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Primates' constructional abilities

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Summary - *In this paper we propose a model of early constructional abilities of human and nonhuman Primates and show how the model applies to the data available in the relative literature, that we review. We also compare our model with primatological models of object combination and tool use. We finally consider what the archaeological record on structures allows us to hypothesize about the evolution of constructional abilities in the* Homo *species.*

Keywords - *Allocentric frame, Body reference, Constructions, Primates, Spatial reasoning.*

Spatial knowledge is a basic cognitive domain in Primates. To survive, all Primates must face and solve problems such as orientation in space or locating food sources. Animals determine the location of objects in space according to one of two general reference frames: egocentric and allocentric. In egocentric or self-referenced or body-referenced frames the location of an object is specified with respect to the organism and its own body, whereas in allocentric frames it is specified with respect to other objects or elements of the environment (e.g., Benhamou, 1997; Benhamou & Poucet, 1996; Bremner, 1982; Mou & McNamara, 2002; Newcombe *et al.*, Drummey & Wiley, 1998; Pick & Lockman, 1981; Pick & Rieser, 1982; Potì, 2000). This applies to behaviors like locating hidden objects in large-scale space as well as to manipulating and positioning objects in relation to other objects in small-scale space.

In the spatial domain, constructional praxis (or constructional ability) is a broad concept that refers to various activities, all requiring the assembling, joining or articulating of parts to form a single unitary structure (Benton & Fogel, 1962). In experimental psychology it includes drawing, assembling blocks, mosaics and puzzles and implies a higher spatial analysis than spatial perception and form recognition, namely, spatial representation and the representative framework (Vereecken, 1961). It is considered one of the elementary spatial functions of the brain, distinct from other functions such as spatial perception, spatial memory, spatial attention, and mental operations like mental rotation (Kritchevsky, 1988).

According to several approaches to cognition in developmental and comparative psychology (e.g. Piaget, 1952; Vygotskij, 1962; Johnson, 2001) mental events are a product of observable behavior and observable actions constitute the content of mental events through the process of internalization. Following these assumptions, when putting together separate elements an individual is not only constructing spatial relations between the objects, but is also constructing his knowledge of those relations. According to this approach, what spatial relations an organism constructs and how it does so indicates what spatial relations it represents and how.

The analysis of what object configurations an organism is able to produce or reproduce and through what processes allows it to be determined whether this organism understands spatial relations between objects within an allocentric framework. In this respect, constructional praxis is a valuable diagnostic tool for comparing cognition in different species of Primates. Furthermore, constructional praxis is an especially advanced form of spatial reasoning. Indeed, reasoning about spatial relations means that two or more elements of a problem or situation are considered together in order to arrive at a course of action (Fragaszy & Cummins-Sebree, 2005, quoting Bermudez, 2003), and includes "consideration of objects and surfaces with reference to each other and movements of objects by the body (such as how to bring object X into contact with object Y)" (Fragaszy & Cummins-Sebree, 2005, first paragraph).

In human cultures, constructional praxis is reflected in building activities like building houses, palaces, towns. Certainly, the level reached by humans in constructional praxis has no counterpart in any other extant Primate species. We can therefore deem unmatched the level reached by modern humans in understanding the spatial relations between detached objects. Still, spatial construction is present, at different levels of complexity, in different species of extant Primates. Moreover, children develop this behavior slowly. Therefore, comparing the development of spatial construction in human and nonhuman Primates and tapping the level reached by each species can contribute to specifying Primate differences in spatial reasoning and cognition, and to understanding the origin of these differences. In this paper we present a model of constructional praxis to be used as a basis for comparative purposes, and also consider what the archaeological record can tell us about the abilities of *Homo* species.

A comparative model of constructions

In the following a model of constructions is proposed that is first intended to single out and order the most important properties of constructions. A first basic distinction to be made is that between constructions as spatial products and as constructional procedures. For instance, if a subject puts a block on another block, the spatial product is a stack, but the process is the manoeuver by which he produces the stack. Products and procedures are treated separately in the following.

Constructions as spatial products

Following Langer's definitions of constructions (Langer, 1980), a minimal construction implies that at least one object is actively placed in contact with at least one other object. Subsequently, new objects can be added to the same construction provided that previous object placements are not changed. A new construction is generated whenever the objects or their positions are changed (i.e., one or more objects are removed and/or the same objects are placed differently). Constructions can be stable or unstable. Stable constructions must last at least 1 second beyond the moment of production and be self-standing independently of the contact with the hands of the builder.

Generating stable constructions is an important achievement because stable constructions allow a subject to observe and internalize spatial relations as stable elements of cognition. Moreover, stable constructions allow a subject to further elaborate and combine spatial relations. For example, once a subject is able to make a stable stack of blocks, it can also start to make two stacks of blocks next to each other. At the level of unstable constructions, human babies only generate minimal combinations of 2 or 3 objects (and one relation and one dimension), whereas they start to generate complex constructions only after generating stable minimal constructions for a long time. However, nonhuman Primates can generate very complex constructions with numerous objects that are unstable (Potì, 2005). Another index of stability can be added for comparative purposes: Sequentially adding new objects without modifying the configuration of the objects already in position. Stable constructions represent a higher level than unstable constructions, but we consider the property of stability as transversal to other properties of constructions. These other properties define different levels and sub-levels of constructions, as discussed below.

