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FINGER-COUNTING IN THE UPPER PALAEOLITHIC

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Abstract. Upper Palaeolithic hand stencils at Cosquer Cave have been interpreted as forming a numeric code. The present analysis examined 'digits' at Cosquer and Gargas from the perspectives of modern ethnography, shared cognitive functioning and human hand anatomy, concluding that correspondences between the 27000-year-old hand stencils and modern finger-counting practices, including the use of so-called biomechanically infeasible hand positions, are unlikely due to chance; thus, the hand stencils may indeed represent integers. Images of finger-signs may provide an additional avenue for interpreting Palaeolithic quantification.

Introduction

Scholars have been trying to interpret the meaning of hand prints found in Upper Palaeolithic caves for about as long as the hand prints have been known to exist. Typically, Upper Palaeolithic hand prints were made by one of two techniques, either by pressing a painted hand against the cave wall (creating a positive hand print, the hand itself marked on the painted surface) or by using the hand as a stencil while blowing or dabbing paint around it (a negative hand print or stencil, the outline of the hand). Interpretive analysis has been mainly focused on inferring characteristics of those who made the hand prints, including how many individuals were involved, their age, amount of sexual dimorphism, gender and handedness (Bednarik 2008; Faurie and Raymond 2003; Gunn 2006, 2007; Nelson et al. 2006; Snow 2006). Additionally, various reasons have been offered as to why hand prints might have been made: as the byproduct of shamanistic rituals; as memorials, signatures, calling cards, records of growth, simple decorations or memorials to phantom limbs; or as images of finger-signs used for nonverbal communication similar to those used by modern hunters (Achrati 2003, 2008; Clottes and Courtin 1994; Leroi-Gourhan 1967, 1982; Saintyves 1934; Sharpe and Van Gelder 2006). Compounding the problem of interpretation, of course, is the likelihood that the hand prints were created for a variety and any combination of purposes; further, interpretations are generally not accurate unless they are based on specific cultural insights (Morwood 2002) or, as in the present analysis, phenomena that are cross-cultural as a function of shared human cognitive functioning.

Other analysis has focused on reasons why some of the fingers in hand stencils appear to be shorter than normal. Early interpretations, no longer much in vogue, speculated that short fingers may have represented mutilations obtained through severe ritual (intentional removal) or unintentional causes such as frostbite or hunting accidents (Luquet 1926; Leroi-Gourhan 1967). In a review of ritualised finger mutilation, Luquet (1938) noted that the custom was prevalent and amply documented in modern peoples, practised for reasons such as mourning, sacrifice, propitiation, protection, atonement, punishment or rite of passage, and had both symbolic and pragmatic outcomes in making visible things like emotional states (e.g. grief), intentions (dedication), status (suitability for remarriage) and identity (tribal affiliation). Luquet (1936) noted that intentional mutilations tended to sacrifice fingers in a way that preserved (as much as possible) the strength and functionality of the hand, generally removing the little finger first, the ring finger next, and so on, sparing the thumb, index, and major fingers. He also stated that the finger mutilations produced by historic practices were inconsistent with the patterns found in Upper Palaeolithic cave art (specifically, hand stencils at Gargas, Aventignan, Hautes-Pyrénées, which have been dated to about 27000 years ago), since the stencils frequently lacked index and major fingers rather than little and ring fingers; this led him to suggest that the stencils had been produced not by mutilations, but by hands with intact, folded fingers, perhaps with the intent of forming a code (Luquet 1926). However, ritual mutilations were not unknown in the Upper Palaeolithic: a site dated to about 30000 years ago, Obłazowa Cave (Poland), contained phalanges (one identified as a male's left thumb) and a female skeleton with the phalanges of both small fingers amputated (Valde-Nowak 2003), findings certainly suggestive of ritual mutilation.

Several decades after Luquet's work, Leroi-Gourhan (1967) analysed the Gargas stencils and speculated that they might have comprised a code of nonverbal hand signals such as those used by modern hunters. He also noted that of the possible 32 permutations of short–long digits formed by flexing (bending) or extending (straightening) all five fingers on a hand, only 10 were found at Gargas, all of which included an extended thumb (Leroi-Gourhan 1967; Pradel 1975 contained a comparable set of drawings of the Gargas digit patterns). More recently, Rouillon (2006) performed a similar analysis of the short–long digits in the stencils at Cosquer Cave, Bouches-du-Rhône, Marseille, France, which have also been dated to about 27 000 years ago, making them roughly contemporaneous to those at Gargas. He observed that only five of the 32 possible finger-patterns were represented and noted their similarity to modern finger-counting systems for integers 1 through 5, speculating that the Cosquer stencils formed a numeric code. Rouillon interpreted extension of just the thumb as comprising the integer 1; extension of the thumb and index finger as 2; the thumb, index and major fingers as 3; the thumb and index, major and ring fingers as 4; and all five digits extended as 5.

Rouillon's (2006) interpretation suggested a follow-on analysis of the stencils at Cosquer and Gargas from the perspectives of modern ethnography, shared cognitive functioning, and the biomechanical constraints of the human hand to answer the following questions:

- Ethnographic comparison: how similar were the Upper Palaeolithic 'integers' at Cosquer and Gargas to modern finger-counting systems? If the two were indeed similar, might this be a phenomenon of direct descent (implying that finger-signs for integers had been conserved in western Europe over tens of thousands of years) or one reflecting the most likely outcome of shared embodied cognition? In addition, was Rouillon's (2006) interpretation of Cosquer finger-counting as proceeding from thumb to little finger likely correct, or were alternate interpretations possible?
- Biomechanical constraints: did the difficulty of producing particular finger-patterns affect the likelihood of their being used?

To answer the first inquiry, the present study analysed modern finger-counting systems listed in Yale University's electronic Human Resource Area Files (eHRAF) database (Biesele et al. 2013), as supplemented by a literature survey. While the resultant small sample would not likely be representative of the full variability possible in finger-counting systems (reviewed in Bender and Beller 2012), they would illuminate the most typical features of such systems; that is, even a small sample would likely detect common characteristics. The finger-signs at Cosquer and Gargas were then compared to the characteristics of modern finger-counting systems. Similarity to modern finger-counting (and acceptance of two assumptions: first, that similarity indicated origins from shared cognition and physical embodiment, and second, that any differences between modern cognition and that of 27 000 years ago were negligible) would support the likelihood that the Upper Palaeolithic finger-signs at these two sites might represent integers, as well as inform their interpretation as specific numbers. Among dozens of Upper Palaeolithic sites at which stencils have been found, Cosquer and Gargas contain some of the most extensive collections (Snow 2006), making these sites well-suited for the analysis.

The second inquiry speculated that the use of any of the four infeasible finger positions (Lin et al. 2000) might imply that greater value had been placed on the sequence produced by adjacent fingers or the resultant shape of the hand (necessitating inclusion of infeasible finger positions), rather than the ease of production (which would skip infeasible positions), strengthening an interpretation of symbolic intentionality. Whole-hand movements, as in grasping, require less activity in the motor cortex than single-finger movements, which engage additional neural resources thought related to inhibition and intentionality, a pattern demonstrated in both macaques and humans (Clark 2008; Kubánek et al. 2009; Schieber 1990; Schieber and Hibbard 1993). Infeasible finger positions result from biomechanical constraints that preclude (in many individuals) independent flexion of the little and ring fingers unless some form of external assistance is provided (Lin et al. 2000). At least one (flexion of just the little finger) is prevalent in modern finger-counting systems; it is typically performed by using the free hand to hold the flexed little finger in place. This assistance enables sequential use of fingers to achieve ordinal or cardinal numbers (the former uses successive fingers, the latter cumulative fingers; see Ifrah 2000). Thus, although biomechanical constraints can easily be overcome, similar assistance would be required if the finger-patterns were to be recreated as painted images; moreover, the assistance would need to be such that it did not impede the stencil process (e.g. pressing flexed fingers against the wall, a palm-down hand position).

Scholarly interest in Palaeolithic counting has focused on artefacts such as the Blombos Cave beads (c. 75 000 years ago) and the notched bones from Abri Cellier (c. 28 000 years ago) and Grotte du Taï (c. 14 000 years ago) (e.g. d'Errico et al. 2005; Marshack 1991; Overmann et al. 2011). Analysis has attempted to infer whether artefacts were used for quantification by separating cutmarks made deliberately (for whatever reason) from those appearing inadvertent, such as those produced by butchery (Marshack 1991). Other analytic techniques have examined cutmark temporal accumulation (e.g. through microscopic analysis to infer whether the same or different tools were used on the grounds that accumulation over time [different tools] might be consistent with quantification, accumulation at a time [the same tool] with decoration) or characterised their disposition (e.g. grouping, a common strategy for achieving higher quantities, might imply quantificational intention, as would uneven distribution across the artefactual surface, a characteristic of temporal separation) (d'Errico 1991, 1998; d'Errico et al. 2003). Quantificational utility has been noted (as a string of beads might instantiate one-to-one correspondence, ordinality, and a number line), as have correspondences with modern practices with cognitive underpinnings, appropriately caveated with the weakened basis for comparison the further back in time one considers through the modern lens (Overmann 2013; Overmann et al. 2011).

