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# Lower Paleolithic Shaped Stone Balls—What Is Next? Some Cultural–Cognitive Questions

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**Abstract:** Shaped stone balls (SSBs) were an integral part of human culture across the Old World for nearly 2 million years. They are one of the oldest implements made and used by humans. In this significant era, which was characterised by biological and cultural transformations, these round implements were a stable hallmark throughout the Lower Paleolithic period and beyond. However, while much research progress has been made in other stone tool categories, and despite the increased research efforts in recent years, attempts to define SSB function and typology have remained inconclusive, and broader cultural and cognitive aspects related to their production techniques, use and dispersal have yet to be explored in depth. What is the significance of their continuous presence and wide geographical distribution? What do these imply regarding the cognitive abilities of Oldowan and Acheulian humans? In this paper, we turn the spotlight on these enigmatic items. We address unresolved issues and explore the ergonomic and perceptual properties stimulated by the geometry of these items. We show that stone ball variability matches (modern) human hand palm variability. Moreover, when using SSBs in percussion activities, they are handled with the entire palm. Following, we discuss the role of SSBs in the context of socio-cultural processes. We suggest that SSBs reflect some of the earliest evidence in human history of a specific form that was conceptualised and recurrently acted upon.

**Keywords:** shaped stone balls; Paleolithic; lithic technology; cognitive archaeology; haptics

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## 1. The Shaped Stone Ball Phenomenon—What Do We Know So Far?

Shaped stone balls are common in Oldowan and Acheulian sites in Africa [1–9], Asia [10–14], and Europe [15,16]; although in northwest Europe they are scarce, see [1], as well as at Middle Stone-Age African sites [17].

These are spherical items that show signs of intentional shaping via faceted intersecting negative flake scars over some or their entire surface. While these general features are common to all SSBs, these implements vary in size and regularity, as some are more rounded, angular, intensively shaped, rounded, or symmetrical than others. Some SSBs are pecked and/or battered to create a nearly smooth surface, while others have projecting ridges (Figure 1). Over the years, several typological classifications have been proposed based on these different morphologies. Clark [18] 2 defined shaped stone balls as lithic artifacts of a spherical shape achieved via the knapping of facets. Kleindienst [19] further classified them into missiles (manuports or slightly shaped implements used as projectiles), polyhedrons (facetted implements shaped by intersecting flake scars), and bolas (almost completely pecked and battered implements with a smooth surface). Leakey [20] defined polyhedrons as having an angular form displaying at least three worked edges, spheroids as items whose entire surface has been facetted or smoothed, and sub-spheroids that are less symmetrical and more angular. Sahnouni et al. [21] differentiated between polyhedrons, items flaked on at least three different faces with some relatively acute edges but a fairly obtuse average core angle, and spheroids, items heavily flaked over much or all of the exterior with very obtuse angles. Each of these categories is considered to reflect a specific technological/functional process [22].

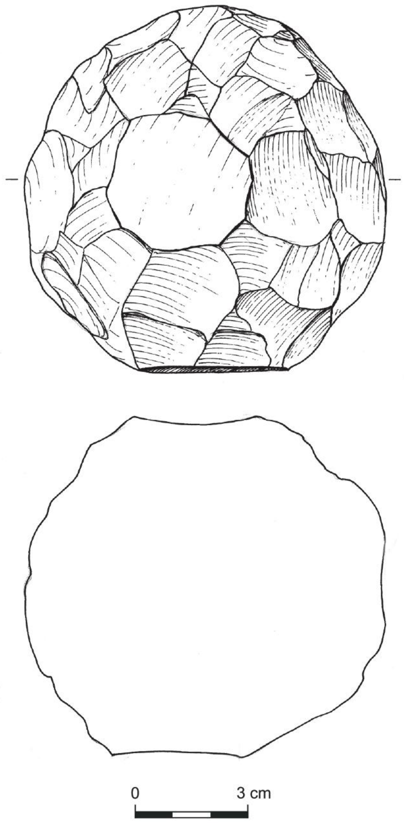


**Figure 1.** Shaped stone ball made of carbonatic rock from Qesem Cave, Israel, dated back to earlier than 300,000 BP (by Rodika Pinhas).

Some interpreted SSBs as end products of a preconceived shaping process [22,23], used as bolas or throwing stones for capturing animals [24–26] and as food-pounding tools [27], while others considered them not as predetermined tools but as by-products of specific technological or functional trajectories: exhausted cores [21,28], hammerstones [5,9,29], or battering tools for processing vegetal material or tendering meat [6].