We illustrate the model in Table 1. The number of dimensions along which a construction extends are the primary indicators of the level of its cognitive complexity, and are indicated by a number (1-3). At level 1 we have unidimensional constructions; at level 2 bidimensional constructions, that are elaborations of unidimensional constructions, and at level 3 we have three-dimensional constructions that are elaborations of bidimensional constructions. For example, a unidimensional construction is a line of four blocks. It is unidimensional because it extends along one of the two dimensions of the horizontal plane of Euclidean space. An example of bidimensional construction is the so-called "horizontal corner" made up of a line of *n* blocks, in contact at 90° with another line of *n* other blocks, and the overall construction extends in the two dimensions of the horizontal plane of Euclidean space. Finally, an example of a three-dimensional construction is a combination of a tower and a horizontal corner, a further elaboration of towers and lines.

Within each level, a first sub-level refers to the type and the number of types of relations included in a construction, and is indicated by a letter. We consider three basic types of spatial relations: *In* (an object into another), *On* (an object onto another), and *Next-to* (an object next to another). The three types of relations can obviously be combined in the same construction.

The three basic types of relations present different levels of cognitive difficulties. Some authors have suggested that constructing *In* and *On* relations requires less coordination and planning than constructing *Next-to* relations (Sugarman, 1983; Stiles-Davis, 1988). *In* and *On* relations are physically more challenging. For example, producing *On* spatial relations requires careful balancing against gravity. At the same time physical constraints simplify constructing these relations by offering a predetermined frame and a limited set of options: There is only a limited number of ways in which one can put an object in or on another. Moreover, to construct

Tab. 1 - The model.

CONSTRUCTIONS		
Level 1-3		Number of Euclidean dimension
First Sub-level A-C		Number and types of relations (*In*, *On*, *Next-to*, and combinations)
Second sub-level 1,…		Number of objects
PROCEDURES		
Level 0		Undifferentiated object placement[a]
Level 1		Simultaneous object placement
Level 2		Sequential object placement
	Sub-level a	One direction
	Sub-level b	Two directions
	Sub-level c	Three directions
Level 3		Shifting object placement between paired constructions

[a] manipulating two or more objects with the same body part.

In or *On* relations it is sufficient to relate only two objects at a time: Each new object has only to be related to that immediately supporting it or to its container, no matter how many objects are stacked or put into a container. However, *In* relations are considered even simpler than *On* relations because they are irreversible: For example, it is impossible to put a cup in a stick. Therefore, to repeat an *In* relation it is sufficient to choose the same type of objects. Conversely, *On* relations are reversible because it is possible to reverse the order of placement between, for example, two stacked blocks (exceptions are possible, see Hayashi & Takeshita, 2009). Moreover, it is possible to elaborate *On* relations, for example, by crisscrossing two sticks. Still, towers are simpler constructions than lines. Making a tower only requires one place, one dimension and one direction of object grouping. In comparison, constructing *Next-to* relations is physically unconstrained, but cognitively more costly: There are multiple ways to put an object next-to another and it is possible to construct in more than one direction (e.g., adding objects to a line on both sides) and dimension (e.g., constructing enclosures). *Next-to* relations can actually extend in the two dimensions of the horizontal plane of space. Moreover, in *next-to* constructions each object occupies an independent position in space which needs be specified with respect to all other objects. In sum, there are more degrees of freedom in constructing *Next-to* relations than in constructing *On* relations, and to repeat a *Next-to* relation, as in making lines, it is necessary to simultaneously consider all the spatial relations between all the objects involved, that is, the number of object relations to be simultaneously considered increases directly with the number of the objects combined (nevertheless, it is also possible to reduce the degrees of freedom when making lines by adopting particular procedures, see the relevant paragraph below).

For these reasons we propose that *In* relations indicate sub-level A, *On* relations indicate sub-level B, and *Next-to* relations indicate sub-level C (see Table 1). It is important to stress that the number of types of relations generated differs from the number of relations in a more generic sense. For example, if a stack of *n* blocks is produced, only one type of relation is generated, the *On* relation, though it is repeated *n* times. Furthermore, if a combination of a stack of three objects and a line of two objects is constructed, two types of relations are generated, although five objects and four relations are generated overall. A construction including two or three types of relations indicates a higher level of construction ability than a construction in which one relation is repeated as in a tower of *n* blocks. Indeed, when generating more than one type of relation in the same construction it is possible to elaborate relations further, as in the case of combining a stack and a line in the same construction.

Each sub-level can be further divided into sub-levels, therefore sub-sub-levels**,** depending on the number of objects in a construction, and these are again indicated by a number (see Table 1). The number of objects included in a construction is another important aspect to consider, because combining several objects together is a prerequisite for generating and repeating the same type(s) of relation(s), which is an index of stability and of mastering that relation(s). We show the application of the model to examples of constructions in Table 2 which also reports the comparison between different species of Primates.