Since all of these methods for inferring quantificational intentionality are indirect, some ambiguity remains — even when cutmarks appear deliberate, temporally distributed and grouped, or beads to have been slid along strings enough to leave patterns of wear — because of plausible alternatives (e.g. uses for decoration or social identity) and the challenge of establishing intentionality through indirect means. Interpreting Upper Palaeolithic quantification from stencils would hardly be immune to similar questions. However, at a minimal, stencils open up an additional avenue for inferring possible quantificational intent. Further, because of the close neurofunctional linkage between the perceptual system for quantity and the control of the fingers, stencils are potentially less ambiguous in representing quantificational intent. That is, while stencils undoubtedly have a significant potential for use as decorations or shamanistic or other social purposes, finger-signs for integers 1 through 5 might represent quantificational intention in a way that cutmarks on bone or beads on strings cannot. Conversely, construal of quantificational intent in the Cosquer and Gargas finger-signs might strengthen the argument of similar intent in contemporaneous material devices, as both might form components of an encompassing system of quantification. However, as painted representations of quantity, finger-signs would also pose new questions, such as why they might be used instead of cutmarks when the capability to produce them both existed and could be used on the walls of the cave.

The relationship between fingers and numbers

The close association between the fingers and counting has been richly documented (e.g. Andres et al. 2008a; Beller and Bender 2011; Rips et al. 2008). The association between the two appears to arise from functionality of the parietal lobe, situated between the frontal and occipital lobes and above the temporal lobe. Parietal lobe functions include (among other things) integrating tactile, visual and spatial sensation; perceiving space, time and number; and controlling finger and arm movements (Bruner 2004, 2010). This neurofunctional integration makes the use of the fingers for counting cognitively prepotent and is likely the reason why fingers have remained useful both for children learning and adults performing arithmetic, even in cultures with well-developed number systems (e.g. Crollen et al. 2011; Domahs et al. 2010; Krinzinger et al. 2011). Finger-signs for numbers provide visuomotor support for the manipulation, representation and communication of numbers, act as an external offload for working memory, and aid the formation of numeric representations in long-term memory (Andres et al. 2008a; di Luca and Pesenti 2011).

Fingers help modern children learn to differentiate quantities by relating phonological patterns (lexical number words) to finger-patterns, and in arithmetic facilitate the mapping of semantic meanings for lexical identifiers onto embodied representations of quantity, supporting the acquisition of number concepts through sensorimotor experience, though how essential the fingers are to the learning process remains an open question (Andres et al. 2008a; Beller and Bender 2011; Rip et al. 2008). The fact that finger-counting remains useful for learning or performing arithmetic by both children and adults, even in cultures with extensive lexical identifiers, well-developed counting systems and complex mathematics, suggests that knowledge of natural numbers may represent a bottom-up process whose foundation rests on finger-based representations, either in the acquisition of number concepts by modern individuals or in their initial development by particular societies (Andres et al. 2008a; Klein et al. 2011). Limited numerical knowledge co-occurs with rudimentary finger-counting, supporting the idea that finger-counting may critically contribute to an ability to understand the natural numbers and develop them into explicit concepts (Andres et al. 2008a; Pica et al. 2004). Further, those who 'know' their fingers better (finger gnosia) demonstrate higher proficiency in numerical calculation, supporting the idea that the finger–number relationship may be central to the development of explicit number concepts (Reeve and Humberstone 2011).

While finger-counting is a cross-cultural phenomenon (e.g. Overmann 2013), culture influences the specific expression of numbers by the fingers, an effect that arises from the way in which practice, a culturally mediated mechanism, influences the development of neural connections (de Cruz 2008, 2012). Cultural mediation gives rise to phenomena such as the differential cross-hand reaction times noted in Chinese and German finger-counting (Domahs et al. 2010). In the German culture, people count to 5 on a single hand, demonstrating an increased reaction time when counting to 6 involves the other hand, which entails cross-hemispheric information transfer; in comparison, Chinese people count to 9 on a single hand using additional finger combinations to represent the numbers 6 through 9, and cross-hand reaction time increases when counting to 10 requires the other hand

(Domahs et al. 2010).

The perceptual system for quantity, known as *numerosity*, enables the identification of small quantities and differential quantity; the former is *subitisation*, which rapidly and unambiguously recognises quantities up to 3 (and infrequently 4), the latter *magnitude appreciation*, which discerns 'bigger' and 'smaller' for quantities above the subitising range (reviewed in Coolidge and Overmann 2012). Numerosity is shared with many species, even fish, which when threatened flee to the larger of two shoals when given a choice, demonstrating the ability to appreciate differential quantity (Agrillo et al. 2007). The subitisation constraint (appreciating quantity differentials rather than individuals above the subitising range) is a function of Weber's law, which states that just-noticeable differences between quantities are proportional to their magnitude, differences that are appreciable as individual quantities at low numbers and as quantity differentials at higher numbers (Piazza 2010; Pica et al. 2004); subitisation additionally engages attentional resources with a limited capacity for identification and enumeration (Alvarez and Franconeri 2007; Burr et al. 2010). The Weber effect appears to be cross-cultural, despite cultural differences in attentional fore- or back-grounding (Göbel et al. 2011).

How Weber's law governs the appreciation of discrete quantities is explained by the Weber fraction ($\Delta I/I$): when the distance between numbers is held constant (as for example the distance of 1 that characterises counting in integers), the fraction decreases as the size of the numbers increases. This phenomenon causes distance and size effects: as the distance between two quantities decreases or their size increases, the Weber fraction diminishes to a point where quantity differentials can no longer be appreciated (that is, quantity differences are so small that they are no longer noticeable). Thus, below the subitisation constraint (where the Weber fraction is relatively large), quantities are appreciated as individuals (i.e. 1, 2 or 3); above it (where the Weber fraction is relatively small), quantity differentials (i.e. smaller and bigger) are appreciated if they are above the threshold of noticeability, a function of their respective sizes and distance from one another. Implicit in the Weber effect is an ability to make judgments of relative quantity; not necessarily implicit are abilities for rank-ordering quantities, which may involve additional cognitive processes (e.g. sequencing); making judgments about quantities (value, a domain that includes emotional reactions [innate] and cultural mediation [informed]); and motivations for counting or rank-ordering quantities (another culturally mediated domain).

The subitisation constraint influences the way in which lexical number words emerge in language: across languages widely separated by geography and culture, counting terms consistently emerge as 'one'-'two'-'three'-'many' (Menninger 1992), reflecting perceptual constraints on differentiating quantities higher than 3. Achieving concepts of discrete higher quantities within the 'undifferentiated *many*, the universal term for quantities higher than the subitising range', requires transcendence of the constraint (Overmann and Coolidge 2013: 83), an enterprise that perhaps entails 'an integrative projection' between the perceptual system for quantity and sensorimotor experience, as fingers and the objects they manipulate make numeric properties tangible and visible (Malafouris 2010: 8). Material culture also provides for tactile interaction (things to count), motivation (reasons to count), and systems of value (status and usefulness) that interact with quantity perception to influence the development of numbers as explicit concepts and make them useful as a cognitive technology, ways of understanding that structure how the environment (both natural and cultural) is understood and reacted to (de Cruz 2008, 2012; Overmann 2013).

Although the perceptual system for quantity does not 'think' in base 10, the majority of counting systems are decimal, while the second-most prevalent counting systems combine bases 5 and 20 (quinary and vigesimal systems, respectively), and a significant minority achieves base 4 (a quaternary system) by counting the spaces between the fingers or base 6 (a senary system) by including the wrist (Bender and Beller 2011; Comrie 2005; Greenberg 1978). These results reflect the canalising effect of embodiment with five fingers, two hands, ten toes and other anatomic features. In addition, linguistic evidence of an 'embodied vocabulary' supports the idea that counting can originate from using the fingers (Andres et al. 2008a: 642). For example, for the Chukchi and Koryak peoples of modern Russia, the word 'to count' means 'to finger' (Antropova and Kuznetsova 1964: 800), while 'digit' means both 'finger' and 'number' in English (Richardson 1916). The close association between fingers and counting in turn implies that finger-counting has been a primary mode for the development of counting systems, whether or not those systems eventually incorporate other body parts, gestures, material artefacts, lexical terms or symbolic notations. Using the same finger configurations repeatedly might not only develop neural connections (practice effects) but endow them with special status as icons and perhaps even symbols (Crollen et al. 2011; di Luca and Pesenti 2011).