In the Levant, a notable assemblage of 50 SSBs was found at the late LP site of Qesem Cave (dated to ca. 300 ka ago, see [10], Figure 2). In a previous techno-functional study, we showed that ten items bear traces of use and organic residues on the high, obtuse-angled ridges, which indicate bone-breaking activities (as percussive tools) for extracting fat/marrow [30].

Our experiments indicated that the spherical shape promotes some useful outline properties; it is particularly suitable for intensive percussion activities such as bone breaking or processing other hard materials, as it concentrates the force and prevents the breakage of the tool itself, while allowing a comfortable grip. The intersecting high, obtuse-angled ridges represent multiple working edges that are sharp enough to effectively and quickly break the bone without small pieces splintering and contaminating the marrow. We suggest, therefore, that the different morphologies of SSBs reflect a variable number of working areas and/or different degrees of wear resulting from varied intensities of use; the smooth outline of the spheroids/bolas, for example, is the result of their highly intensive percussive use, leading to smoothed ridges and surfaces (see [31] for further details and Figure 3).

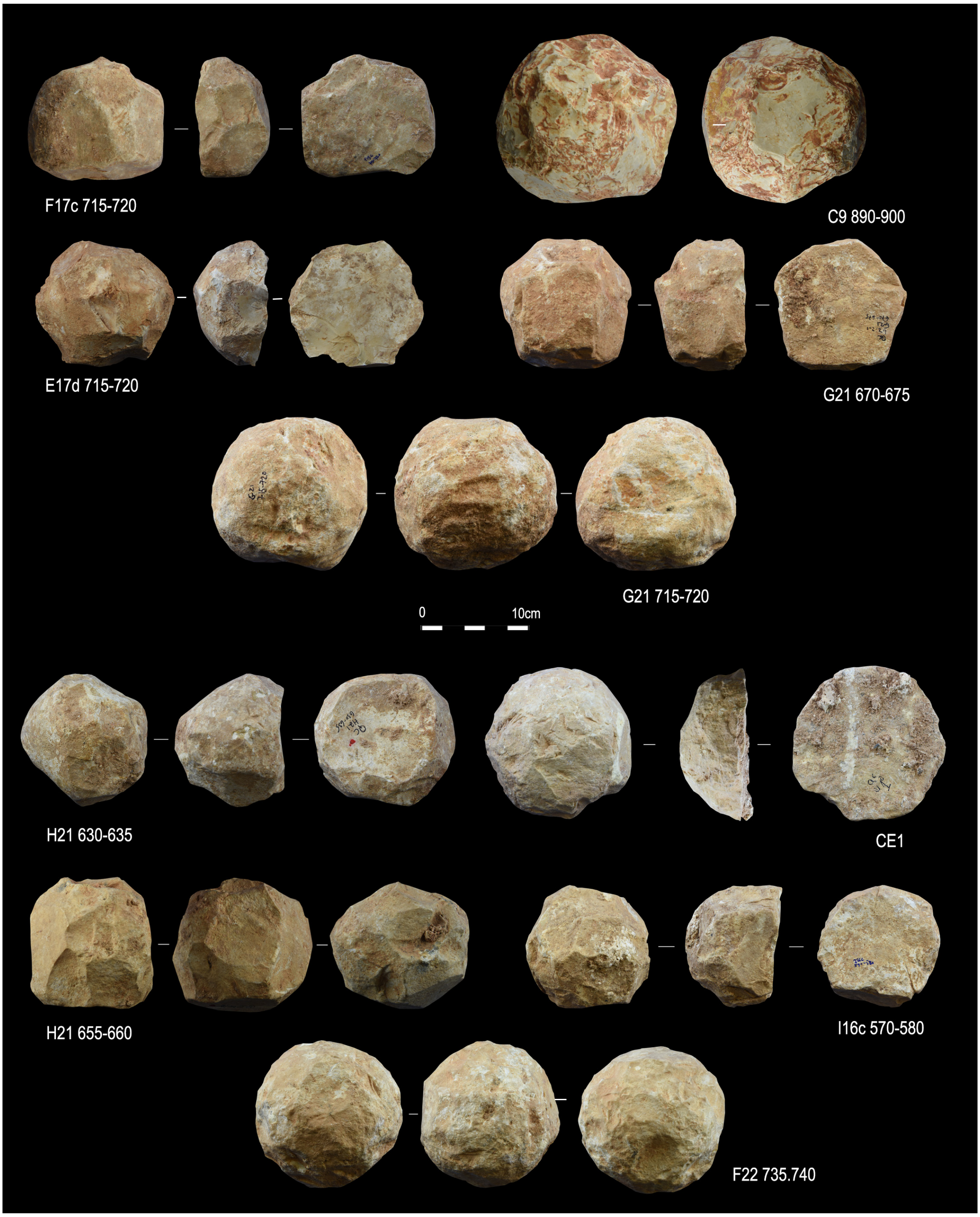


**Figure 2.** A sample of shaped stone balls from Qesem Cave, dated to earlier than 300,000 BP. As is evident, some items have smoother faces compared to others with more angular morphologies.

SSBs were usually made of carefully selected rocks. Cabanes et al. [1] noted that hard stones (with high resistance to a physical constraint) available locally were commonly selected to produce SSBs, as well as soft sedimentary rocks, whereas siliceous materials were left aside. The notable specific selection of homogeneous carbonatic rocks such as limestone and dolomite, which were conspicuously different to other lithic artifacts in the assemblages, was detected at dozens of sites worldwide, and was further investigated in a series of experiments in which stone ball replicas were shaped from different materials and used to break bones [31]. The results show that limestone/dolomite (that are softer and more elastic rocks compared to flint and quartz) is preferable for the peripheral knapping of stone balls because it allows better control of the knapping process, which prevents the balls from splitting.

**Figure 3.** An experimental SSB replica made of limestone used for bone breaking. It can be seen that while some areas are more angular, showing high ridges and detachments, other areas (showing white dots) are smoother. The smooth areas were used for bone breaking.

Cabanes et al. [1] attribute this selectivity to the possible function of these items, pointing out that raw materials of SSBs are often similar to those of heavy-duty tools in assemblages, which could provide clues about their functions for tasks requiring a resistance to shock. However, our own experiments showed no difference with regard to the efficiency of flint versus limestone SSBs as percussion tools; therefore, we attribute this selectivity to the shaping process itself. We