Construction procedures

Also the properties of the construction procedures can indicate different levels in the organization and integration of relations (see Table 1). Different procedures may index different levels of detachment of the spatial product from the specific actions used and therefore different degrees of detachment from the body reference. The lowest level of detachment is indicated by an undifferentiated placement procedure: to manipulate and combine two or more objects together with one action and/or with the same part**s** of the body, for example taking two objects together and placing them on the ground with one or both hands at the same time. If necessary, the objects can also be held using some parts of the body (Potì & Langer, 2001). Using this procedure it is difficult to monitor the spatial relations constructed between objects step-by-step, and it is difficult to detach inter-object relations from the relations between the body and the objects. Therefore, this process indicates one particular instantiation of body reference and represents a limit in focusing on object relations, not to mention relations of relations. We rank this procedure as level 0.

At level 1 we have the simultaneous procedure, in which the two hands act simultaneously and often in a similar fashion, although separately, on two objects. A classical example involves producing object matching by banging two objects together, with each hand holding one object. In this procedure the spatial product depends on specific causal and/or symmetrical actions of the two hands, and is therefore still attached to the body reference. In fact, using symmetrical and/or causal actions is one way to reduce the degrees of freedom of making lines.

At level 2 we have the sequential procedure, in which objects are placed separately one after the other. For example, a subject puts a block on the ground with one hand, then places another block next-to the first and aligned with the same or the other hand. The subject may then repeat the same procedure with a third block and so on, to produce a line. In this case, constructions are more detached from the constructional activity that created them than in simultaneous actions because the coordination is the result of separate actions. A sequential procedure indicates that subjects focus on object relations rather than on the specific effects of their actions (Sugarman, 1982). A sequential procedure thus indicates one step forward in the direction of using an allocentric reference. However, it is still possible that a specific effect of the action is reproduced over time. Moreover, it is also possible that a sequential procedure is used to reduce the degrees of freedom of producing, for example, lines, that is, by keeping one and the same direction of object placing, as when a child places a block on the ground, then a second block to the left of the first and aligns it, then a third block to the left of the second and aligns it, and so on.

At level 3, and a further step toward using an allocentric reference, we have the shifting and integrating procedure in which at least two sub-constructions are made in parallel, either by switching between them, or else joining them afterwards. For example, a subject may put block 1 on the floor, and then block 2 on the floor, close to but separate from block 1; it may then put block 3 on block 1, and then block 4 on block 2 (it may go on by putting block 5 on block 4 or 3, and then block 6 on block 3 or 4). The result is two stacks of two (or more) blocks each, that have been made by shifting back and forth between stacks. The simplest case of spatial integration is making two separate constructions in a similar fashion and then combining them. For example, putting a stick into a cup, then putting another stick into another cup, and finally drawing the two constructions closer. In these procedures, there is no longer any repetition of a particular effect, and the action is definitively subordinated to constructing object relations that have been planned in advance.

Constructional praxis in children

The combinatory activities of very young babies are the precursors of proper constructional activities and are an integral part of the development of constructional abilities in humans. In the spontaneous play of children aged two or three years it is possible to discern miniature architectural forms, like bridges, towers, tunnels, houses. These constructions develop from simpler constructions that can be observed from the first half of the first year (Langer, 1980, see below). Several studies allow a consistent picture of this development to be traced. This literature comprises developmental scales, in which models to be reproduced are used (Bayley, 1969; Gesell, 1940; Ikuzawa, 2000; Uzgiris & Hunt, 1975; Stiles & Stern, 2001), and observational studies of the spontaneous behavior of children presented with specific objects (Forman, 1982; Guanella, 1934; Langer, 1980, 1986; Stiles-Davis, 1988; Sugarman, 1983; Vereeken, 1961). It represents a relatively small body of literature, but one which is very consistent in its results and in its approach. The general approach refers primarily to the process of internalization of practical experience with objects. The model proposed here fits the data presented in this literature very closely.

Constructions as spatial products

The main differences in scoring criteria across the various studies are related to whether only objects placed in contact (e.g., Ikuzawa, 2000) or also in proximity (e.g. Langer, 1980; 1986) were considered as part of a construction, and whether or not a construction had to be stable to be scored as such (Ikuzawa, 2000). However, a consistent pattern of the development of constructions as products emerges from literature on children. As they grow older, the children's constructions become increasingly stable. Up to the middle of their second year children mostly produce minimal unstable object combinations that do not last beyond the time of construction (Forman, 1982; Gesell, 1940; Guanella, 1934; Langer, 1980; 1986). For example, they hit one object with another, or slide one object against another, or bang two objects together with both hands. Causal and dynamical actions like these reduce children's opportunities to observe the results of their activity as separate from the activity itself. However, Langer (1980, 1986), investigating children's constructions from age 6 months on showed how the combinatory actions of very young babies, seemingly aimless and disorganized, gradually develop and turn into the clearly recognizable constructional activities observable from the second half of the second year of age of children.

