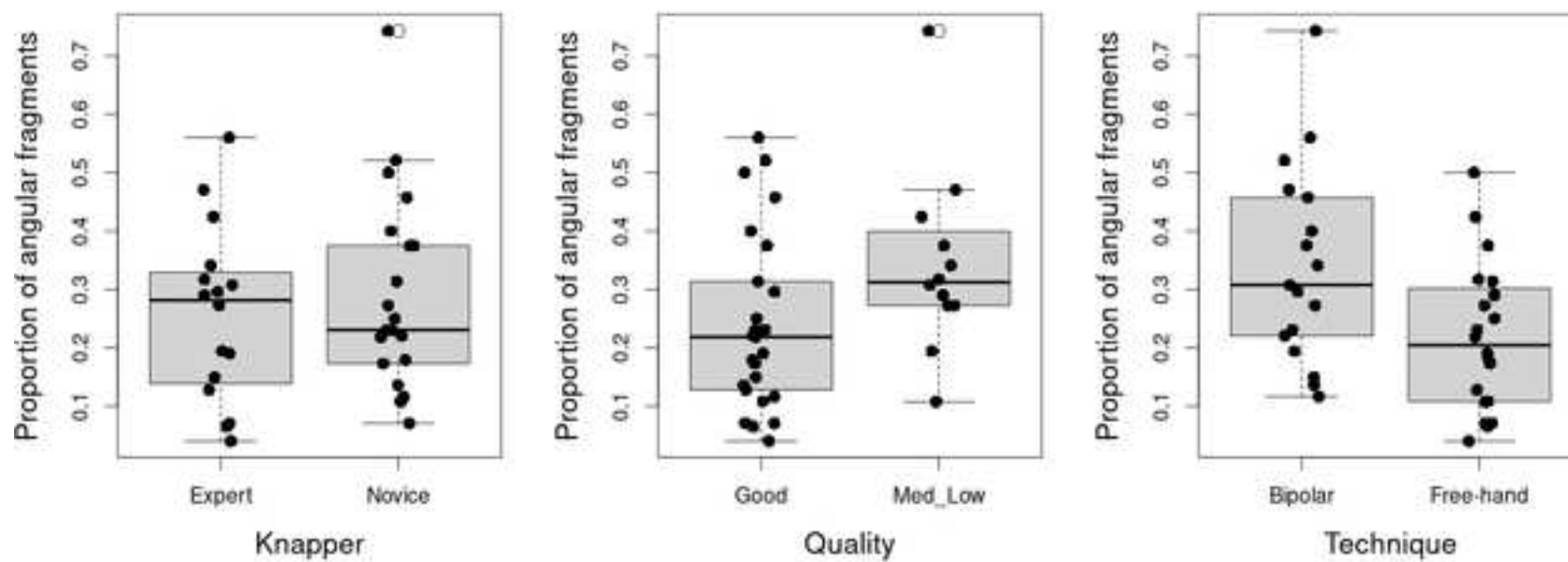


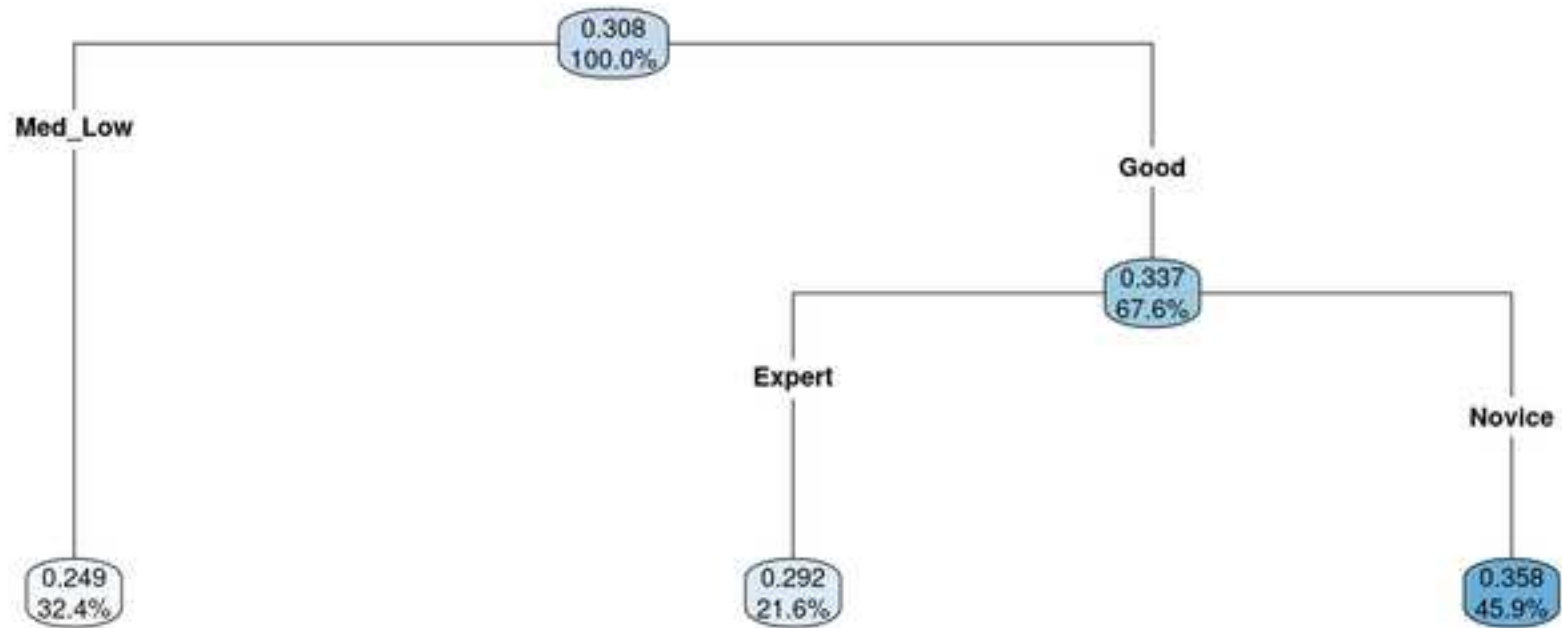
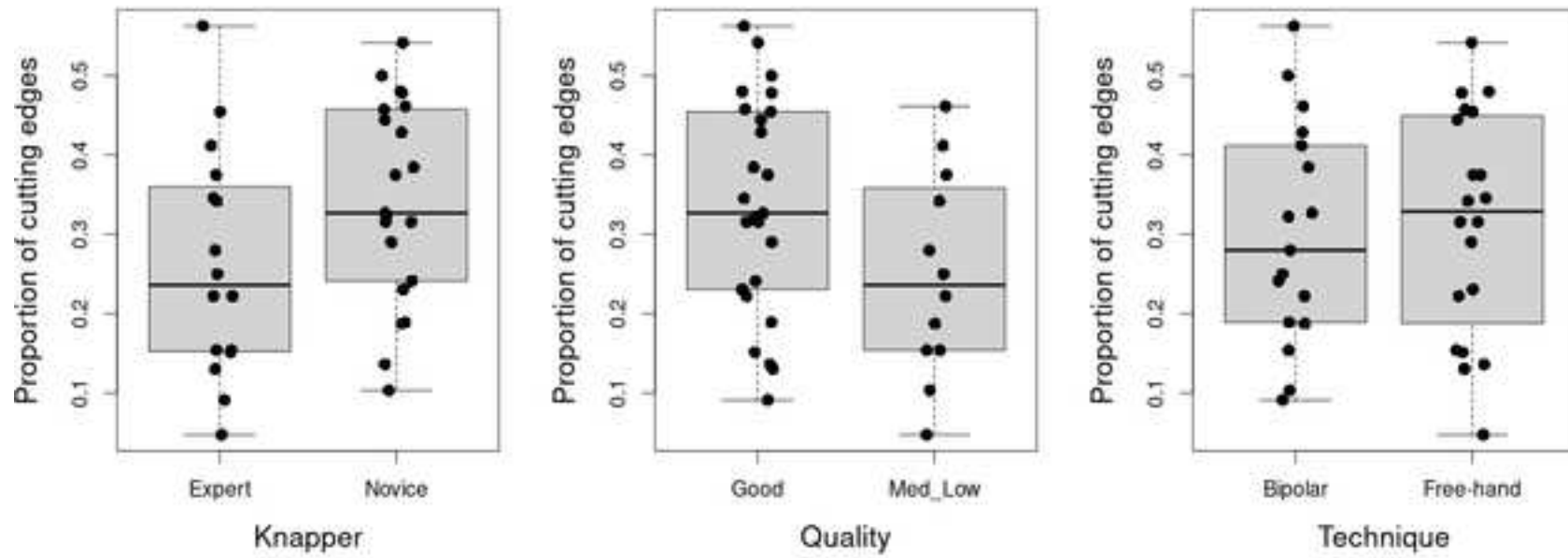