Finger-counting likely preceded the use of material artefacts for counting; after all, hominins have had fingers and the ability to perceive quantity longer than they have had material culture, though artefacts capable of scaffolding the development of number concepts may go back as far as 100 000 years (Coolidge and Overmann 2012; Overmann et al. 2011). Unambiguous finger-counting has had only a fairly recent presence in the archaeological record, depicted pictorially and in writing by historic cultures; the earliest extend as far back as far as 5000 years ago in Egypt (Ifrah 2000).

The Greek philosopher and biographer Plutarch (c. 45–120 CE) documented the practice of finger-counting in the Mediterranean some 2300 years ago, with the earliest finger-counting system documented with sufficient granularity to enable recreation of specific finger-patterns attributed to the English monk Bede (c. 672–735 CE) in the early eighth century (however, some scholars have noted that Bede's finger-counting system might have been more intellectual exercise than actual custom; see Bragg 1997; Karamanolis 2010; Menninger 1992; Olsen 1982).

Bede's system differs from the finger-counting system prevalent in western Europe (Pika et al. 2009), suggesting — were Bede's account taken as accurate reflection of custom — that significant alteration can occur over relatively short spans of time (i.e. mere centuries). Further, Bede's system is much younger than the images at Cosquer and Gargas: It is only about 1200 years old, leaving a shortfall of nearly 26000 years in any direct comparison with the Upper Palaeolithic stencils. The generic depictions of finger-counting from Egypt fall similarly short in direct comparison, a shortfall of roughly 20000 years. However, there may not be a need to assume that similarity reflects direct descent and the preservation of cultural practice for tens of thousands of years: independent invention is a plausible alternative, with similarity of result viewed as the predictable outcome of shared embodied cognition. Peoples have independently invented similar number systems, despite being widely separated in both time and space; similarity reflects shared embodiment of the perceptual system for quantity (and other cognitive processes contributing to quantification) with 10 fingers. Interpreting similarity as the most likely outcome of common cognitive abilities and physical anatomy, given the morphological similarity of modern and Upper Palaeolithic skulls and hands, implies that modern finger-counting systems would have relevance for interpreting the finger-signs at Cosquer and Gargas.

Ethnographic counting systems

Yale University's electronic Human Relations Area Files (eHRAF) contained sufficient data to describe 28 finger-counting systems in terms of features such as hand position, type of finger modification, beginning and ending fingers used to count from 1 to 5 and from 6 to 10, and the additional use of the toes and material artefacts. These data were supplemented with literature describing finger-counting by the New Guinean Yupano and Kewa peoples and three contemporary European groups (Franklin and Franklin 1962; Pika et al. 2009; Wassmann and Dasen 1994), bringing the final sample to 33. The final sample contained societies from Africa (18.2%), Asia (15.2%), North America (24.2%), South America (24.2%), Oceania (6.1%) and Europe (12.1%) (Fig. 1A). Several societies were geographically proximal and/or linguistically related, making non-independence of the data likely (Naroll 1967; 1973; Eff and Dow 2009). Thus, descriptive percentages were used rather than statistical strength of association techniques, which can inflate values in non-independent data, even in small samples. It should also be noted that the described percentages (see Table 1) were based on the available data for particular features rather than the total sample (and thus do not include the percentage of missing data).

Hand used to initiate counting. The hand used to initiate counting was specified with sufficient detail to enable its characterisation for 11 of the 33 cultures in the sample (Fig. 1B). A majority (63.6%) used the left hand to begin counting, making adjustments to the counting hand with the right; the remaining 36.4% used the opposite arrangement (right hand used to initiate, left hand to adjust). While this was consistent with the finding of left-hand bias in Western participants by Fischer (2008) and Lindemann et al. (2011), the right-hand bias found in Middle Eastern participants in the second study also suggested that the hand used to initiate counting may be culturally influenced (possibly by matters such as reading direction, clearly a modern effect), rather than a function of handedness (e.g. Sato and Lalain 2008) or a particular orientation of the mental number line as has been found by some researchers (e.g. Fischer 2008; Priftis et al. 2006; also see Núñez 2011, who argues against a left-to-right orientation in the mental number line; Previtali et al. 2011, who note that orientation of the mental number line is influenced by both handedness and culture).

Finger modification. The manner in which fingers were modified to produce integers was specified for 21 of the societies in the sample (Fig. 1C), with 38.1% flexing the fingers, 28.6% extending them, 14.3% pointing at segments (base of the finger, knuckles etc.), 9.5% grasping the fingers, 4.8% shaking them, and 4.8% using a combination of techniques. This was interpreted as indicating that selection of finger-modification technique may be a matter of chance or culture, albeit one likely governed by pragmatic considerations (e.g. distinguishability of finger-patterns from one another, communicability of finger-patterns between individuals etc.). In one instance an observer appeared to suggest a difference in the finger positions used for counting and communicating numeric values (the latter is *finger-montring*; see di Luca and Pesenti 2008; this was noted for the Assiniboine people of the North American Great Plains by Dennig and Hewitt 1930). Finger-montring was not noted for any other society in the sample, though several elevated or turned their hands to make quantities more visible.

Beginning and ending fingers for integers 1 through 5. Beginning fingers were specified in 22 of the finger-counting systems, ending fingers in 20 of them (Figs 1D and 1E, respectively). To begin counting sequences with the integer 1, 59.1% started with the little finger, 31.8% with the thumb, and 9.1% with the index finger. To end counting sequences with the integer 5, 65.0% ended with the thumb, 25.0% with the little finger, and