As they grow up, children increase the number of dimensions of their constructions from 1 to 2 to 3, according to the properties of the Euclidean geometrical space. Typical unidimensional products developed by children between 1 and 2 years of age are towers and lines which extend in either the vertical or the horizontal plane of the space. Typical bidimensional constructions of children include arches or bridges (which comprise a minimum of three objects, with the two bottom objects put in relation by the third object on top which is supported and in contact with both bottom objects), walls and surfaces, and combinations of a stack and a line or of two lines (e.g. Stiles & Stern, 2001). All these constructions can be considered further elaborations of lines and towers. Children develop these constructions between 30 and 36 months of age (e.g., Forman, 1982; Stiles-Davis, 1988). Three-dimensional products appear at around age 3 years and are a further elaboration of the two-dimensional products. Examples are superimposed layers of surfaces or enclosures, or series of walls (e.g., Guanella, 1934).

As for sub-levels, a robust developmental finding is that the three basic *In*, *On*, and *Next-to* relations are developed by children at different rates, at least when stable constructions of two or more objects are considered. The *In* relation is developed earlier than the *On* relation, and the *On* relation is elaborated earlier than the *Next-to* relation. This pattern holds both when children combine two or more objects together, such as when they build two separate, but proximal constructions similarly (construction matching). For instance, children first develop minimal stable constructions of two objects with the *In* relation (putting a block in a container) at 9 months (Bayley, 1969; Ikuzawa, 2000; Uzgiris & Hunt, 1975), and they start to stack two objects at 11 months (Forman, 1982); then, between 11 and 12 months, children can put two objects in a container (e.g, Bayley, 1969) or match stable constructions with the *In* relation (e.g., a spoon-in-a-cup near another spoon-in-a-cup: Sinclair *et al.*, 1989; Sugarman, 1983). At 18 months children start stacking three objects (e.g., Bayley, 1969), although they make stable lines of two objects only (Gesell, 1940; Stiles-Davis, 1988). Between 18 and 24 months children can make two stacks of two objects next to each other (Sugarman, 1983), and only at 24 months do they start making lines of three objects (Gesell, 1940). Finally, between ages 30 and 36 months children start matching stable constructions with *Next-to* relations (e.g., pairing two rows of four objects each: Sinclair *et al.*, 1989).

The brief outline presented above also illustrates how children develop other aspects of constructions, namely increasing the number of objects per construction. An early development shown by children is to increase the number of simultaneously related objects, that is repeating one type of relation with more objects. For example, children progressively increase the number of the objects in a stack. This marks an important developmental step, because repeating a certain relation or pattern is a fundamental way to master it. Moreover, as far as the *On* and *Next-to* relations are concerned, the objects are also placed exactly in the same way with respect to one another, that is, the way in which a first object is put in relation to a second object is then repeated almost exactly between the second object and a third one, and so on. For example, when making a stack of three objects, children try to ensure that their borders are aligned, or when children put three objects next to one another they align their borders to obtain a more or less straight line (object matching).

Construction procedures

Several studies have analysed the procedures by which human infants produce their constructions, in particular object matching or construction matching (e.g., Langer, 1980; Stiles-Davis, 1988; Stiles & Stern, 2001; Sugarman, 1982, 1983). Children can manipulate two objects with the same hand (e.g., banging two objects on the ground together with the same hand), thus using an undifferentiated object placement, but they do so very rarely.

Children use the simultaneous procedure at an early age. A classical example is producing object matching by banging two objects against each other, holding one object in each hand. This procedure is observed in children as early as 7 months, peaking at about 16 months and then declining (Forman, 1982). Another example of simultaneous procedure is building lines as a consequence of symmetrical actions by the two hands. This is how children construct lines up to age 22 months (Vereeken, 1961). Using symmetrical and/or causal actions is actually one way to reduce the degrees of freedom of making lines.

By age 24 months children use the sequential procedure to produce object or construction matching by acting with one or two hands sequentially on the objects (Sugarman, 1982). By age 24 months, but more systematically from ages 30 and 36 months, children also use the sequential procedure to match two separate constructions. For example, a child puts a spoon into a cup and soon after another spoon into another cup. Constructions matched in immediate sequence can include any type of spatial relation.

Finally, children start to combine separate constructions at age 24 months, but they do so more systematically between ages 30 and 36 months in the context of construction matching (Sugarman, 1982). The simplest case is making two separate constructions in a like fashion, for example putting a stick into a cup, then putting another stick into another cup, and finally drawing the two constructions closer. More advanced integrations involve multiple integrations. For example, a child puts a stick into a cup, then puts a second stick into a second cup, and draws the two constructions closer; the child then places a third and a fourth cup on floor, and afterwards puts two new sticks into the new cups with each stick into each cup, and finally draws the two new constructions closer to the previous ones. These multiple integrations indicate children can construct the same spatial relation at the same time between objects and between constructions, that is to coordinate and plan relations within and between constructions simultaneously. The overall picture is that in constructional play children are progressively able to plan, compare and co-ordinate multiple relations throughout the first three years of their life (Sugarman, 1983, pp. 100-102).

