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7 The archaeology of number concept and its implications for the evolution of language

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7.1 Introduction

Given that language per se was not itself a component of pre-historic material culture, archaeologists are limited to indirect assaults on the question of language evolution. We can document specific components of language that do have material instantiation, such as symbolism (Davidson and Noble 1989; Noble and Davidson 1996; Henshilwood and Dubreuil 2009), activities that clearly required language (though this is harder than it might appear, e.g. Ambrose 2001), or cognitive abilities related to language in some way (e.g. working memory capacity, Wynn and Coolidge 2010). None of these methods, taken alone, has provided an iron-clad argument for the presence of language at any point in prehistoric time. However, taken together such indirect approaches can provide strong circumstantial evidence. In this chapter we aim to add to this circumstantial evidence by documenting the evolution of number concept, via the ability to conceive of and use other representations of quantity.

7.2 Tally boards

Our choice of number concept as a side door into language was motivated initially by a curious set of artefacts found in late Palaeolithic sites in Western Europe—the so-called tally sticks or tally boards. The best examples, such as the Tāi plaque (Fig. 7.1) and the Tossal de la Roca plaque (Fig. 7.2), date back about 12,000–14,000 years, but earlier examples such as the Tartet plaque (Fig. 7.3) may be as old as 28,000 years.

FIG. 7.1. Engraved bone plaque from Grotte du Taï (after Marshack 1991).

FIG. 7.2. Engraved bone plaque from Tossal de la Roca (after d'Errico and Cacho 1994).

These plaques are flat pieces of bone engraved with a series of lines, slashes, and dots. Forty years ago Alexander Marshack examined many of them under a microscope and concluded that they were lunar calendars (Marshack 1972, 1985, 1991). Some of the marks were crescent-like, but

FIG. 7.3. Engraved bone plaque from Grotte Lartet (after Coolidge and Wynn 2009).

more tellingly for Marshack, the marks appeared to group into sets of 27 and 28. More recently, Francesco d'Errico (d'Errico and Cacho 1994; d'Errico 1995, 2001; d'Errico et al. 2003) has re-examined most of the extant examples and confirmed a key feature: the marks on an individual plaque were often produced by different tools at different times; thus, they were not decorative or doodles. D'Errico has been more cautious than Marshack and concludes that the plaques kept track of something, acting as a kind of external memory device. It is this 'keeping track of something' that is so provocative, more so even than external memory, because it implies a use of counting and number.

7.3 Number concept

Modern number concept is a cultural construct built on a foundation of innate cognitive abilities. The recent history of number concept is fairly well known—development of irrational numbers (for example, the square root of negative one), the concept of zero, and so on. These developments have had a profound impact on human reasoning ability, but they are cultural algorithms. Also, they are far from universal; indeed, very few humans attain a comfortable ability to think with irrational numbers, and many educated adults struggle with rational numbers such as decimals and fractions. Even such a seemingly simple idea as the positive integers is a cultural construct not shared by all modern cultures. Many non-industrial peoples have been reported to have only a few count words—one, two, three, many—including the notorious Pirahã (Hurford 1987; Carey 2009). It would seem, then, that number concept is a cultural development that arose with complex societies with little relevance for the evolution of cognition or language. Such a conclusion is too hasty. Even an integer concept is built upon certain cognitive understandings that are hard-wired into the human brain. The primary evidence for them comes from research on human infants and on non-human primates.

7.4 Core numerosity

A basic integer (or counting) concept is deceptively simple: $1 + 1 = 2$; $2 + 1 = 3$; $3 + 1 = 4 \dots n + 1 = x$. A lot goes into this, in a cognitive sense. The primary concept behind integers and counting is cardinality, the notion that a specific label identifies a countable number that is one more than the previous number in the count. This is a cultural construct, as are the labels for the values. Cardinality is not a human universal; as mentioned in section 7.3, there are examples of cultures whose ‘counting’ consists only of ‘one, two, and many’ (Menninger 1992). However, cardinality is based on other concepts, some of which are universal and innate:

- 1) Subitization—This is the ability to contrast the number of elements in small sets or arrays: +++ vs. ++, for example. We can do this automatically without any intervening symbols of number quantity. It applies to sets of at most three or four. We cannot contrast a set of ten things to a set of eleven things without counting.