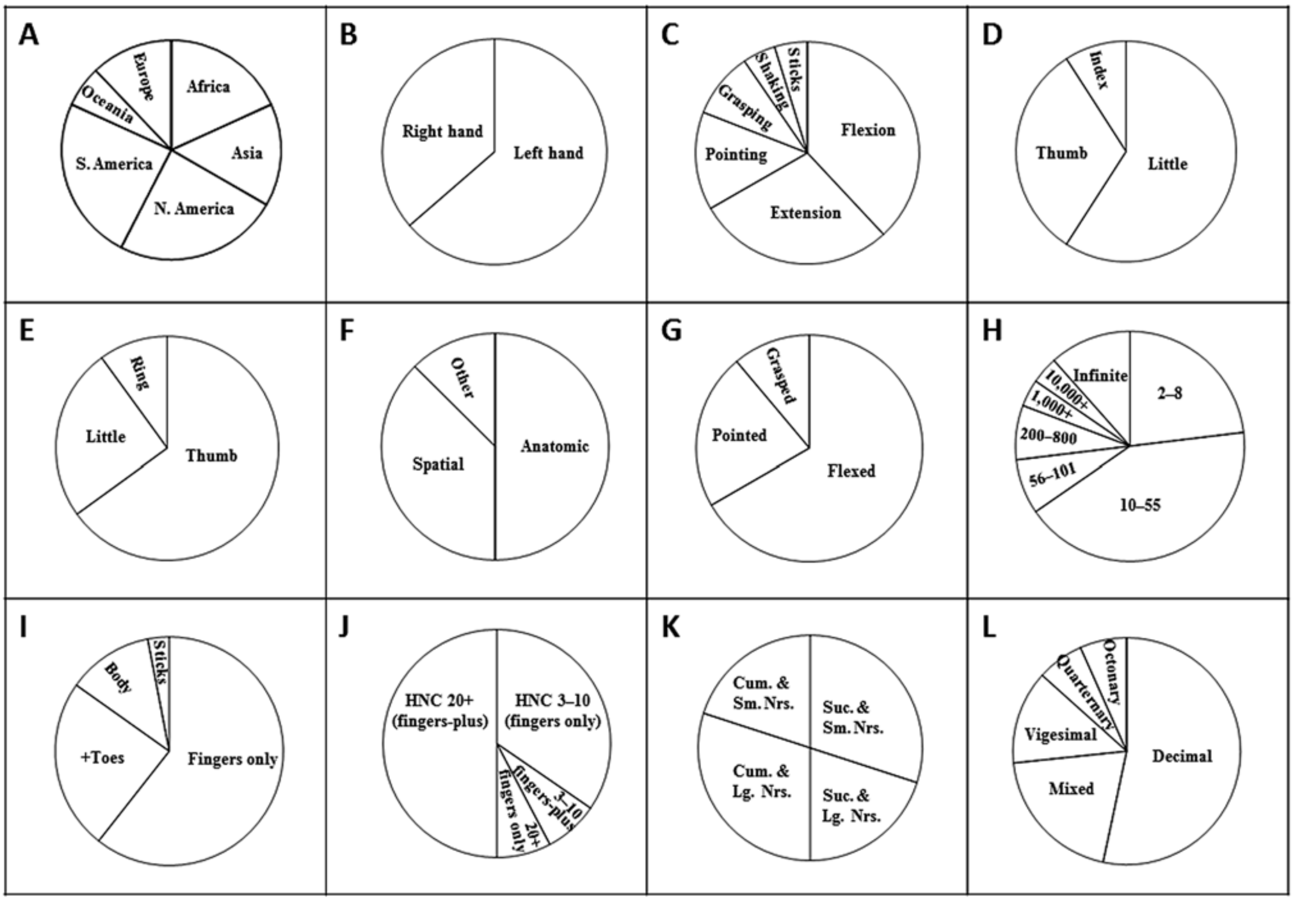
Society	Geographic subregion	Number system		Finger-counting system				
		Base[4]	Highest[5]	Used	Hand	Finger	Begin-end	Symmetry
Africa								
Masai	Eastern	-	-	+Toes	Right begins	Flexed	Little-thumb	Anatomic
San	South-central	-	3	+Toes	-	-	-	-
Zulu	Southern	10	-	Fingers	-	-	Little-thumb	-
Barundi	Central	10	-	Fingers	-	Mixed	Index-thumb	Asymmetric
Dogon	Western	Mixed	22	Body	-	-	-	-
Kpelle		-	10	Fingers	Right begins	Flexed	Little-thumb	-
Asia								
Lepcha	Central	20	20	Fingers	-	Pointed	Little-thumb	-
Chukchee	Northern	20	20	+Toes	-	Extended	-	-
Yupno[1]	Papua New Guinea	Mixed	34	Body	Left begins	Flexed	Little-thumb	Anatomic
Kewa[2]		4	47	Body	-	-	Little-thumb	-
Andamans	Southeast	-	3	Fingers	-	-	Little-thumb	-
North America								
Copper Eskimo	Arctic and Subarctic	-	5	+Toes	-	-	-	-
Alutiiq		-	20	+Toes	-	-	-	-
Yuki	California	8	10	+Sticks	-	-	Thumb-little	-
Klamath	Plains and Plateau	5/20	100	Fingers	-	-	Little-unk.	-
Assiniboine		-	100	Fingers	Left begins	Flexed	Little-thumb	Spatial
Chipewyan	Central	-	10	Fingers	-	-	-	-
Tlingit	Northwest coast	10	200	+Toes	-	-	-	-
Seminole	Eastern Woodlands	-	-	Fingers	Left begins	Pointed	Little-thumb	Spatial
South America								
Bakairi	Amazon and Orinoco	-	-	Fingers	Left begins	Grasped	Little-ring	-
Jivaro		-	10	Fingers	Right begins	Grasped	Thumb-little	Anatomic
Nambikwara		-	8	Fingers	Left begins	Extended	Thumb-ring	-
Mapuche	Central Andes	-	1000	+Toes	-	Pointed	Thumb-little	Spatial
Otavalo Quichua		-	-	Fingers	Left begins	Flexed	Little-thumb	-
Mataco	Southern	-	4	Fingers	Right begins	Extended	-	-
Ona	Tierra del Fuego	-	5	Fingers	-	-	-	-
Yahgan		-	10	Fingers	-	Shaken	-	-
Oceania								
Santa Cruz	Melanesia	-	100000	Fingers	-	Flexed	-	-
Maori	Polynesia	10	200	+Toes	Left begins	Flexed	Little-thumb	-
Europe								
Eastern[3]	Eastern	10	Infinite	Fingers	-	Flexed	Thumb-little	-
German (Medieval)	Central	10	-	Body	-	Extended	Thumb-unk.	-
English[3]	Western	10	Infinite	Fingers	-	Extended	Index-thumb	Anatomic
French[3]		10	Infinite	Fingers	-	Extended	Thumb-little	-

Note. Sourced from Yale's eHRAF database (Biesele et al. 2013) and [1] Wassmann and Dasen 1994 (Yupno); [2] Pika et al. 2009 (Kewa); [3] Franklin and Franklin 1962 (Eastern Europe, English, and French); [4] Comrie 2005 and Dryer and Haspelmath 2011 (number system base); and [5] Divale 1999 (highest number counted).

Table 1. *Sample of societies in the ethnographic comparison.*

9.1% with the ring finger. These percentages indicated a strong tendency to start with an outside finger and move across the hand. In all cases moving from thumb to little finger or from little finger to thumb, the procession of fingers was sequential (i.e. no fingers were skipped). The pattern of sequential fingers was also followed when the index finger initiated or the ring finger ended the sequence, except at the point where involvement of the thumb necessarily disrupted it. Though all finger-counting systems in the sample used all fingers on a single hand before involving the second, such need not be the case: as noted by Bender and Beller (2011), African Bantu finger-counting systems switch from hand to hand to maintain equality in the numbers being added.

Type of symmetry based on beginning and ending fingers for integers 6 through 10. When the second hand becomes involved in counting (a characteristic applicable only to those systems whose count exceeds the capacity of a single hand), it can repeat, reverse or alter the sequence used by the first hand. The first is *anatomical symmetry* (e.g. thumb to little finger on



(A) Geographic distribution of the societies in the sample (*n* = 33). The European group included one medieval instance; all others were contemporary.

(B) Hand used to initiate counting (*n* = 11), showing left-start bias. In comparison, while most of the Cosquer and Gargas stencils were left-handed, the need to hold flexed fingers against the painted surface would have influenced hand choice; starting hand was thus indeterminate.

(C) Type of modification made to fingers to represent number (*n* = 21). Flexion and extension were preferred. The Cosquer and Gargas stencils appeared to represent extended finger systems.

(D) Finger used to initiate counting on the first hand (*n* = 22), showing preferences for using outside fingers and starting with the little finger. The Cosquer and Gargas stencils appeared to start with the thumb.

(E) Finger used to end counting on the first hand (*n* = 20). Considered with Fig. 1D, a preference for little finger-to-thumb sequencing was suggested. The Cosquer and Gargas stencils may have ended with the little finger.

(F) Type of symmetry (*n* = 8), showing preference for anatomic symmetry. Since the Cosquer and Gargas stencils may represent single-hand quantities, type of symmetry was indeterminate.

(G) Use of infeasible finger-pattern for 1 or 4 (*n* = 9). Both Cosquer and Gargas included this pattern.

(H) Distribution of highest number counted (*n* = 26) as categorised by Divale (1999). The upper limits of Divale's two lowest categories were extended to include all sample data. The Cosquer and Gargas stencils suggested a system in one of the two lowest categories.

(I) Fingers-only or fingers-plus (*n* = 33), showing preference for fingers-only or fingers plus-toes. Fingers-plus systems were more likely to count to higher quantities (Fig. 1J). The Cosquer and Gargas stencils could represent fingers-plus systems if considered with material artefacts for counting.

(J) Distribution of highest number counted (*n* = 26) according to system type (fingers-only or fingers-plus). Since the stencils were temporally and geographically proximal to artefacts for counting, both might have been components of an overall system capable of representing higher quantities.

(K) Successive (ordinal) and cumulative (cardinal) systems compared to highest number counted (*n* = 10), showing even distribution among the categories. The Cosquer and Gargas stencils might represent a cumulative, small number system.

(L) Base number distribution (*n* = 15), showing decimal as most common. 'Mixed' systems used groupings of 5 (i.e. 5, 10, 20 and 60). The Cosquer and Gargas 'integers' would have had a similar anatomic basis.

Figure 1. *Distribution of the most typical features of finger-counting systems in graphical format. Not shown are two single category (*n* = 33, 100.0%) distributions: dimensionality and dimensional representation, and the distribution (*n* = 26) of the use (52.2%) or non-use (47.8%) of material devices for counting.*

both hands), the second *spatial continuity* (e.g. thumb to little finger on the first hand but little finger to thumb on the second; see Bender and Beller 2012), and the third *asymmetry* (i.e. using different patterns for counting with right and left hands). In the sample, for those finger-counting systems described well enough to examine second-hand counting (*n* = 8; Fig. 1F), half (50.0%) were anatomically symmetric, and a substantial minority (37.5%) were spatially symmetric, suggesting a preference for the former. Interestingly, the African Barundi people (12.5%) were described as using asymmetric continuity for the second hand, cumulatively flexing fingers from the index to the thumb until the first hand formed a fist and commencing the second-hand count by placing the little finger against the fist (Merker 1910). These findings were consistent with the preference for anatomic symmetry and the averaged proportions (55.7% anatomic, 36.0% spatial, 8.3% other) found in Western and Middle Eastern participants, despite opposite preferences (presumably culturally mediated) for the hand and finger used to initiate counting (Lindemann et al. 2011).