Differences in constructional procedures are telling. In particular, the analysis of the constructional procedures allows developmental deviation from a normal developmental profile to be detected. In a study on the effects of early left (LH) and right hemisphere (RH) injury of 4.5- and 5.5-year-old children in a block modeling task, Stiles *et al.* (1996) found that the children with focal brain injury could copy complex constructions such as arches, horizontal corners and enclosures like normal controls at age 48 months, but, compared to normal controls, injured children did so by simpler procedures. In particular, the children with focal brain injury did not use the shifting procedure even at age 5.5 years.

Constructional praxis in nonhuman primates

Some comparative studies have examined the development of constructional praxis in nonhuman Primates by following the general framework of children's studies. There have been observational studies (e.g., Hayashi & Matsuzawa, 2003; Potì & Antinucci, 1989; Takeshita, 2001) and studies with models (Potì *et al.*, 2009). Also in this literature, the criteria for defining constructions vary slightly, but the main reference is Langer's (1980) method. Using a method similar to that for human studies allowed a meaningful comparison with babies. This literature is also restricted as the children's literature, but consistent to the same degree. Again, the model proposed here fits the data, although the results for nonhuman Primates differ in several respects from the results with children.

Constructions as spatial products

We show in Table 2 the ages at which human babies and nonhuman Primates first generate certain typical constructions during spontaneous play with objects. All nonhuman species spontaneously produced some constructions when given simple geometrical objects to play with. Moreover, they all spontaneously produced the three basic spatial relations *In, On*, and *Next-to*. These species include *M. fascicularis, Cebus apella*, *Pan troglodytes* and *Pan paniscus*.

Nonhuman Primates mainly generated constructions that did not endure beyond the time of production, but they did so to different degrees and they also differed in the level of complexity of constructions (i.e., whether constructions included one or more dimensions, one or more types of relations, and three or more objects). In particular, only chimpanzees and bonobos starting at age 6 years produced extended constructions complying with the criterion of durability of adding objects sequentially, i.e, without modifying the configuration of the objects already in position (see relevant paragraphs below).

Long-tailed macaques (*M. fascicularis*) constructed less often than capuchins or chimpanzees and they mainly made minimal constructions of 2 objects each (Potì & Antinucci, 1989) (see Table 2). Moreover, as they primarily held the objects with some part of the body (see the following section on procedures), their constructions were not self-standing. Macaques appeared limited to the precursors of true constructions: Their level was comparable to that of human babies aged about 6-9 months. Macaques were tested at two ages, 22 and 34 months, that both belong to the juvenile phase, which should be considered the most promising phase for curiosity and flexibility of behavior. However, the sample was small and it is possible that the subjects lacked motivation. They were separated from their mothers in their early infancy and then raised in the lab in age-mate and sex-mate couples. To better investigate macaques' potential in constructional praxis, it would be possible in principle to train macaques to produce more complex constructions in the lab. In the wild, different species of macaques have been observed to spontaneously use tools (Beck, 1980). Recently, long-tailed macaques have been reported to crack detached gastropods and crabs open with a stone by placing them on a rock (Malaivijitnond *et al.,* 2007). This type of stone-tool usage involves two detached objects (e.g., a crab and a stone) and a substrate (the rock) and is similar to the anvil-and-stone combination used to crack open nuts that has been reported for capuchins and chimpanzees (e.g., Boesch & Boesch-Achermann, 2000; Fragaszy *et al.*, 2004; Matsuzawa, 2001; McGrew *et al.*, 1997).

Three capuchins (*C. apella*) were tested at three ages: 16, 36 and 48 months (Potì & Antinucci, 1989; Potì, 1997). They started matching three objects at the age of three years, and they repeatedly produced both *On* and *Next-to* relations (Tab. 2). This finding is consistent with recent results on capuchins' use of tools in the wild. Capuchins have actually been reported to have combined three detached objects in nut-cracking behavior: A nut is placed on a stone used as an anvil, and another stone is used as the hammer to crack the nut open (e.g., Fragaszy *et al.,* 2004). However, capuchins mainly produce causal and unstable constructions (Potì & Antinucci, 1989; Potì, 1997) as children do up to their second year of age (e.g., Guanella, 1934; Langer, 1980). Moreover,

Tab. 2 - Comparison of the ages at which four species of Primates first spontaneously construct some types of spatial relation between objects.

CONSTRUCTIONS	*MACACA FASCICULARIS*	*CEBUS APELLA*	*PAN TROGLODYTES*	*HOMO SAPIENS*
1.A.2 One object into another	22 months[a]	12 months[b]	8,8 months[c]	6[c]-9 months[e,f,g]
1.B.2 Tower of 2 same shape objects	34 months[a]	16 months[h]	24 months[i]	6[d]-11 months[j]
1.C.2 Row of 2 same shape objects	22 months[a]	36 months[h]	15 months[i]	6[d]-18 months[k,l]
1.B.3 Tower of 3 or more same shape objects	No	36 months[h]	32 months[m]	10[d]-18 months[k]
1.C.3 Row of 3 same shape objects	No	No	36 months[n]	10[d]-24months[k]
2.BC.3 An arch or bridge	No	No	No	30 months[o]
1.B.2 One object onto another crossing it at 90°	No	No	6 years[p]	33 months[q]