- 2) Analogue magnitude—We can also compare larger sets to one another and determine which is bigger. The larger the difference, the easier the judgement. The term ‘analogue’ means that this number assessment is really a size judgment.
- 3) One-to-one correspondence—This is the ability to match individual items in one set or array to individual items in a second set or array (Menninger 1992). One can do this without labelling the matches, and thus it is simpler than counting.
- 4) Ordinality—This is a principle of stable order or sequence with ranking. One can order items according to size, or indeed any criterion (e.g. darker vs. lighter) as long as it is stable.
- 5) Labelling—Cardinality relies on the ability to label values. A label allows a number to be taken out of its ordinal sequence (or one-to-one scheme) or small set without losing its value.

Are all of these abilities innate in some way, or are some also cultural constructs? This is the key evolutionary question, and a question that may also bear on the evolution of language. There are several methods of investigation one could apply in trying to answer this question. One of the best is via child development. Over the last thirty years, child psychologists have developed an array of clever techniques for assessing what infants, even recent neonates, expect about quantities of objects. In effect, the technique measures an infant’s surprise at viewing an ‘impossible’ event, as when an item that should exist behind a screen disappears.

Research on infants and children clearly documents that humans come endowed with an innate subitizing ability and an innate ability to judge analogue magnitude. They can discriminate between small sets of items (two vs. three, for example) and discriminate between large sets based on relative numerical size. This should perhaps not be a surprise, as comparative research has established that non-human primates and many other animals also have these abilities. So how does a young child develop counting and a number concept from this innate numerosity? This is where it gets interesting from the perspective of language evolution. In cultures that use a number concept, young children acquire the understanding by using a memorized numeral list as a scaffold (Carey 2009). They first learn the counting words without understanding what an integer is. Then they learn that small sets of one, two, and three (sometimes even four) follow the $n+1$ rule, an interim understanding that many

children operate with for over a year. Finally, they generalize to all positive integers; that is, a natural number concept. Two cognitive abilities clearly help this process—one-to-one correspondence and ordinality. The child matches an item to a numeral word and learns (through the list) that numerals follow an invariant sequence: ordinality. This one-to-one correspondence and ordinality initially organizes real-world items. It is when the child generalizes to all possible situations that he or she achieves true abstract number concept. This generalization appears to occur when the child merges one-to-one correspondence and ordinality with his or her ability to judge analogue magnitude. What is provocative from a language evolution perspective is that the child's acquisition of number concept leans heavily on a language scaffold, something Hurford realized twenty-five years ago (Hurford 1987). From Carey's perspective, the key is the memorized set of words that is the numeral list. It acts as a set of symbolic placeholders as the child constructs the number concept. But what if there is no numeral list and no counting words? How did a numeral list develop in the first place? How can one bootstrap without bootstraps? If we can document the presence of a number concept in deep prehistory, is this evidence for language via the requirement for a numeral list?

7.5 Evolving a number concept

On reflection, it would seem impossible that a list of integer labels could have somehow evolved prior to an integer concept. Thus, even if modern children do use the numeral list as a scaffold on which to build an integer concept, the evolutionary development must have been different. Here we must turn to the ethnographic and archaeological records, because an integer concept was almost certainly in place in some cultures prior to the invention of writing, which was almost certainly developed as an aid to accounting (Schmandt-Besserat 1992).

Based on work by Schmandt-Besserat (1992), Malafouris (2010) has documented the pre-writing development of number concept in the Near East. Initially, Near Eastern accountants used clay tokens to match the quantities of items, each type of item having its own shaped token (e.g. an ovoid token for a jar of oil). This is one-to-one matching. Note that there is no need for there to be a labelled quantity and no need for a set serial

order. Comparison via analogue magnitude would be sufficient. Also note that there is a semiotic component. The tokens stand for items. Given that the shapes were not completely arbitrary, an iconic/indexical marking best explains them. These tokens eventually developed into stamps impressed on the outside of clay containers and later into traced pictographs. Here we have a functional number system without an established numeral list. One can certainly envision children in this culture bootstrapping their number understanding via use of tokens rather than number lists. The key similarity between this token system and an integer concept is the reliance on one-to-one correspondence to construct sets. What was missing was ordinally arranged labels.