Use of infeasible finger positions. Of the nine finger-counting systems described as using the little finger to create the integers 1 or 4 for which it was also possible to determine the manner of modification (Fig. 1G), a majority (66.7%) were flexed-finger systems; of the remainder, 22.2% pointed the little finger, while 11.1% grasped it. That is, a significant number of finger-counting systems incorporated one of the four finger positions deemed infeasible based on biomechanical constraints of the hand (Lin et al. 2000). None of the remaining three infeasible finger positions was used in any counting system in the sample; this was not surprising since none but the first falls in an adjacent-finger sequence suitable for counting. Neither were any of the remaining three used in the complex finger-counting system recounted by Bede, despite its expanded repertoire of finger-signs. Flexing the little finger by itself is difficult because the ring finger tends to accompany it as a function of hand musculature and normal degrees of independent control (this constraint may be bypassed in some individuals as the result of practice or unusual musculature; see Gray and Howden 1913). As previously mentioned, the constraint disappears for all individuals (assuming normal physiology) when assistance is provided by the other hand, as was the case for six of the seven flexed-finger systems (the final case being ambiguous rather than negative on this point).

Highest number counted, fingers-only or fingers-plus, and the correlation between the two. Highest number counted is an important measure of number systems because it indicates whether the subitisation constraint has been transcended and because higher numbers expand the opportunity for mathematical operations, facilitating the discovery of explicit rules (e.g. addition, multiplication, the successor function and lexical rules for creating new quantities; see Beller and Bender 2011; Hurford 1975; Overmann 2013). In the sample, highest number counted was characterisable for 26 societies (Fig. 1H); these were categorised according to Divale (1999), with 23.1% counting from 2 to 8, 42.3% counting from 10 to 55, 7.7% counting from 56 to 101, 7.7% counting from 200 to 800, 3.8% counting beyond 1000, 3.8% counting beyond 10 000, and 11.5% counting to infinity. In addition, involvement of the fingers, toes, body or sticks placed between the fingers (Fig. 1I) was characterisable for all 33 societies in the sample, with the majority (60.6%) described as fingers-only systems, 24.2% using fingers and toes, 12.1% as body-counting systems, and 3.0% placing sticks between fingers. The use of material devices was also considered (*n* = 26; distribution chart not provided), with just over half (52.2%) using devices such as knotted strings or notched sticks, the remainder (47.8%) not described as using material artefacts (eHRAF data supplemented by Beller and Bender 2005; Best 1907; Dorsey 1901; Fischer 2001; Kroeber 1920).

Finger-counting systems are not naturally limited to a highest number of 10, since the fingers may be repeated or used in combinations representing higher numbers. However, involving toes enables each individual to count to 20, and involving additional people enables counting by 20s for the number of individuals included in the count (Bender and Beller 2011). Similarly, additional body parts (wrists, arms, shoulders, ankles, legs, head etc.), sticks placed between the fingers, or finger segments can extend counting beyond 10, and the use of material devices can potentially expand the highest number counted to hundreds or thousands. Involvement of the toes, body and/or material devices (fingers-plus systems) might therefore suggest the achievement of numbers to 20 and beyond. To assess whether this was the case, fingers-only and fingers-plus systems were compared to highest number counted (Fig. 1J). Fingers-only systems comprised 81.8% of the societies described as counting no higher than 10 and 12.5% of the societies described as counting beyond 20. Conversely, fingers-plus systems were 13.3% of those counting no higher than 10 but 86.7% of those counting beyond 20. This finding was consistent with the idea that attainment of higher quantities is supported through some form of physical or material scaffolding (Overmann 2013) and demonstrated that the attainment of higher quantities may not only require material scaffolding, but will reflect the characteristics of the scaffold.

Type of finger modifications and highest number counted. There was, however, no correlation between the type of finger modifications and highest number counted (Fig. 1K). That is, the 10 systems where finger modifications could be characterised as either successive (i.e. flexing just one finger for each number counted) or cumulative (i.e. previously counted fingers remaining flexed as higher numbers are counted) were evenly split between restricted numbers (below the subitisation constraint), transitional numbers (above the subitisation constraint but still relatively limited in expressing higher quantities and performing arithmetical operations), and unrestricted numbers (systems unlimited in expressing higher quantities and performing arithmetical operations). Ifrah (2000) suggested that successive finger-counting might indicate the use of one-to-one correspondence and the development of a concept of ordinality but not cardinality (possibly indicating a more rudimentary number system), while cumulative finger-counting might indicate that a concept of ordinality had been achieved (a more complex number system). However, the lack of correlation between finger modification type and highest number counted did not support a conclusion that this was the case in the sample.

Dimensionality. Finger-counting systems can be characterised in terms of dimensionality. In a one-dimensional system, fingers (or fingers and toes etc.) directly correspond one-to-one with the objects they count (Bender and Beller 2011, 2012). Typically, the second (non-counting) hand, beyond its use for adjusting the fingers of the counting hand, extends the number counted in a simple additive manner (that is, the second hand may be used to form numbers 6 through 10). In comparison, in a two-dimensional system, the second hand is used to indicate base and power. An example would be the Indian system described by Bender and Beller (2011), in which the first hand counts integers while the second hand counts multiples of 5, the base number. Three-dimensional systems additionally add a sub-base, such as that seen in systems using bases 5 and 20: base 5 (quinary) is used as the base for lower numbers, base 20 (vigesimal) as the base for higher numbers (Bender and Beller 2011, 2012; Sizer 2004).

The present sample contained no instances of two-dimensional systems. While many societies in the sample counted beyond 10 (by including such things as toes, body parts, and additional individuals), none of them indicated the inclusions by reference to a base (that is, for example, four individuals had to be present to enable counting to 80, demonstrating the use of one-to-one correspondence rather than a base). Further, while many grouped their counts by fives, grouping by fives does not in itself suffice to constitute a base system (Bender and Beller 2012). In addition, in all instances in the sample, counting cumulatively involved the fingers of the second hand once the fingers of the first hand had been used, rather than the second hand being used to indicate the number of hand-counts. (Note: a distinction must be made for the eastern European, English and French finger-counting systems included in the present study; the associated verbal and notational counting systems obviously contain base and power, but these are not represented in finger-counting, which remains useful in [but fairly restricted to] learning number concepts and as an aid to working memory in manipulating small quantities [Andres et al. 2008b].) Since all of the finger-counting systems were one-dimensional, a chart was not generated to depict the distribution.

Dimensional representation and base size. Dimensional representation can be instantiated by finger quantity or shape: the former is a cumulative system, in which modified fingers are aggregated to form the indicated number; the latter is a ciphered system, in which numbers are indicated through the use of finger-signs beyond the 32 possible from simple digit flexion and extension (Bender and Beller 2011, 2012; note that this is a different use of the term 'cumulative' than that of Ifrah 2000, who contrasted it with 'successive' to describe systems with, respectively, cardinality and ordinality). An example of a ciphered number would be the finger-sign for 7 in the Chinese finger-counting system described by Domahs et al. (2010), which consisted of the thumb, index, and major fingers extended and pressed together with the ring and little fingers pressed against the palm. The present sample did not contain any ciphered systems; all of them (n = 33) represented numbers through finger quantity (and again, a distribution chart was not generated).

Base size, as would logically follow from embodiment with five fingers on each hand, two hands, and two feet with five toes each, is typically 5, 10 and 20; in the present sample (n = 15, Fig. 1L), over half (53.3%) were decimal; 20.0% mixed bases 5, 10, 20 and 60; 13.3% were vigesimal; 6.7% quaternary (base 4); and 6.7% octonary (base 8), with bases 4 and 8 representing the use of sticks between fingers. The preponderance of decimal and anatomically informed bases was consistent with previous findings by Comrie (2005) and Greenberg (1978). There was no correlation between base number and highest number counted; that is, decimal systems were no more likely to count to higher quantities than were systems with other bases.

Invented number system principles. Gelman and Gallistel (1986) proposed five principles of number systems that were not innate but rather had to be invented from human cognitive capabilities under the influence of culture, principles that continue to inform mathematical systems analysis. These are: (1) the one-to-one principle, which assigns distinct representations or words to each item counted; (2) the stable-order principle, the idea that order is fixed; (3) the cardinal principle, the idea that the number for the last object in a set represents the set's quantity or cardinality; (4) the abstraction principle, the idea that numbers can be applied to any type of object to be counted; and (5) the order-irrelevance principle, the idea that numeric value is not based on order (Gelman and Gallistel 1986).

Andres et al. (2008a) noted that finger-counting supports the development of discrete quantities higher than 3 (transcending the subitisation constraint) by providing a physical scaffold for internal representations of quantity connected through embodied sensorimotor experience. Stable order (principle 2) then emerges as a function of a unique first element (usually the thumb or little finger) and its immediate successors (the adjacent fingers in sequence across the hand), and cardinality (principle 3) emerges as a function of the use of cumulative fingers to represent higher quantities (Andres et al. 2008a). However, stable order can obscure the fact that neither kind nor order (principles 4 and 5) are relevant, an inherent limitation of finger-counting systems; further, as concrete instantiations of numbers, fingers cannot represent negative numbers (Beller and Bender 2011). Such limitations can be overcome through the addition of, for example, an ancillary counting system based on material artefacts or words, with analysis of the mismatches between the different systems illuminating the nature of the properties of each (Bender and Beller 2012).