[a] Potì & Antinucci, 1989.
[b] estimated from Spinozzi, 1989
[c] Hayashi & Matsuzawa, 2003.
[d] Langer, 1980
[e] Bayley, 1969.
[f] Ikuzawa, 2000.
[g] Uzgiris & Hunt, 1975.
[h] Potì & Antinucci, 1989.
[i] Potì, 1996
[j] Forman, 1982.
[k] Gesell, 1940.
[l] Stiles-Davis, 1988
[m] Hayashi, 2007
[n] Takeshita, personal communication
[o] Guanella, 1934
[p] Potì & Langer, 2001
[q] Vereecken, 1961

Note - Most spatial products produced by human infants up to the age of 10 months and by the capuchin monkeys at all ages are only momentary, i.e., they do not endure beyond the moment of construction and are the result of the subjects' causal and dynamic actions on the objects. Moreover, capuchins and macaques increasingly manipulate two or more objects in the air with the same part of the body.
For human infants, when two ages are given, the second one indicates when more stable and durable products are observed.

capuchins did not produce two-dimensional constructions and they did not display construction matching. In sum, capuchins present a low potential to represent spatial relations between objects independently of body and action reference. It has also to be noted that capuchins make towers and lines of three objects at the age of 36 months, well within their juvenile phase, but at age 48 months, when they become adults (Rowe, 1996), they made unstable towers and lines of 4 objects only. It is to be noted that capuchins show complex object manipulation already at 3.5 months of age (Fedigan *et al.*, 2004). So, constructional behaviors develop very slowly in capuchins and it is plausible to hypothesize that no further developments take place later in their life.

Compared to children, chimpanzees never spontaneously construct in two dimensions: They never make arches or the other types of two-dimensional constructions such as a tower and a line assembled together, which children typically develop by age 30 months. The only intermediate case reported was making two towers close to each other (Potì *et al.*, 2009). So, constructing in two dimensions may be chimpanzees' upper limit in construction.

However, chimpanzees are more advanced than both macaques and capuchins. First of all, like capuchins, also chimpanzees (*Pan troglodytes*) develop constructions with 3 objects at around 3 years (Potì, 1996) but, differently from capuchins, at that age they are still infants (Rowe, 1996). Moreover, beyond infancy, starting at age 6 years when they are still young, chimpanzees and bonobos produce complex constructions with *In* and *On* relations that are absent in monkeys (Potì, 1996, 2005; Potì & Langer, 2001). For example, when receiving 6 objects, chimpanzees stacked them all, and these towers were stable. When receiving 12 objects of three different forms, an 11 year old adolescent bonobo put four rings in a cup and then four sticks in the rings (Potì, 2005). An exceptional example of combining two types of object matching was even shown by an adult chimpanzee: He made a line of three sticks and then a stack of three rings upon the line; this construction was stable and the result of attentive placement of each object (Potì & Langer, 2001). Furthermore, unlike monkeys and children, chimpanzees showed construction matching, though predominantly with *In* and *On* relations (Potì & Langer, 2001). For example, they put a stick in a ring and then another stick in another ring spaced apart. It has also to be stressed that the chimpanzee subjects older than 5 years and showing the most advanced products had been raised in a very enriched human environment from a very early age, so that their interactive experience with objects was more comparable to that of human children than to that of the monkeys (e.g., Savage-Rumbaugh, 1986; Savage-Rumbaugh & Lewin, 1994).

In any case, chimpanzees also show specific differences from human children in their spontaneous constructional abilities. First of all, it is true that chimpanzees start producing stable *In* relations at about the same age as children do and before *On* relations. In fact, putting a block into a cup is observed in children at age 9 months (Bayley, 1969; Ikuzawa, 2000) and in chimpanzees as early as age 17.8 months (Hayashi & Matsuzawa, 2003), but putting a rod into a circular hole in a box is observed at age 13.4 months in children (Ikuzawa, 2000) and between 8.8 and 18 months in chimpanzees (Hayashi & Matsuzawa, 2003). Then, in any case, chimpanzees seem to develop *In* relations more rapidly than children: Chimpanzees seriate three nesting cups between ages 13.0 and 17.8 months (Hayashi & Matsuzawa, 2003) whereas children do so at age 17.3 months (Ikuzawa, 2000). At the same time, chimpanzees develop *On* relations more slowly than children: None of Hayashi & Matsuzawa's (2003) subjects developed stacking behaviour in their first two years of life and only one out of three chimpanzee subjects was observed by Hayashi (2007) to start stacking 2 or 3 blocks spontaneously at age 2 years and 7 months, whereas children do so between ages 11 and 18 months (Bayley, 1969; Forman, 1982; Gesell, 1940; Guanella, 1934). So, chimpanzees develop relatively more complex and extended *In* relations than children before starting producing *On* relations. Likewise, after starting constructing *On* relations, chimpanzees develop relatively more complex *On* relations whilst still producing simple *Next-to* relations. From age 6 years chimpanzees generate more complex constructions than children at age 24 months with the *In* and *On* relations. An example is stacking three sticks so that they cross each other. Another significant example is putting two rings in a cup, then four sticks on the cup crossing each other and making a stable base for a stack of the two other rings and then of the remaining three cups (Potì, 2005). Crossing objects is a particular development of stacking relations that is observed in children after age 33 months (Vereecken, 1961).