Numbers need not be ordinally arranged labels for integers. Ifrah (1985, cited by Malafouris 2010) documents the example of people in the Torres Straits between New Guinea and Australia who marked time using a technique in which number of days was marked by touching different parts of the body in a particular order. The pattern stood for a number of days. Malafouris argues that this is an embodied, iterative gesture associated with a quantity. It thus is more indexical than arbitrary; there is no inherent $n+1$ function in the system, so that even though it can handle quantities that exceed the subitization range, it does not have the abstract power of a 'true' natural number system (Malafouris 2010).

These two examples are important to us for three reasons. First, they confirm the existence of number concepts that exceed the potential of subitization and analogue magnitude assessment but which are not as abstract and general as the system of natural numbers. Second, they differ from one another and would therefore not appear to represent stages on some kind of invariant developmental scale. Third, they do highlight some important shared features: matching via one-to-one correspondence is present in both, though more salient in the token example, and some form of semiotic marking is present, though in both cases it is via material/embodied resources, not numerical labels.

Consider again the *Tai* plaque (Fig. 7.1). It too was a material/embodied form of number concept in the sense that individual marks were matched in one-to-one correspondence to phenomena in the world. And this example, too, differs from the other two examples. For one thing, the marks were more permanent; they were each engraved at a specific point in time. Unlike the Torres Island time tally, the marks were not transient (they survive today, 12,000 years later), and unlike the tokens, they cannot

be rearranged or reused. Minimally, each mark was an index of some item. But recall that groups of marks were made by different tools at different times. Unlike tokens, the marks apparently did not match to elements of a set in constant view. If the marks were made at different times, then it is probably because the groups of marks matched *different actual sets* of items, with the engraver never observing the cumulative total, which accrued over time. How, then, could he or she re-establish a one-to-one correspondence? This would be possible if there were a set of labels that he or she could attach to previously marked groups, labels that would then continue through the new set. These labels must have been number words, acting as a count of cardinal values, that is, a natural number concept. Of course, this is true only if the tally boards were cumulative counts, but there is no other obvious reason for adding notches to a previously used plaque. It is possible that whoever made this tally board simply added marks whenever he or she saw more items, whether hours, days, or weeks later, and then compared the total to some other bunch of marks via analogue magnitude comparison (i.e. 'there are more marks here than there'). However, this possibility seems unlikely. Francesco d'Errico argues that the plaques acted as external memory (d'Errico 2001), and there may be a grain of truth to this. But it also seems possible that the marks stood for sequential phenomena such as days marking menstruation, game movement, or lunar phenomena. Such a system relies on labelled items. The only reason to do this is to anticipate an event that is a set number of days in the future, in which case there must have been some concept of ordinally arranged labelled individual entities. The number of marks on the Tāi and Tossa de la Roca plaques leads us to two further conclusions: first, the number concept far exceeded the limits of subitization; and second, it is large enough to suggest a general system that lacked an upper limit: $n+1$. The Tāi and Tossa de la Roca plaques therefore represent a number system that was a bit more powerful even than the Near Eastern Neolithic token system. It may even have been equivalent to our system of positive integers.

The Tāi plaque is 12,000 years old, more or less. The oldest tally boards are more than twice as old, and though they do not have as many marks, they are clearly the same kind of device. This tells us that a number concept comparable in most respects to the modern integer concept was in place in Western Europe from 28,000 to 14,000 years ago. It was certainly a cultural construction, but one with remarkable resilience.

From an evolutionary perspective, it tells us that the cognitive hardware to construct a number concept was in place by 28,000 years ago, probably earlier. By extension, it implies a system of labelling—words—was in place as well. This is not a surprising conclusion. Most palaeoanthropologists have long assumed that all people living within the last 30,000 years had fully modern capacities. This conclusion about numbers and labels thus provides an additional bit of concrete evidence for the conclusion. But what about earlier?