Cultural mediation. Culture not only informs the selection of matters such as which finger is used to initiate counting and how it is modified to do so, increasing complexity in material culture has been correlated with increases in the highest number counted (Divale 1999; Overmann 2013). Once available, numbers act as a cognitive technology, a socially situated body of knowledge that imposes organising conceptual structures on environmental stimuli, changing the way individuals comprehend and react (de Cruz 2008, 2012). As a cognitive technology, numbers are extended to a variety of social purposes (e.g. survival and economic functions, trade, gambling, rituals, time) and imply the development of social values (e.g. wealth, social prestige, pragmatic utility; see Overmann 2013). Higher numbers counted, then, imply greater complexity in material culture and the use of numbers as a cognitive technology in socially situated contexts, a characterisation that might inform the interpretation of the culture creating the Cosquer and Gargas stencils.

Another recurrent theme of cultural influence on counting in the sample was the importance of social attitudes regarding its knowledge. In several societies, counting was considered unimportant (for example, though not considered in the present study, the Amazonian Pirahã have been described as believing that they do not need to know how to count; see Everett 2005). In others it was considered esoteric knowledge and thus was reserved to or proscribed for certain classes of individuals (for example, for the Yupno, mature men were included, while boys and women of any age were excluded; see Wassmann and Dasen 1994). These social attitudes restrict the availability of number knowledge in the general population, creating a secondary effect of making the knowledge more perishable (as demonstrated by the Yuki's losing the ability to perform octonary counting with sticks between the fingers through the loss of knowledgeable individuals; see Foster 1944).

Summary of finger-counting features in the ethnographic sample. In summary, the survey of modern ethnographic counting systems and consideration of biomechanical hand constraints provided information useful for interpreting the finger-signs at Cosquer and Gargas: finger-counting systems may start with either hand, involve both hands when counting to higher quantities, and include a particular biomechanically infeasible finger-pattern (whose inclusion in stencils would imply a hand placed palm down). Such systems are most likely to flex or extend the fingers. The difficulty of depicting painted representations of grasped or shaken fingers or fingers with sticks placed between them must be noted; Rouillon (2006) stated that other Upper Palaeolithic sites contain images of hands whose fingers are marked with dots, notation perhaps compatible with systems pointing at finger segments while counting. Finger-counting systems can involve just the fingers (rather than adding toes, body parts or sticks) and typically proceed across the hand sequentially from little finger to thumb or vice versa (leveraging the 'anchoring properties' of the outside digits; see Reeve and Humberstone 2011: 4). The integer 1 is most commonly formed by extending only the thumb (in which case the integer 5 is formed by extending all five finger) or by bending just the little finger (in which case 5 may be represented by a closed fist).

The characteristics of a finger-counting system might not reveal the extent of its numbers or whether explicit rules or concepts such as cardinality had been discovered. However, single-hand systems generally counted only to small quantities, and systems that included things like body parts or material devices were likely to count beyond 20. Finger-counting systems were typically one-dimensional, represented number cumulatively, and had a base number reflecting human anatomy. The inherent limitations of finger-counting (i.e. obscured order and kind; negative numbers not intuitive; Beller and Bender 2011) could be overcome through the use of material artefacts, and possibly by recording images in paint. Finally, number systems in general, especially those of societies developing abilities to represent and manipulate higher quantities, implied increasing complexity of material culture, as well as emerging social purposes and value systems; social attitudes occasionally restricted the knowledge of numbers, making the knowledge more perishable.

Interpreting the Cosquer and Gargas stencils

About two-thirds of the Cosquer stencils (Fig. 2, upper top row) were made with the thumb placed to the right (Clottes et al. 2005; Rouillon 2006), a pattern produced either by the left hand placed palm down or the right hand placed palm up. The former was more likely for two reasons: first, it is easier to bypass biomechanical constraints on the independent flexion of individual fingers when the hand is pressed against a surface; second, using the left hand as the stencil frees up the right (dominant for a significant

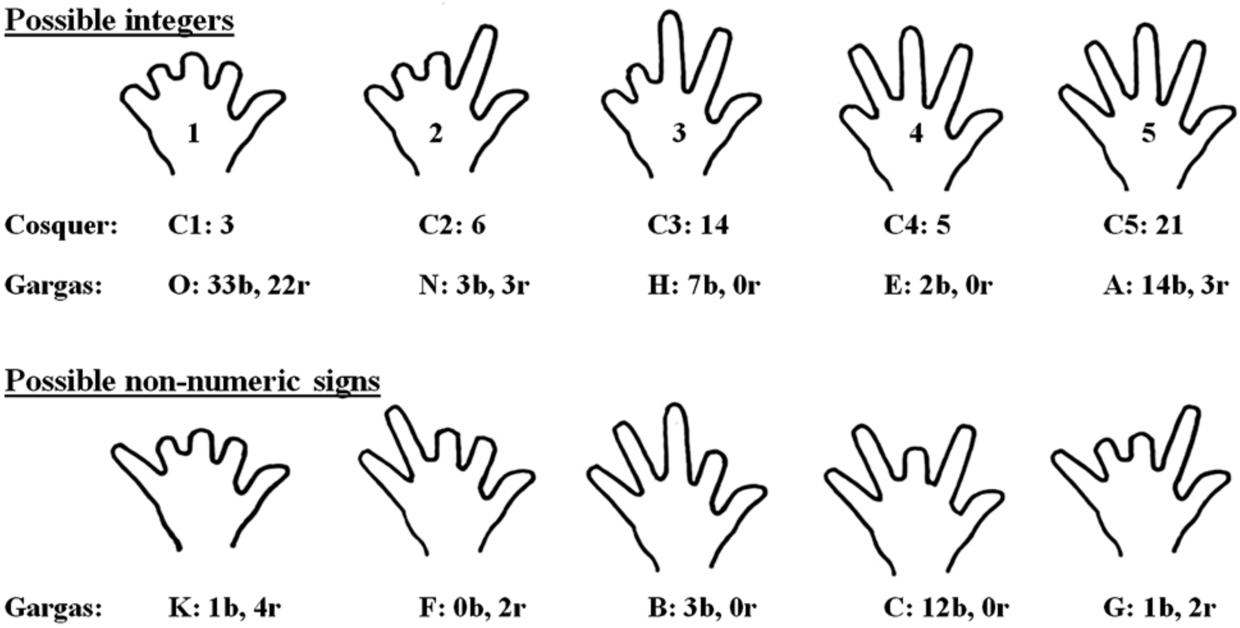


Figure 2. *Finger-signs found at Cosquer and Gargas (adapted from Leroi-Gourhan 1967 and Rouillon 2006). Top: finger-signs possibly comprising the integers 1 (C1, Cosquer; O, Gargas) through 5 (C5, Cosquer; A, Gargas) and associated frequency of occurrence. Only 112 of 157 Gargas stencils were characterised in terms of finger-pattern (Leroi-Gourhan 1967). Labels are read as follows: the finger-sign C1, possibly the integer 1, occured three times at Cosquer; the corresponding finger-sign O occured at Gargas 33 times in black (b) and 22 times in red (r). Bottom: additional finger-signs found at Gargas, with associated designators (K through G) and frequency of occurrence; these have possible non-numeric intent. Leroi-Gourhan (1967) noted that K and C corresponded to finger-signs for warthogs and giraffes used by modern Kalahari Bushmen.*

majority, handedness that has persisted for perhaps tens of thousands of years) for other tasks, including those requiring greater skill or fine manipulability (Marchant and McGrew 1998; Marchant et al. 1995; Uomini 2009; also see Gunn 2007, who notes that handedness can be outweighed by compositional concerns). Tasks in producing hand stencils might include the manipulation or application of stencil materials, especially if brushed instead of blown with the mouth. Consistent thumb-right placement might also imply that number was represented independently by each stencil rather than cumulatively (i.e. by adding the fingers on both hands together or with one hand representing base and power), though thumb-left stencils could possibly be interpreted in this manner. Both cumulative and base/power (two-dimensional) representation would be achieved (and might be depicted) by multiple-hand groupings with a mix of right–left orientations, with the former consisting of all five fingers on one hand plus additional fingers on a second hand and the latter consisting of any number of fingers on both hands; of the five Cosquer sectors in which complete stencils appear, two contain only left-hand stencils, while the other three contain a mix of right- and left-hand stencils (Clottes et al. 2005). Two-dimensionality might entail distinguishing right from left hands to differentiate base/power from counting; however, the Cosquer stencils do not provide a clear pattern (Clottes et al. 2005; Rouillon 2006). The most likely interpretation, considered independently of artefactual context, is a single-hand system capable of small quantities. Characteristics such as colour, handedness, artist characteristics and context are discussed in detail in the Appendix.