At the same time chimpanzees' construction of *Next-to* relations remained relatively undeveloped. They could align three objects or match pairs of similar objects (Potì, 2005). At 24 months children already construct lines of three or more aligned objects (e.g, Stiles-Davis, 1988), and between ages 30 and 36 months children can match two rows of four objects each (Sinclair *et al.*, 1989).

As discussed above, the *In* relations are the easiest to produce and reproduce from a cognitive point of view. Stable *On* relations are slightly more difficult to reproduce and the *Next-to* relations are the most difficult to generate and reproduce. Children and chimpanzees present the same sequence of development, but they differ in the relative rate at which they develop the three types of relations. In sum, chimpanzees' pattern of development of the basic spatial relations presents a deviation from the human one, not just a delay.

The overall pattern of differences between chimpanzees' and children's constructions point to chimpanzees' relative difficulties in simultaneously considering and coordinating independent positions in space. Further differences between monkeys and chimpanzees, as well as between chimpanzees and human babies, become apparent when considering nonhuman Primates' construction procedures.

Construction procedures

Besides the presence or absence and timing of different constructions, the way in which nonhuman Primates produce their constructions reveals species differences. First, all nonhuman species use the undifferentiated placement procedure, although they do so to a different extent. Macaques almost exclusively use the undifferentiated procedure to produce their constructions: They usually hold and manipulate two objects together with one hand and/or the mouth (Potì & Antinucci, 1989).

Most of capuchins' constructions are generated by means of causal and/or dynamic actions. Moreover, when combining three or more objects together, capuchins use the undifferentiated procedure, performing causal and dynamic actions with the same hand on two or more objects together (Potì & Antinucci, 1989). So, in the case of capuchins we find two indices of low detachment of construction as products of the properties of constructional activity: The use of causal and/or dynamic actions and of the undifferentiated procedure. Both aspects point to a reduced opportunity to observe the results of one's own activity and to internalize the relations produced as elements of cognition.

Young chimpanzees use the undifferentiated procedure when they combine three or more objects together, and with increasing age they first increase the frequency of the undifferentiated placement up to age 4 years (Potì, 1997), then confine its use to particular constructions. Young and adult chimpanzees also use the other procedures, but depending on the type of relation they repeat or match. Chimpanzees preferentially use the simultaneous procedure to match constructions with *Next-to* relations, whereas human children do so up to their second year. Conversely, when constructing towers or when they match constructions with *In* or *On* relations chimpanzees sequentially and individually place objects (Potì, 2005). Chimpanzees using simpler procedures to generate *Next-to* relations is confirmation that their pattern deviates from that of children.

Still, chimpanzees are able to perform the most complex procedures, albeit rarely. From age 6 years chimpanzees can switch between constructions as though they were matching them. Even one instance of spatial integration between two corresponding constructions was observed in an adult chimpanzee: After making two corresponding constructions each comprising a ring inside a cup, Sherman drew the two constructions closer (Potì, 2005). On this occasion, the adult chimpanzee manifested planning and was apparently representing a construction with the *In* relation as a cognitive constant, detached from the body reference. This performance remains exceptional.

Constructing in the wild: the case of nest-building

All extant Great Apes build nests, whereas no extant monkey species do so. It can actually be considered the most widespread form of object manipulation in wild apes (Fruth & Hohmann, 1996). Apes build day nests for resting and night nests for sleeping (e.g., bonobos: Horn, 1980; Kano, 1979; chimpanzees: Baldwin *et al.*, 1981; Bolwig, 1959; Fruth & Hohman, 1994; Goodall, 1962, 1968; gorillas: Bolwig, 1959; Harcourt, 1979; Schaller, 1965; orang-utans: MacKinnon, 1974). Variations are observed in several aspects of nest building both between and within ape species and variations have been attributed to a number of different factors, from species (e.g., Fruth & Hohmann, 1994) to sex (e.g., Matsuzawa & Yamakoshi, 1996) to environmental conditions (e.g., Fruth & Hohmann, 1994; McKinnon, 1974) to traditions (McGrew, 1992). Moreover, experience and learning are necessary to reach functional mature forms of nest building (Bernstein, 1962).