suggest that the distinct spherical morphology of SSBs is a result of a complex knapping trajectory, which required careful planning and necessitated a high degree of knowhow and precision. Titton et al. [16] carried out a study of SSBs from the Oldowan site of Barranco León (Spain), combining diacritical and 3D geometric morphometric analysis with an evaluation of the raw material (limestone) and of percussive use-wear. The authors suggest that subspheroids are the result of a systematic management of rounded cobbles. According to their analysis, while the organisation of the removal negatives reflects the same type of management as that observed on multidirectional cores, they differ in that the last phase of reduction was aimed at creating more open facet angles, following the morphology of the initial rounded cobbles and giving the final subspheroid form. De Weyer [22] demonstrated that polyhedrons, spheroids and bolas from Ounjougou (Mali) were shaped through independent chaînes opératoires for specific tasks. Opportunistic knapping was ruled out by the author, while the evidence of shaping was highlighted by diacritic schemes showing that the flakes detached are not controlled for their usability, but for shaping the morphology of the spheroid. Our experiments further support these assumptions, indicating that these items are likely to have been desired tools rather than by-products of functional activity (as suggested by Sahnouni et al. [21].

According to our reconstruction, the shaping process of SSBs began with the selection of a suitable blank in terms of the type, morphology and quality of material, followed by the creation of a flat, right-angled surface, which would have been the main challenge for the knapper, and lastly, the creation of a symmetrical, spherical morphology. In this process, specific technical and technological procedures were applied sequentially. These appear separately in other knapping processes but altogether, they are endemic to SSB production. In addition, it seems that some of these items underwent several "life cycles," indicating a very long history of use, and that their production process was not always continuous. In Ubeidiya (layer I-15, personal observation) and Qesem Cave (see Assaf et al. [30] and personal observation), for example, few SSBs show phases of the re-shaping of (sometimes patinated) surfaces reflecting various knapping stages and a possible time gap between them.

## 2. Interpretations and Unresolved Issues

What are the insights obtained from the studies carried out so far? Technology-wise, we suggest that this is some of the earliest evidence in human history of a specific form that was conceptualised and recurrently acted upon. For this kind of operational complexity, long-term planning, decision making, control, and precise intentionality are needed [32,33]. In our view, imposing form through multi-stage, multi-directional techniques at such an early stage of human history set the stage for the development of later technologies. Furthermore, the peculiar (and regular) geometry of stone balls necessarily stimulates a debate on its ergonomic and perceptual properties.