Of the 10 recurrent finger-signs found in a sample of stencils at Gargas (Leroi-Gourhan), five were the same as those found at Cosquer (Fig. 2, lower top row). That is, the stencils at Gargas represented the five finger-patterns found at Cosquer plus five additional patterns not found at Cosquer. The majority were left handed (Leroi-Gourhan 1967) and were thus produced similarly (thumb-right) to those at Cosquer. Thus, if the Cosquer stencils are interpreted as representing integers, the same finger-signs at Gargas might also represent integers. This interpretation would also imply that the five unique Gargas finger-patterns (Fig. 2, bottom row) might have had a different intent, either non-numeric or numeric, perhaps comprising hunting signs as postulated by Leroi-Gourhan or finger-signs for quantities higher than 5. As hunting practices can involve the communication of quantity, hunting might provide a context or motivation for number representation (Natalia Carden, pers. comm. 2013).

The five 'integers' at Cosquer and Gargas resemble modern finger-counting systems as follows: both included the infeasible finger-sign made by flexing the little finger while extending all other fingers and the thumb; it is represented five times at Cosquer but only once at Gargas (Leroi-Gourhan 1967; Rouillon 2006). Leroi-Gourhan considered this particular finger-pattern to be quite easy to produce, an interpretation opposed to the biomechanical constraint modeling of Lin et al. (2000). Both Cosquer and Gargas included the finger-sign made by extending just the thumb, and neither included the finger-sign made by flexing all five fingers. Taken together, these suggested an extended-finger counting system proceeding sequentially across the hand from thumb (extended to form the integer 1) to little finger (extended cumulatively with the other fingers and thumb to form the integer 5), the interpretation offered by Rouillon. Given the variation in modern finger-counting systems, alternative interpretations are also possible (for example, flexing the little finger rather than extending the thumb to form the integer 1, though 5 in such a system tends to be formed by flexing all five fingers, a finger-sign not found at either site). In view of the consistency with modern finger-counting systems and the shared cognitive functioning it represents, non-numeric interpretations of the Cosquer and Gargas 'integers' seem less likely.

Notably, both the Cosquer and Gargas integers show a pronounced decrease in the occurrence of 4 relative to more extensive use of 3 and 5 (as Rouillon 2006 noted was the case at Cosquer). Surveys of restricted-number systems (e.g. Dryer and Haspelmath 2011) show that 5 is often the first quantity to emerge above the subitisation constraint, which limits most initial counting sequences to 3 (i.e. to quantities perceived as individuals as a function of Weber and attentional constraints). The quantity 5 is typically scaffolded by the fingers on a single hand and initially represents equivalence rather than a concept of a discrete quantity per se; as knowledge of the correspondence between five fingers and five counted objects becomes more culturally prevalent, the quantity 5 receives a lexical label that enables it to join the emerging counting sequence. A counting system in this stage of development might be characterised by greater use of digits 1 through 3 plus 5, with the quantity 4 either absent or underrepresented. The correspondence of the stencils at Cosquer and Gargas to this pattern is suggestive of number systems with emerging concepts of 5 that might not have counted much beyond that quantity. However, while the integers 3 to 5 occur at a highly similar frequency (as percentages of the total 'integers') at both sites, the integer 1 does not: representation of the integer 1 was ten to twelve times greater at Gargas than it was at Cosquer (see Appendix).

The consistency with modern finger-signs, coupled with the circumstance that few of the Cosquer finger-signs appeared to have been situated conjointly (Rouillon 2006), suggested a system for counting to quantities up to 5 using the fingers on one hand in a one-dimensional and cumulatively representative fashion (i.e. 'cumulative' in the sense of quantitative, as the term was used by Bender and Beller 2012, and perhaps also in the sense of supporting a concept of cardinality, as the term was used by Ifrah 2000). Although highest number counted is difficult to construe from characteristics of finger-counting systems, Bender and Beller (2011, 2012) suggested that the range of counting is a function of dimensional representation and base, suggesting that the finger-signs at Cosquer and Gargas would comprise a number system limited to lower rather than higher quantities, with a lower-quantity range implying a restricted opportunity to discover arithmetic operations, bases and power. These characteristics would be consistent with decreased frequency at the quantity 4, as previously discussed. However, once the larger context is considered — that of material devices suggestive of quantification such as the notched bones found at Abri Cellier — an interpretation of the finger-signs as comprising part of a larger system capable of quantifying to 20 or more (likely nonverbally through the use of toes or artefacts) might also be possible, though it would necessarily assume a persisting regional tradition for quantification (i.e. a tradition connecting images with artefacts would need to span the time and distance separating the various sites).

A one-dimensional, cumulatively representative system is capable of providing nominal information (mutually exclusive categories, consistent with one-to-one correspondence), ordinality (rank ordering without regard to the differences between quantities), interval information (rank ordering with uniform and thus meaningful quantity differences), and cardinality (the last number counted represents the quantity of a set), though its ability to impart ratio information would remain limited without a meaningful notion of zero, a concept not found in any finger-counting system in the present ethnographic sample and one known to have developed slowly even in highly capable counting systems (e.g. Justeson 2010). A one-dimensional, cumulatively representative system would also be capable of supporting the development of the principles of one-to-one correspondence, stable-order and cardinality (Bender and Beller 2012; Gelman and Gallistel 1986).

The Gargas stencils included finger-signs beyond the set comprising potential integers 1 through 5, though Leroi-Gourhan (1967) did not report the use of finger-signs beyond the 32 formed by digit shortening (e.g. there were no finger-signs that might represent ciphered numbers). The number of finger-signs as reported by Leroi-Gourhan showed that those possibly interpreted as integers (Fig. 2, lower top row, O through A) occurred three times more frequently than those that were possibly not integers (Fig. 2, bottom row, K through G). This distribution supported an interpretation of K through G as possibly comprising the hunting signs suggested by Leroi-Gourhan (i.e.

signs with non-numeric intent, an interpretation he informed by comparing them to finger-signs used by modern Kalahari Bushmen; K corresponded to a warthog, C to a giraffe). Alternatively, these finger-signs might signify quantities 6 through 10 (i.e. signs with numeric intent), noting that this interpretation would entail that some of the finger-signs were ciphered rather than cumulative, an interpretation deemed less likely because the use of ciphered finger-signs is unusual in modern finger-counting systems.

As quantification devices, fingers are fairly limited, even when supplemented by other anatomy or artefacts, functioning mainly to aid working memory in the moment of counting (aside from the occasional possible recording in paint). Their accuracy, or their ability to reproduce a quantity's actual value, is generally limited to values that can be counted using both hands (as supplemented by the feet and conventionalised locations on the arms, legs, head and torso), with the result that systems based solely on these aids may be restricted and somewhat eccentric in the quantities they can express and manipulate. The problem is demonstrated in Yupno body-counting, where body positions used for higher quantities are unique to the individual, with the result that quantification becomes increasingly erratic as quantities increase (Wassmann and Dasen 1994).

The precision of a finger-counting system, or its ability to reproduce a quantity's value under different conditions, diminishes whenever something interrupts the counter's attention. The capacity of a finger-counting system does not generally afford an ability to handle large or complex numbers (which can only be manipulated through features such as dimensionality or ciphered representation; however, such complex systems are also associated with increased calculation errors, concomitantly decreasing their accuracy and precision; see Bender and Beller 2012). Further, finger-counting systems lack the ability to communicate across time or distance. Such limitations, however, can be overcome through the use of material devices, with spatial–temporal communicability limitations possibly overcome if finger-signs were depicted as images. However, stencilling numbers as finger-signs in caves would not resolve all communicability issues: They could not be dispatched between social groups in the way that, for example, knotted strings could be, instead necessitating travel to dark and difficult-to-access locations, an infrequency and spatial restriction suggestive of an esoteric tradition. Recording finger-signs in paint might, however, also imply that those who made them were becoming aware of the limited persistence, accuracy, precision and communicability of their finger-counting system and had begun transcending these constraints by enhancing system attributes with iconic means.

The interpretation of the Cosquer and Gargas stencils as finger-signs with quantificational intent does not, of course, remove all questions regarding intentionality. For example, the finger-signs do not appear in an explicit sequence of 1 to 5 (Leroi-Gourhan 1967; Rouillon 2006), an organisation that might be consistent with teaching or initiation. Just as they do not appear in obvious combinations (thereby not supporting interpretations of forming higher quantities), they do not always appear in clear association with images and thus remain ambiguous regarding what they may have been intended to count or record (Clottes et al. 2005; Rouillon 2006). Interpretation is additionally challenged by the fact that natural and intentional processes have altered or destroyed stencils (Clottes et al. 2005), reducing the likelihood that numeric information can be reconstructed.