7.6 Evolutionary antecedents

We believe that the archaeological evidence supports attribution of a true number concept—or something very close—to Stone Age people living 30,000 years ago in Western Europe, and probably elsewhere. That this evidence is earliest in Western Europe is an accident of the history of archaeology and the cultural history of Europe, not a measure of European precociousness. We imagine that when other regions of the Old World are as well known archaeologically as Europe is, there will be evidence of other cultures that used number concepts as early as, or perhaps earlier than, 30,000 years ago. The archaeological evidence from Africa already supplies hints of cultural developments similar to those of the European Upper Palaeolithic that antedate 30,000 years ago. It has become more and more apparent from the genetic, fossil, and archaeological records that modern humans evolved initially in Africa. The earliest evidence of modern anatomy stretches back almost 200,000 years (Shea et al. 2007), but it was not until after 70,000 years ago that modern humans initiated the rapid expansion out of Africa that ultimately replaced more archaic forms. The Europeans of 30,000 years ago were descendants of this expansion (with a 1–4 per cent contribution of Neanderthal alleles!). Are we justified, then, in attributing number concept to these earlier *Homo sapiens*? This would require a leap of faith. There is no a priori reason that number concept or its cognitive underpinning could not have evolved after modern anatomy. Moreover, evidence of an expanded working memory capacity appears to have followed just this pattern (Wynn and Coolidge 2010). What we need is evidence for number concept antedating 30,000 years ago, and unfortunately there is nothing as

dramatic as the plaques to provide this evidence. But palaeoanthropology does supply two avenues of investigation, both of which are indirect. The first is via changes in brain shape documented by fossils; the second is via archaeological evidence for some of the cognitive components of number concept.

7.7 Parietal hypertrophy

The fossil record of changes in hominin brains tells two parallel stories (at least) for the last half million years. The first is an increase in overall cranial capacity. From an average of perhaps 1,200 to 1,300 cubic centimetres (cm^3) 500,000 years ago, brain size increased to an average of 1,400 to 1,500 cm^3 in both Europe and Africa (Asia is too little known to warrant a generalization). This increase in overall size was not accompanied by an equivalent increase in body size, and thus it is reasonable to conclude (though far from certain) that behavioural changes of some sort drove the increase in brain size. The second story is a story of shape. In Europe, the Neanderthal lineage's increase in brain size was not accompanied by a significant change in proportions: their brains resemble large *Homo heidelbergensis* brains. But in Africa, both size and shape evolved.

Recent work by Emiliano Bruner (Bruner 2004, 2010) using 3D morphometry of X-rayed endocranial volumes and shapes has established that *Homo sapiens*' increase in brain size was accompanied by a change in shape away from the early hominin pattern. There was the expected increase in frontal lobe volume predicted by the size increase, but a much greater than predicted increase in volume of the parietal lobes. In particular, Bruner identified the region of the superior parietals as having the greatest relative expansion. He suggested that this parietal hypertrophy reflected developments in behaviour traditionally associated with the parietal lobes: visuospatial integration, sensorimotor integrations, multi-modal processing, and social communication. The superior parietal lobes also include a brain landmark/feature known to be involved in quantitative thinking—the intraparietal sulcus (IPS).

The IPS is a curved fissure located in the superior parietal that is easily identified in both humans and non-human primates. It has been the focus of extensive research using brain imaging techniques on humans and

invasive techniques on macaques, including single cell firings. Diester and Neider (2008) found that neurons in the IPS and the prefrontal cortex (PFC) in monkeys showed selective activity in experiments where the subject judged quantities of items and also shapes associated with varying quantities. In fMRI work with human four-year-olds, Cantlon et al. (2006) found that four-year-olds demonstrate that there is non-symbolic number activation in the neurons of the IPS, and that from that age on the IPS begins to respond more strongly to numerical judgements than to shape changes. Thus it appears that the IPS is somehow engaged in judgements of quantities. But exactly how is far from clear. Also, it is important to emphasize that the IPS contains millions of neurons, making interpretation difficult. Recently, neuroscience has begun to fractionate the IPS into functionally distinct sub-areas. Fias et al. (2007) found that the horizontal segment of the sulcus (hIPS) is activated in tasks demarking ordinal relationships between numbers, as well as ordinal relationships between non-numerical series such as letters of the alphabet and days of the week. In an earlier study using fMRI on monkeys and humans, Orban et al. (2006) were able to identify an anterior part of the IPS that had no analogue in the monkey IPS and noted that this area was evolutionarily new. They further concluded that these new regions, which process visual stimuli, might function to allow a much more 'detailed analysis of the object to be manipulated along many dimensions such as size, 3D orientation, 2D and 3D shape, etc. providing very sophisticated control of manipulation' (Orban et al. 2006: 2664).