### *2.1. Stone Balls, Haptics, and Technological Extension*

Humans were occasional tool users probably before 2 million years ago, then became habitual tool users after 1.7 my, and finally became obligatory toolusers in the last 300,000 years [34]. This suggests an increasing "prosthetic capacity", in which tools are progressively integrated into the body structure and into the neural schemes of the body [35]. In archaeology and evolutionary anthropology, tooluse and toolmaking have been the main topic of technological evolution, in this sense. Nonetheless, before *using* and *making*, we should consider possible changes in the process of *sensing*, which is the very foundation of body–tool structural and functional integration [36]. Sensing and perceptual integration are the processes through which the body, as the interface, assimilates the tool into the cognitive system. In this context, haptics is of crucial importance, intended as the ability of the body to sense and perceive spatial, gravitational, and material properties of external elements, involving both proprioceptive and exteroceptive feedbacks [37,38]. Tactile feedback is, in this sense, a crucial element to remap the sensorimotor process into spatial and chronological frames [39], and it is based on a comprehensive integration between action and perception, in which somatosensorial and motor adjustments are mutually dependent [40]. During tool sensing and integration, the whole body is used to achieve a new dynamic balance that is able to include the tool within the structural architecture of the subject [41]. This process is further improved through the additional contribution of visual elements [42].

Of course, it can be hard to import all these concepts into archaeology and paleontology, because of the general lack of information associated with fossil species or extinct populations. In general, most studies in human evolution and ergonomics have dealt with the anatomical evolution of the human hand [43,44]. Biomechanics can indeed provide some interesting clues to the structural relationships between hand features and stone tool properties [45]. Nonetheless, there are limitations in these approaches, and there are still many disagreements on the evolutionary changes associated with the evolution of the manipulative abilities in the human lineage [46–48]. In fact, the gross hand anatomy can supply poor and incomplete information on hand functions, the fossil record is largely fragmented, and the evolution of the hand has probably experienced mosaic, parallel and independent phylogenetic diversification [49]. Indeed, because of these limitations, the most we can do is integrate anatomical and behavioural differences in order to provide speculative but reasonable hypotheses on the evolution of the body–tool perceptual and cognitive system [50,51].

With these caveats in mind, we can consider what kind of perceptual or structural features can be associated with the special shape of the stone balls, namely with tools that tend towardsa spherical geometry. On the one hand, we can consider the effects and factors associated with their regular geometry, providing a gross comparison with choppers and handaxes. This comparison is relevant because all these kinds of tool share an important feature: they are handled (and sensed) with the whole hand. It is likely that most Lower Paleolithic tools were handled with the whole hand while, after technological specialisation and increased complexity (especially during and after the Middle Paleolithic), most tools were sensed with the fingers and then with the fingertips, a perceptual change that was probably associated with consistent cognitive differences [52,53]. It is worth noting that the variation in stone ball proportions seems to occur in accordance with the same rule of variation in the (modern) human palm. A preliminary survey on the relationships between stone ball size and palm size shows that if we plot the length and width variation in the adult palm [52] and in a sample of stone balls [30], we can see that the two proportions display the same allometric pattern (Figure 4). That is, stone ball variability matches human hand palm variability (at least when considering modern humans). Results of a recent experimental study further support this distinction; in the framework of this experiment, six individuals between the ages of 25 and 60 broke 10 limb bones of cows and pigs for ten minutes using different replicas of SSBs. Two women and four men participated; two had experience in bone-breaking activities, while four had no experience. In the experiment it was shown that when using SSBs in percussion activities, they are handled by all the participants with the entire palm (personal observation). Conversely, when a hammerstone is held in knapping, it is held with the fingers and not in direct contact with the palm. This pattern suggests the possible existence of a structural correspondence, which underlines that, when investigating human technological evolution, we should consider the hand–tool system as the functional and structural unit, instead of analysing the two parts separately [54].