Once they had been painted, stencils would not be as easily altered in the quantity they expressed as material artefacts can be, though more stencils could be added, as additional cutmarks could be made to a notched stick. The stencil's more static nature implies a difference in quantificational intent relative to that of material artefacts, perhaps that of recording rather than accumulating (Natalia Carden, pers. comm. 2013). The use of finger-signs to represent quantity (rather than cutmarks on the cave walls) also has interesting cultural implications (e.g. perhaps a magical intent), especially given the contemporaneous use of material artefacts for quantification.

Leroi-Gourhan (1967) noted that many of the Gargas stencils might have been made by children, and Groenen (1988) proposed, based on comparison with modern hands, that the Gargas stencils were made by both males and females, with ages that ranged from young to old; Clottes et al. (2005) noted the inclusion of both male and female adult hands in the Cosquer stencils, with hand-markings by children appearing to have been limited to engravings or fingers pressed into clay rather than stencils. Certainly, the involvement of both sexes in producing 'integers' would argue against a tradition restricting number knowledge to mature males. Four pairs of Cosquer stencils appear to have been made by a small number of individuals (Clottes et al. 2005), and there are 23 pairs and four trios at Gargas (Leroi-Gourhan 1967), a characteristic that might suggest specialisation (if not restriction) in the knowledge of numbers (production by the same hand is more apparent when finger-patterns are similar, reduced when finger-patterns differ, thus obscuring the true number of individuals involved). However, the number of repeated stencils at Cosquer represented a minority, suggesting wider participation by different artists in their manufacture than may have been the case at Gargas. These variations in the inclusion of children and the number of participating artists suggest that there were differences in the traditions represented by the two sites. Finally, all of the finger-sign characteristics, including their colour, handedness and orientation, must be considered when inferring cultural meaning and intention. Thus, the finger-signs, even if unambiguously quantificational, do not yield all of their secrets, remaining mysterious as to their larger role within Upper Palaeolithic life.

The social context of the Cosquer and Gargas stencils was rich. It contained material artefacts suggestive of quantification and astronomy, representational art, complex lithic tools, exotic raw materials implying travel and trade, ornaments made of a variety of materials suggesting status systems, and regional variation implying cultural differences (Conneller 2011; Jègues-Wolkiewiez 2005; Hayden and Villeneuve 2011; Marshack 1972, 1991; Overmann 2013; Vanhaeren and d'Errico 2006; Woods 2011). A conservative interpretation of the stencils supports the idea of a society with numbers for lower quantities, if not one on its way to inventing explicit concepts of higher quantity (Overmann 2013; Rips et al. 2008). Further, the location of the Cosquer and Gargas stencils in fairly inaccessible underground locations suggests an esoteric tradition (e.g. Clottes and Courtin 1994) that would be consistent with cultural themes of restricting number knowledge to prestige groups in such a way that might also render it fragile, given the loss of certain group members (i.e. hunting was dangerous, and age and gendered division of labour tends to put mature men, the most likely to possess numbers in an esoteric tradition, at the forefront of hunting; see Kuhn and Stiner 2006; Trinkhaus 1995, 2011).

In summary, the Cosquer and Gargas 'integers' are highly consistent with modern finger-counting practices showing cross-cultural tendencies related to the embodiment of the perceptual system for quantity with 10 fingers. The stencils may represent quantificational intention in a less ambiguous manner than material artefacts do, and should be considered in the context that artefacts capable of instantiating quantity were known in the same general time frame, with both images and artefacts comprising components of a more capable quantification system. The finger-counting at Cosquer and Gargas most likely proceeded from thumb (1) to little finger (5), involved a single hand in a one-dimensional, cumulative system, and may indicate a society transcending the subitisation constraint to develop an emerging concept of 5 and possibly counting to 20 or higher (at least nonverbally) if material devices were also used.

Other interpretations are possible, especially for the question of whether particular finger-signs mean specific integers, consistent with the range of variability found in modern finger-counting systems; however, these would represent variants found less frequently in the modern sample. Since there are dozens of Upper Palaeolithic sites with stencils, though few with as many as Cosquer and Gargas, future studies should consider additional sites (particularly Chauvet, Pech-Merle and Tibiran in France, El Castillo and La Garma in Spain, since they contain larger stencil collections; see Snow 2006), including stencils and hand prints marked with dots, to determine whether similar quantificational patterns hold. If other sites with stencils are found not to show a similar pattern, it should be noted that modern groups in geographic proximity to each other (i.e. where cultural diffusion is more likely) occasionally show differences in their ability to quantify (e.g. Overmann 2013), though this might also argue against a persisting regional tradition. Moreover, modern groups have forgotten number knowledge either in whole (e.g. the Yuki; see Foster 1944) or in part (e.g. the Ifaluk; see Burrows 1953). Thus, it would not be impossible for Cosquer and Gargas to represent an isolated tradition of numbers. Additional analysis of artist age and sex and the number of individuals involved in recording the finger-signs might shed further light on the cultural use and meaning of Upper Palaeolithic numbers.

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APPENDIX

Stencil characteristics

Number, colour, handedness and percent of 'integers" in the Cosquer and Gargas stencils:

Characteristic		Cosquer					Gargas				
		Quantity	Percent	Quantity	Percent	Total	Quantity	Percent	Quantity	Percent	Total
Stencils	Total	66	100%				231	100%			
	Sample	49	74.2%				157	68.0%			
Colour		Black		Red			Black		Red		
	Total	44	67.7%	21	32.3%	65	143	61.9%	80	34.6%	231
	Sample [1]	33	67.3%	16	32.7%	49	108	68.8%	49	31.2%	157
Handedness		Left		Right			Left		Right		
	Total [2]	41	62.1%	9	13.6%	66	136	86.1%	22	13.9%	158
	Sample	42	85.7%	7	14.3%	49	Mostly left-handed (Leroi-Gourhan 1967)				
'Integers'	Sample	Integers		Other Signs			Integers		Other Signs		
		49	100.0%	0	0.0%	49	87	77.7%	25	22.3%	112

Note. Data from Barrière (1976); Clottes et al. (2005, especially pp. 168–176); Leroi-Gourhan (1967), Rouillon (2006); and Snow (2005). [1] At Gargas, a minority of the stencils (n = 8, 3.5%) were yellow, brown, or white (Barrière 1976). In addition, black–red ratios were consistent (about 2 to 1) across finger-signs with possible numeric and non-numeric intent. [2] At Cosquer, about a quarter (n = 16, 24.2%) of the stencils were indeterminate regarding handedness (Clottes et al. 2005).

Finger-sign distribution:

Cosquer			Gargas					
			Possible integers			Other finger-signs		
Finger-sign	Quantity	Percentage	Finger-sign	Quantity	Percentage	Finger-sign	Quantity	Percentage
C1	3	6.1%	O	55	63.2%	K	5	20.0%
C2	6	12.2%	N	6	6.9%	F	2	8.0%
C3	14	28.6%	H	7	8.0%	B	3	12.0%
C4	5	10.2%	E	2	2.3%	C	12	48.0%
C5	21	42.9%	A	17	19.5%	G	3	12.0%
Total	49		Subtotal	87		Subtotal	25	
			Total	112				

Note. Data from Clottes et al. (2005, especially pp. 168–176); Leroi-Gourhan (1967), and Rouillon (2006). Both Cosquer (Rouillon 2006) and Gargas showed a decrease for the 'integer' 4 relative to 3 and 5 ; however, the frequency of occurrence of the 'integers' 1 and 2 varied across the two sites.

Other information:

Characteristic		Cosquer	Gargas
Context		The stencil (*n* = 1) in Sector 105 appeared alone, those in Sector 127 (*n* = 11) with a single animal figure (ibex); stencils in Sectors 107 (*n* = 2), 117 (*n* = 16) and 205 (*n* = 35) appeared with multiple figures, including some that were human (Clottes et al. 2005).	The Gargas stencils were distributed in Sections 1 through 5 in Ensemble I, Groups 36 and 38 in Ensemble II, and Section 27 and Groups B through F in Ensemble III; all three areas contained animal figures (Barrière 1976; Leroi-Gourhan 1967).
Artist	Age	Adults only for stencils; hand-markings by children appeared restricted to engravings and pressing fingers into wet clay (Clottes et al. 2005).	Ages ranged from young to old, and many of the stencils appeared to have been made by children (Groenen 1988; Leroi-Gourhan 1967).
	Sex	Produced by males and females.	Produced by males and females.
	Number	Four pairs of stencils appeared to have been produced by a limited number of individuals (Clottes et al. 2005).	There were 23 pairs and four triplets of repeated stencils (Leroi-Gourhan 1967); the text was unclear as to whether these were repeated by artist hand, finger-pattern or both.