Not surprisingly, given the parietal lobe's reputation for being involved in multiple cognitive abilities, the resulting picture of IPS function is far from simple. It appears to be activated in assessment of quantities, but also ordinal sequences and object manipulations in 3D space. Thus, while the expansion of the parietal lobes (and perhaps the IPS) that occurred with the evolution of *Homo sapiens* is certainly provocative, it need not—indeed, *cannot*—itself act as evidence for development of number concept per se. Coincident developments in the archaeological record may provide a different perspective on what had evolved, because almost certainly something had.

7.8 Archaeological hints

The engraved plaques of the European Upper Palaeolithic are the earliest strong evidence for number concept in the archaeological record. However, this should not be construed as the earliest evidence for the cognitive capacity for number concept. Number concept is, after all, as much a cultural construct as a neurological one. In the absence of earlier archaeological evidence for the ‘full package’ of number concepts, we must approach the subject piecemeal and look for evidence of the constituent components of number.

7.8.1 *Subitization and analogue magnitude estimation*

The abilities to judge the cardinal value of small sets (two to four items) and judge the relative quantity of larger sets are evolutionarily old. Many mammals have this ability, and human infants demonstrate it as well (Carey 2009). The abilities likely evolved in both mammals and humans via direct natural selection. Food, resources, predation, and competition (including confrontation) are among the common situations in which numerical information is relevant to ultimate reproductive success. Subitization and judgement of analogue magnitude are the core cognitive abilities upon which number concept is built ontogenetically and, presumably, in evolution. It is uncontroversial to grant these two abilities to all early hominins.

7.8.2 *Individuation, one-to-one correspondence, and ordinality*

Individuation is the understanding that even large sets consist of individual (countable) items. This understanding is ‘built into’ small subitizable sets but not comparison of large sets. Before a number concept can develop, individuation must be understood to apply to large sets. One-to-one correspondence is the matching of individual items in one set to those of another set. It is key to any form of counting. In finger counting, for example, each digit is matched to items in the set to be counted. Ordinality is the construction of an invariant serial order of items. The ordered items must be dissimilar in some way, or else they could not be ordered. There are many ordinal series in modern culture—days of the

week, months of the year, alphabets, colours of the spectrum, and so on. The numeral list is simply the most familiar, and it is also somehow the most ‘natural’ in the sense that most people would agree that alphabets are cultural constructions but numbers are somehow ‘real,’ that is, out there in the world.

Individuation and one-to-one correspondence are difficult to tease apart, partly because the latter is the best evidence for the former. Interestingly, individuation is often built into languages: countable quantities are often treated differently from mass quantities. This makes language competence a confounding variable; using ‘few’ and ‘some’ in speech can act as a scaffold for learning the concepts of countable vs. mass quantities (of course, most of our native-English-speaking students confuse ‘fewer’ with ‘less,’ so competence is far from given). It is unclear the degree to which human infants understand individuation and one-to-one correspondence. In habituation/dishabituation protocols, infants appear to expect that the individual items of small sets will continue in existence even if removed from view, but this is true only if the items differ from one another. If the items are all the same, the infants instead attend to continuous variables of the set, such as cumulative size. Heterogeneity of individuals apparently enables the infant to focus on individuality (Carey 2009: 141–7). It would seem, then, that a general notion of individuation is not part of infants’ innate numerosity.

The non-human primate literature is also hard to interpret. Several chimpanzees have learned to count items in sets beyond the subitization range. Ai, for example, has famously learned to count to nine (Matsuzawa 2001) using homogeneous sets of dots. Without some ability to individuate beyond four, she could not do this. But this may not be a general understanding of individuation. For every successively larger set, she needed the same amount of training—thousands of trials. Similarly, it is clear, we think, that chimpanzees learn one-to-one correspondence when they learn to count, and they can continue it beyond the subitizable range. But, at least to date, this ability is limited to learned set sizes and is not general. So, as with infants, individuation and one-to-one correspondence appear not to be merged with analogue magnitude judgements into a general idea of number (but chimpanzees continue to surprise us, and many confident assessments of what they cannot do have proved embarrassingly wrong).

It is possible to imagine many scenarios in which individuation and one-to-one correspondence could be preserved in the archaeological record. Clearly, Malafouris' example (2010) of counting tokens qualifies as an instance of individuated sets, as do the marks on the Taï tally plaque, but both also imply the presence of number concept. Could there ever be a pattern of individuation without also having a number concept? It would have to be a pattern that required discrimination of individual items beyond the subitizable range but without quantification. There are such patterns in the modern world, but they are all in ordinal series.