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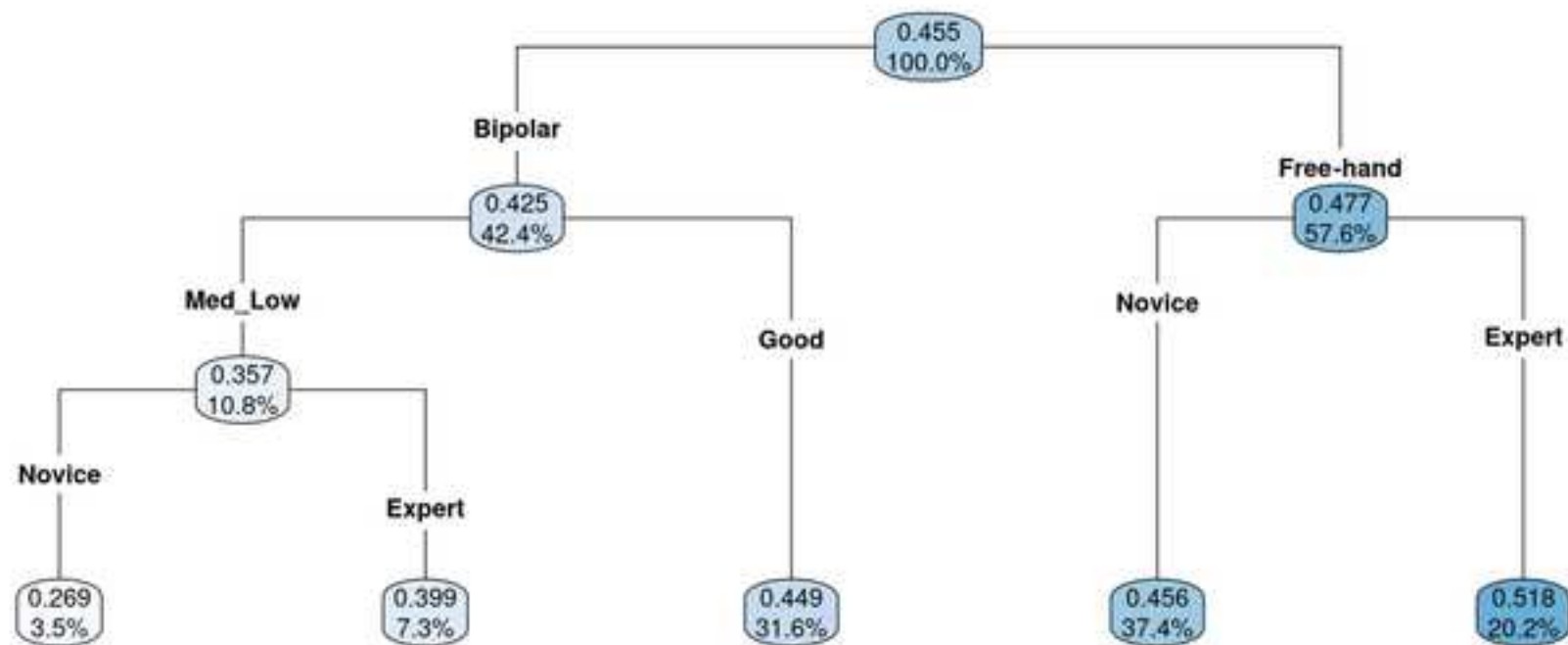