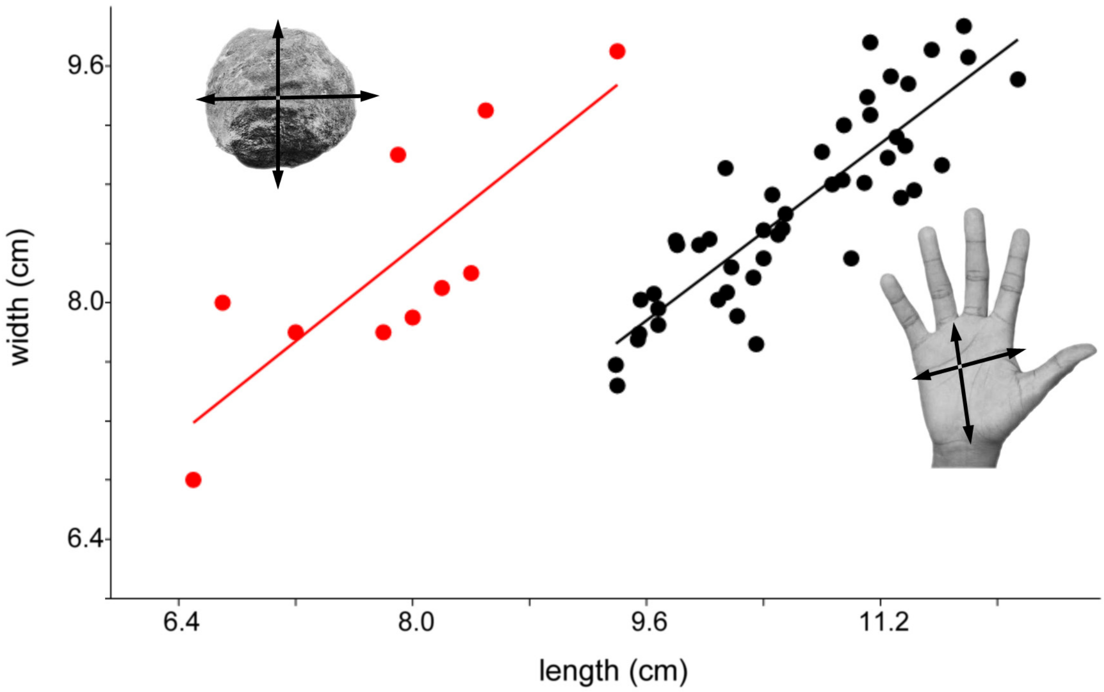


**Figure 4.** Hand palm (black dots) and stone ball (red dots) length and width. A preliminary analysis of covariance supports differences in the intercept ($p < 0.0001$) but not in the slope ($p = 0.80$). Namely, despite their differences in size, the modern human palm and the stone balls do vary with the same pattern of proportions. In particular, stone balls are shorter than the human palm, but display a similar range of width. Data from [30,52].

When comparing choppers with handaxes in terms of shape, we can see that the main pattern polarising their morphological variability is the degree of elongation, while the second factor involved is the longitudinal position of the maximum thickness [53]. The first factor (elongation) separated the two tool typologies (although with a certain degree of overlap), while the second source of variation (the longitudinal position of the maximum thickness) is shared by both types of tools [55]. If we plot a perfect sphere into this shape space, we can see that it is projected right in the middle of the chopper distribution (Figure 5). Therefore, at least for these two main geometric features, stone balls were probably intended as a special case of choppers, at least according to their gross spatial properties. It is worth noting that according to our experimental study, these two tool types are also held in a similar way—in direct contact with the palm—and the thumb is not in line with and close to the other fingers but instead a few centimetres away from them, so as to increase the grasping aperture. This pattern may have implications regarding the distribution of these two tool types in LP sites, although in some sites they coexist (e.g., Revadim, Evron, see [56,57], while in others (e.g., Qesem Cave, Jaljulia, see [58,59]) they do not.