Ordinality is the poor stepsister to subitization and analogue magnitude in studies of numerosity. Numbers are a serial sequence with special qualities—they follow the $n+1$ rule of cardinal value. Without such a rule, an ordered sequence appears little more than a finite memorized list, something well within the abilities of many non-human primates such as macaques (Brannon and Terrace 2000). The infinitely generating list of numerals is far more powerful. But it had to come from somewhere, and we suspect that lists of ordinal qualities are not an accident. There is good reason to believe that ordinality—the ability to construct and attend to sequences—has an innate component, just like subitization and analogue magnitude estimation do. The evidence comes from two sources, neuro-imaging and synaesthesia.

Fias et al. (2007) have identified a region of the anterior portion of the IPS that is activated in any task requiring use of sequences, including numbers and the alphabet. As always, it is somewhat difficult to interpret this result. In human adults, the IPS processes sequential phenomena, but it may be that when adults must learn ordinal sequences, the IPS does it. This does not require ordinality per se to be innate, but it is tantalizing. So is synaesthesia, which is the odd condition experienced by a small percentage of people in which they perceive qualities of one perceptual domain while perceiving or thinking in another—for example, musical notes are experienced as colours, or shapes elicit specific tastes (Hochel and Milan 2008). For every such synaesthete, the phenomenon remains stable over his or her lifetime: it is not a mutable association of perception. The leading hypothesis for the mechanism behind synaesthesia is that at some point during downstream processing of perceptual information there is 'leakage'—information from one separate neural network 'leaks' into the other network. We must emphasize that the effect is not a learned association; it occurs naturally. So what does this have to

do with ordinality? As it turns out, far and away the most common form of synaesthesia is grapheme synaesthesia, in which letters of the alphabet and/or numbers elicit specific colours. Almost as common (often the same individuals) are synaesthetes who see days of the week, months of the year—indeed, just about any ordered sequence—as being coloured (for the synaesthete known as TW, Sundays are red, Mondays are green, Tuesdays are blue, Wednesdays brown/orange, Thursdays very pale blue, Fridays yellow, and Saturdays white). Somehow the synaesthete's brain colours the items in the ordered lists. It could only do this if sequencing is performed by a discrete neural network available for colouring: in other words the sequencing component of ordinality is innate. We have no reason to ascribe innate ordinality to non-human primates; chimpanzees such as Ai require strict training. It may well be that ordinality is a derived cognitive ability for humans. Interestingly, the region of the IPS activated in ordinality is very close to the region activated in 'detailed analysis of objects to be manipulated' (Orban et al. 2006: 2664), as well as to spatial organization in general. Could it be that ordinality evolved for complex manual sequential tasks (toolmaking and tool use) and was later exapted into other systems? We do not know, but the role of the IPS in all of this is very provocative.

Does the archaeological record provide evidence of ordinality prior to number concept? Again, alas, the answer is 'not obviously', but here at least we have hints.

7.8.3 *The Blombos Cave beads*

The Blombos beads are 77,000-year-old artefacts from a Middle Stone Age site on the southern coast of South Africa. To date, archaeologist Christopher Henshilwood and colleagues have recovered over forty small blue shells of the genus *Nassarius*, in each of which a small hole had been punched. Wear patterns around the edges of the holes indicate that the beads had been strung onto some kind of cord and carried around; body movement produced distinctive wear patterns (Fig. 7.4) (Henshilwood and Marean 2003; d'Errico et al. 2005; Henshilwood and Dubreuil 2009).

At one spot in the excavation, archaeologists found several of these beads together in a pattern suggestive of a necklace. The beads from Blombos Cave are not, however, the earliest. The nearby site of Pinnacle

FIG. 7.4. Punctured *Nassarius* shell beads from Blombos Cave (after d’Errico et al. 2005).

Point has yielded similar beads that may be 20,000 years older (Marean 2010a).

Henshilwood and his co-authors (Henshilwood and Marean 2003; d’Errico et al. 2005; Henshilwood and Dubreuil 2009) have used these beads to argue that the Blombos people must have had fully syntactical language, primarily because the beads must have been ornaments communicating social identity. This argument has been forcefully challenged by Rudolf Botha (Botha 2008b, 2009), and though Henshilwood and Dubreuil (2009) have replied, Botha’s critique remains intact (Botha 2010). The beads cannot act as archaeological evidence for syntactical language. However, even Botha seems comfortable with the interpretation of the beads as personal ornaments. We agree that this is perhaps the most likely interpretation, but there is another possibility that no one appears to have considered: the beads were not ornaments, but tokens in a counting device.¹ Note that such a device would be likely to produce the same wear patterns as seen on the shells. This would be a bit like the Near Eastern Neolithic system described by Malafouris (Schmandt-Besserat 1992; Malafouris 2010).