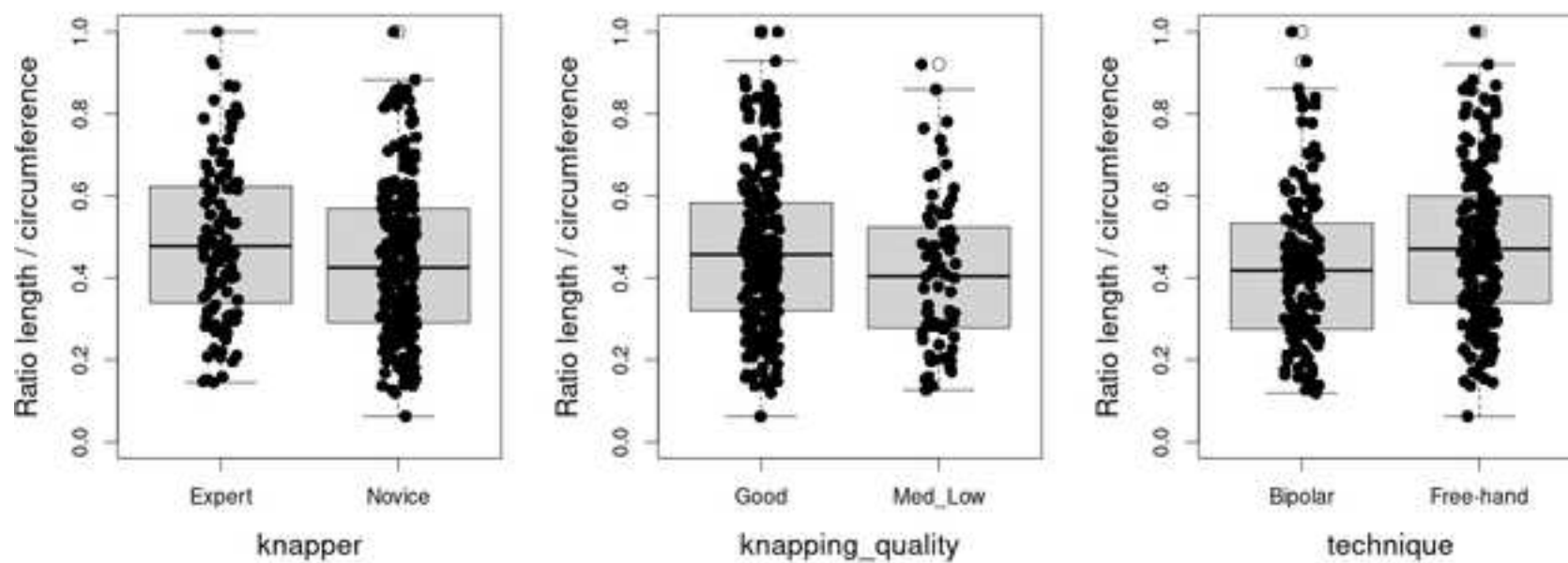


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