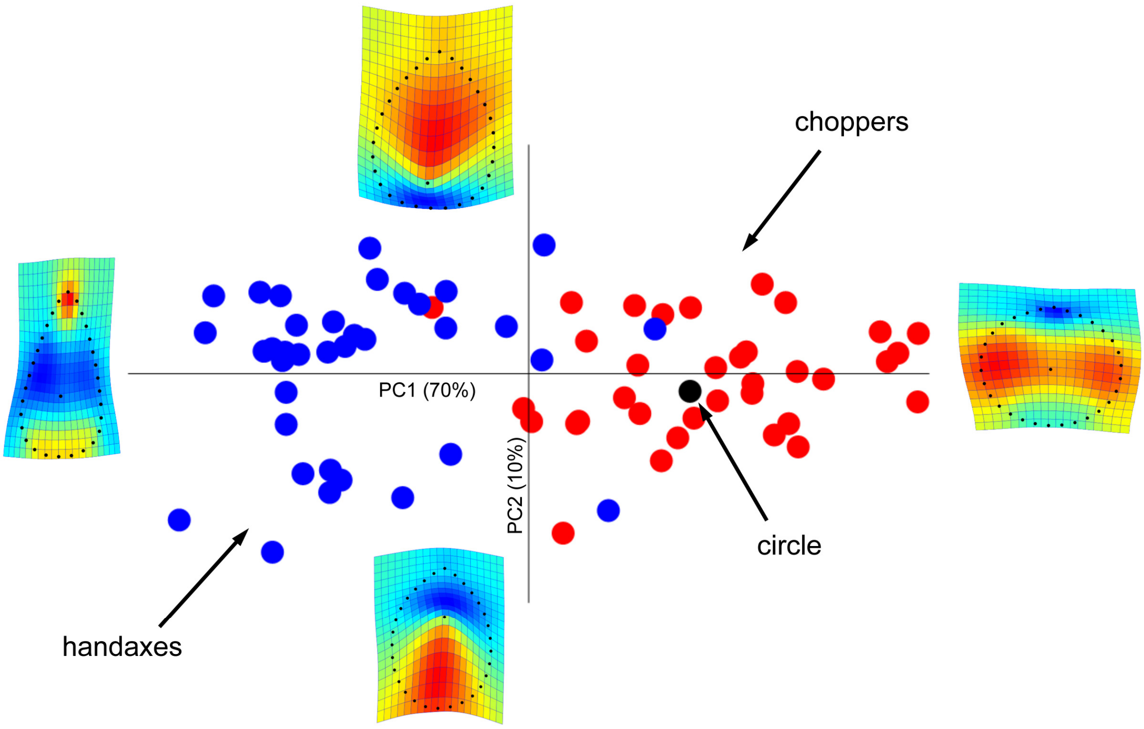


**Figure 5.** A principal component analysis of the chopper (red dots) and handaxe (blue dots) shape (including the outline and the position of the maximum thickness) showing that the first axis of variation is due to elongation, while the second is due to the longitudinal position of the maximum thickness. A perfect sphere (black dot), in this case, lies in the centre of the choppers' range. Data from [55].

In sum, when dealing with the evolutionary meaning of stone balls, we should also take into consideration their features in terms of affordance (*sensu* Gibson, 1979 [60]) and perceptual properties. This means that, apart from their implications as tools to be made and to be used, we should also consider their special perceptual aspects, associated with body–tool integration at the somatic and visual level. If they are a "special case" of chopper-like tools in terms of geometry, we can probably apply to their physical and perceptual interpretation most of the conclusions considered valid for Oldowan technology. Instead, if their spherical regularity adds to the perceptual feedback, we should consider the possibility of additional embodied aspects. Regularity (including symmetry, ergonomic intentional design, or even symbolism) is, indeed, a concept that has been often proposed to be associated with some kind of cognitive complexity. However, regular designs in nature are often due to spontaneous (unintentional) spatial adjustments that follow basic geometrical rules, and the existence of regular forms should hence not be interpreted, *per se*, as the result of a conscious or abstract process. However, at the same time, the distinctive morphology of this implement, i.e., the spherical shape with the high, obtuse-angled ridges, which were a useful outline for bone-breaking activities, and therefore may have been conceptualised with purposeful intent, was preserved and passed down over hundreds of thousands of years. Indeed, as discussed below, the outstanding geographical and chronological distribution of stone balls merits attention and deserves further inquiries into their possible structural and functional role in the scenario of human technological extension.

### *2.2. SSBs and Socio-Cultural Processes*

As SSBs display recurring and recognizable common features that represent a universal phenomenon (e.g., the selectivity in rock type, the round morphology, and the intersecting negatives and ridges), should we regard them as cultural products (as suggested for the handaxe, see Wynn and Gowlett [61]), or as genetic products (as suggested by Corbey et al. [62]). Corbey et al. propose that LP handaxe production would have involved both genetic transmission and social learning. Some aspects, such as raw material selection, the manufacturing process, and basic design principles would have been under genetic control, while the fine-tuning phase involved social learning—mainly with specific role models rather than as a direct transmission within a group [62].