¹ This idea was brought to our attention by a first-year undergraduate, Klint Janulis, who had used a set of strung beads to keep track of distance walked at night, one bead for every hundred paces.

It would be an example of extended cognition (Wilson and Clark 2009), counting via physical objects. The beads would be individuated and also ordinal in their arrangement on the cord. We do not want to overemphasize this possibility; it is no more likely than the ornament interpretation. But even if the beads began simply as personal ornaments, stringing them on a cord would have eventually had profound consequences for the development of number concept.

Evolution of number concept needed a cognitive scaffold. When a modern human child learns a number concept, he or she relies on a pre-existing cultural scaffold, the list of numerals (Hurford 1987; Carey 2009). A young child actually learns the list by rote before understanding the cardinal rule $n+1$ that lies behind integers; he or she can count to ten or twenty before understanding what the list means. Typically, the child next learns that the cardinal rule applies to subsets of the list, first ‘one’, then ‘one’ and ‘two’, then ‘one’, ‘two’, ‘three’, and sometimes even ‘one’, ‘two’, ‘three’, ‘four’, before he or she makes the qualitative shift in understanding and is able to apply the $n+1$ rule to all possible cardinal values. The numeral list supplies the child with an interim framework or model, which can be gradually enriched as the child uses the numeral words. The list is, of course, an ordinal sequence of labels. But in the absence of such a scaffold, how could number concept arise—how did the list itself come about? It seems impossible that the list of numerals could have evolved before number concept itself, so there must have been some other way to get to a number concept. One possible way would be through an embodied sequence, such as the use of fingers (Malafouris 2010), or through an artefactually ordered sequence, such as the use of tally marks or beads. The latter has more potential. If people matched quantities via one-to-one correspondence between phenomena and a physical device such as a string of beads, there would be physical instantiation of the $n+1$ principle. A string of beads is a one-dimensional, ordinal sequence—a feral number line, if you will. Even without labels for numerals, such a device could enable the bootstrapping of a true number concept. Then, all one would need would be a system of labels. Thus, it is possible to model the evolution of number concept prior to the establishment of a numeral list.

Of course, we do not know if the Blombos people did this 77,000 years ago, or even if the people at Üçağizli in Turkey (Kuhn et al. 2009) did it 44,000 years ago. However, stringing beads for tens of thousands of years provided ample opportunity for the potential of an ordinal counting

device to be realized. Our intent here is not to argue that number concept was in place in southern Africa 77,000 years ago. Rather, it is to suggest that potential artefactual scaffolds were in place, scaffolds that instantiated individuation (beads), ordinality (strings of beads), and a tangible version of $n+1$. Such devices could easily lead to counting devices with one-to-one correspondence and a general understanding of cardinality. Even in the absence of labels, beads could ‘hold the place of’ and ‘stand for’ items of other phenomena.

7.9 Abstraction

Also necessary for the construction of a true number concept is the ability to abstract cardinality into a general concept applicable to all countable phenomena. There is actually a low level of abstraction built into subitization. Infants understand that three diverse items are somehow equivalent to the three items in another diverse set, but they cannot do it if the items are all the same. This is clearly not a general rule. Moreover, it is likely that it is ‘built into’ the encapsulated subitizing ability, and thus it is unavailable to other neural systems. There is nothing abstract about analogue magnitude assessment, which compares amounts of real-world phenomena. Thus something must be added to these core systems of numerosity before they can transform into an abstract number concept.

There is also an inherent abstraction to some counting schemes. The earlier example of Near Eastern Neolithic tokens used to mark quantities is not an abstract system. There was a one-to-one correspondence between tokens and countable items, but comparison could be done by relying on analogue magnitude representations (this bunch of tokens is bigger than that bunch of tokens). Counting with body parts takes one-to-one correspondence out of the subitizable range, and even if it makes a provocative intermediate concept, it remains a closed set (I have an ‘elbow’s-worth’ of pigs, and you have only a ‘wrist’s-worth’). Counting with beads is limited only by the number of beads, so it has more scope than body counting. As with the tokens, one could simply use beads to match quantities via one-to-one correspondence and then compare them via analogue magnitude assessment (my string of beads is longer than yours). And as is true of the tokens and body counting, beads could be used to count anything. What

makes beads rather more likely to incite abstraction is the presence of a fixed ordinality not true of the first two, along with a naturally occurring $n+1$. Thus, bead counting comes closer to an abstract number concept than the other two, but it is still not quite there. Something needs to occur that transforms tangible, extended cognitive counting systems into an intangible, general rule of cardinality.

Abstract thinking depends in part on the ability to hold multiple pieces of information in attention, compare them, and extract commonalities. This ability depends on working memory capacity. In modern humans, there is a clear correlation between working memory capacity and fluid intelligence, which is the ability to solve novel problems (Engle 2010). By extension, it is probable that understanding the natural number concept requires an appropriate level of working memory capacity. As Carey (2009) has argued, a child's understanding of number concept only emerges with neurological maturity and an appropriate cultural scaffold. The neurological component may well be working memory capacity. In this case, what is true in ontogeny may also have been true in human evolution. The archaeological record indicates that a modern working memory capacity emerged very late in humans, certainly by 30,000 years ago but no earlier than 100,000 years ago (Wynn and Coolidge 2010). Of course, this does not solve the abstraction problem. Modern working memory capacity may be necessary for abstraction, but it is not sufficient. Here extended cognition may have played a role: external devices such as tally plaques and depictive images of animals actually extended people's working memory capacity even further, 'holding' some information in view while allowing attention itself to bring in more and different information to bear on the problem.

It is appropriate at this point to reiterate an important qualification. Number concepts are cultural constructions, and they are not universal. They arise in cultural milieux that require a system of numerosity with more problem-solving power than subitization and analogue magnitude estimation. Such problems are common in the modern world, but they only became common in the recent past with the development of market economies. Few hunter-gatherers need such a system. Clearly, however, some late Palaeolithic cultures developed one anyway. One characteristic of late Palaeolithic cultures was the establishment and maintenance of long-range social contacts; another was the creation of complex ritual

systems. Either might have benefited from a more powerful system for tracking quantities.

7.10 Implications for language evolution

The role of language in the development of number concept has been explored by both linguists and developmental psychologists. Hurford (1987) argued that language accounted for the two-step development of number concept in human history, with small count numbers being mono-morphemic and larger numbers relying on syntactical resources for their construction. According to Hurford, a true natural number concept could not develop before modern syntax. Of particular note is that Hurford assumed that ordinality and one-to-one correspondence evolved prior to number concept; moreover, he explicitly argued ‘without language, no numeracy’ (Hurford 1987: 305). More recently, Carey (2009) has argued that number concept in children relies on the scaffold of linguistic numeral lists, as well as inherent features of language such as plurals and countable vs. mass nouns. It seems her account differs from Hurford’s in arguing that emergence of true natural number requires a cognitive reorganization on the part of the child (based partly on neural maturation).

Our account of the evolution of number concept in no way vitiates either Hurford’s or Carey’s more exhaustive analyses. Rather, it extends both deeper into the evolutionary past by sketching a possible mechanism by which a number concept could emerge in the absence of an established linguistic scaffold. Our analysis carries several specific implications for the evolution of language itself:

- A techno-cultural milieu like that instantiated by the Taï plaque must have had a linguistic base. This was a counting system that extended well beyond the subitizable range and, given that the plaques were used episodically, there must have been labels to re-establish the count.
- If not already present, this counting milieu would have forced the development of syntactic resources to handle the higher numbers (as Hurford suggests).

- Modern language must have been in place by 14,000 years ago (hardly a startling conclusion).
- Labels for smaller, subitizable counts must have emerged even earlier. These numbers are invariably mono-morphemic and often difficult to link to specific semantic origins. Objects similar to the Taï plaque date back almost 30,000 years in Europe, though these earlier examples are not as clearly episodic or count based, nor do they have such large numbers.
- These labels must initially have developed as verbal placeholders for an embodied or extended count system of some sort. Evidence for potential artefactual scaffolds dates back to beyond 70,000 years ago. Perhaps not coincidentally, evidence for the final enhancement of working memory and the attendant potential for abstraction have a similar antiquity.

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