Wynn and Gowlett [61] argue that sequential tasks such as knapping stone tools practiced by Lower Paleolithic humans relied on a complex neural network that evolved for object manipulation, incorporating portions of the frontal, parietal and temporal lobes (as observed in modern stone knappers, see Hecht et al. [63]). For handaxe shaping, the working memory mechanism also played an important role, as suggested by Stout et al. [64]. According to this approach, the knapping process was an ergonomically guided procedure derived by cognitive features, for which the neural resources of the human object-manipulation network were self-sufficient. While it could have developed again and again over the course of the Stone Age, the Acheulian record appears to reflect a continuing tradition in many ways, as suggested by Wynn, Gowlett and others [65]. Moreover, it has been argued that Lower Paleolithic humans were capable of transmitting the necessary knowledge from generation to generation [58,66–68] (, which was evident even earlier at Oldowan sites [69,70].

How do SSBs fit into the overall Lower Paleolithic picture? The dispersion of SSBs can reflect processes of social learning and cultural transmission or, alternatively, processes of convergent evolution. Among humans, learning and sharing are enhanced [71], leading to the accumulation of information and the development of tools, beliefs, and practices that enable adaptation to new environments and habitats [72]. As part of this process, innovations are gradually assimilated into a population's knowledge base through mechanisms of social learning—a phenomenon known as 'cumulative culture' [73]. Some aspects of it require a highly accurate transmission of knowledge [74,75], and the question arises as to when, why, and how high-fidelity learning mechanisms arose in prehistoric times. As mentioned, some scholars view the Lower Paleolithic period as a turning point in the evolution of social learning and knowledge transmission mechanisms [76]. While some suggest [71] that technological behaviours of the LP constitute low-precision solutions in response to a trigger associated with a specific social or external change, others suggest that early Paleolithic technologies were learned via detailed copy [77,78].

Based on the current data available, we link the development of SSBs with an increased consumption and extraction of fat of large-medium sized herbivores in the Lower Paleolithic period. Indeed, SSBs may also have been used as percussion tools for processing vegetal material, perhaps similarly to handaxes, which were primarily used for butchering (i.e., [79,80]), but were occasionally used for woodworking [81]. However, current functional and experimental data associate these items with marrow extraction activities, as well as some contextual data linking these items with faunal remains [17,82]. We thus argue that these are designated tools shaped in a complex procedure—a technological solution invented during the LP in order to respond to the growing need for fat consumption [83,84]. They were gradually assimilated into the LP population's knowledge base during the Acheulian, enriching their repertoire through mechanisms of social learning. Given the technological complexity and sequential nature of the shaping process of this implement, we raise the possibility that the knowledge about it was preserved and passed down from generation to generation, and formed the basis for the development of later technologies.

## 3. What Is Next for the Study of Shaped Stone Balls?

After decades of studying SSBs, fundamental enigmas still remain. The next step, we suggest, requires a multidisciplinary approach to better understand the circumstances behind the production and long-term use of SSBs, and their eventual replacement by other technologies and stone implements. A type of research that would integrate fields representing a meeting point will take us a step forward and provide a significant evolutionary perspective [85].

Such research can include 'traditional' archeological analysis, with an emphasis on techno-morpho-functional analysis, in order to deepen our understanding of the shaping process and use of SSBs worldwide, while examining aspects of cultural transmission, technological persistency, and tradition versus change. Experimental archaeology is an important part of the picture. Experimental procedure can contribute to the recognition of specific techniques of SSB production as well as the identification of particular techno-types in the assemblages. These will allow us to identify similarities in shaping strategies and detect their presence even if the SSBs themselves are absent from the assemblage. It will form the basis for a general discussion on cognition and spheroid geometry, and ergonomic and perceptual properties, while referring to haptics and aspects of technological extension. Finally, cultural evolution mathematical models will allow us to estimate the rate of dispersal and routing of SSBs throughout the Old World while discussing social learning mechanisms possibly involved in the process.

Hopefully, future in-depth integrative studies will contribute to a deeper understanding of this enigmatic tool type and the cognitive abilities of the ancient humans who used it throughout the Lower Paleolithic period and beyond. While exploring extinct species necessarily involves many limitations [85], these multidisciplinary studies are expected to provide a detailed reconstruction of behaviours related to the application of early stone tool technologies and their broader cultural and evolutionary implications reflected in one of the oldest stone tools made and used by humans.

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