However, despite all possible variations in nests and the importance of experience in the ontogeny of nest behaviour, several authors have observed that the basic building technique is the same across species and/or populations and/or rearing conditions and/or environments (e.g., Fruth & Hohman, 1994; McGrew, 1992). Fruth & Hohman (1996) consider nest building a phylogenetically conservative behaviour that must have evolved in the Miocene. A nest is composed basically of three or four main components. 1. First of all, the animal chooses a foundation, which may be a horizontal fork perhaps at the top of a branch, or two adjoining parallel branches (Goodall, 1962). 2. Once the foundation has been chosen, the animal starts making the floor of the nest by putting branches one atop of and crisscrossing each other. At the beginning the animal may break one branch and put it on the foundation, and then break another branch putting it on and across the first one and then continue bending branches in (Bolwig, 1959). Or the animal may start bending the branches over the foundation without breaking them. Then the animal keeps the first branches in place by standing on them, and continues bending other branches that fan out from the foundation so that they crisscross each other. About half of the branches may in any case break in the process (Goodall, 1962). The animal uses hands and feet to hold the branches down before bending another branch over them. The leafy ends of these branches also form part of the nest, and they too are bent to crisscross each other. The animal may bend the branches backwards or forwards across the foundation (Goodall, 1962). In doing all this, the animal works from within the nest, standing on the crosspieces, and taking the branches while moving either in a circle or from one side to the other. The result is a very complicated interweaving of larger and smaller branches (Bolwig, 1959; Goodall, 1962). 3. Sometimes a ring or rim is made by bending in the ends of the branches laid down or of neighbouring branches (Bolwig, 1959). Other times a rim is not clearly distinguishable from the floor and a concave springy platform is observable (MacKinnon, 1974; Goodall, 1962). 4. Finally, the animal adds a lining to the floor with smaller branches and leafy twigs that can either project from the larger branches already laid down or be broken off from neighbouring branches (Bolwig, 1959; Horn, 1980; Goodall, 1962; MacKinnon, 1974). The loose elements of the lining are added in no particular order. Sometimes a "roof" is added which is made of a branch completely detached from the tree and held piled on top of the nest (MacKinnon, 1974). Simpler constructions have also been reported for gorillas (Harcourt, 1979) and bonobos (Kano, 1979). In all cases, the whole process may take one to five minutes whether the nest is made at ground level or high up in the tree.

Nest building requires some constructional ability. The key spatial relation in ape nests is that of placing an elongated element (a branch) on another elongated element (another branch) so that they crisscross each other (not necessarily at 90°). This is a remarkable relation to generate (human children start to crisscross blocks at around 33 months (Vereecken, 1961). Yet, the resulting interweaving of the branches is strongly facilitated by two factors: First, most branches forming the base of a nest remain attached to the trunk, so they do not fall down, although they tend to spring outwards and must be kept in place by the weight of the animal, which represents a challenge for young animals (e.g., Harcourt, 1979). Second, the natural structure of the branches allows interweaving merely by crisscrossing them at one point. As more branches are progressively added the interweaving becomes more stable. Moreover, the animal works from inside the nest, literally making the nest around and under itself. Therefore, the various elements are put in place with respect to the body of the animal as much as to other elements. For example, as they pull in and bend down the branches the animals move in a circle or move first to one side and then to the other of themselves (Goodall, 1962). The direction and rhythm of the movements of the animals result in a relatively systematic interweaving of the branches. As another example, the interweaving of the branches may appear particularly complex when the branches are bent either forwards or backwards in order to be anchored (Goodall, 1962). We suggest that the animal perceives through his body the proper direction to bend the branches as he proceeds. In sum, body reference is involved in nest-building and object-to-object relations are not generated independently of objects-to-body relations. This interpretation is consistent with the evolutionary hypotheses put forward by Fruth & Hohman (1996, p. 235). These authors suggest that nest building is a by-product of the feeding habits of the apes as they were evolving in the Middle Miocene, which probably derived from feeding nests that are observable also today. Feeding nests result from apes bending and breaking toward their bodies the distal peripheral branches carrying the tastiest and ripest fruits. Apes do this as they sit on more solid parts of the branches proximal to the trunk, so that their hands are free. After a while the end of the branch is made more solid by broken branches that form a kind of feeding platform and apes go and sit there. Nowadays apes build night nests not in feeding trees, but nearby, and they can build day nests in feeding trees. In fact, the authors suggest that nest building was one way of monopolizing food resources which, together with body size, group size and physical power, allowed apes to compete successfully with monkey species and survive through the Middle Miocene. Moreover, nests must have allowed apes to sleep safely, thus avoiding ground predators and, by increasing the quality of sleep, even to evolve higher learning and cognitive abilities. Fruth & Hohman (1996) consider nests the first tool and the foundation for all future tool use ability.

Also Baldwin *et al.* (1981) proposed that this behaviour evolved million years ago in the common ancestor of the apes and that it was already a stable pattern before the different pongid lines diverged. They proposed three hypotheses to explain why that behaviour first evolved, all concerning different aspects of the need for safely and/or comfortable sleeping. However, as the authors observed, more than one functional method was possibly devised to build a platform capable of supporting the weight of an adult ape. So, the fact that nest building evolved millions of years ago is no direct answer to the question of why apes should build nests in such a conservative manner. We suggest that nesting behaviour is relatively inflexible because, as already discussed above, the body of the animal and its actions and movements are an integral part of the scheme. Nest building depends on sensorimotor routines. There are also structural reasons why nests are not susceptible to change: The foundation is chosen, not constructed, and most of the main components are also attached elements.

To conclude, apes, and chimpanzees in particular, show spontaneous constructional behaviour in the wild. However, apes' constructional behaviour in the wild is relatively inflexible compared to the spontaneous constructional behavior of human children. Moreover, according to the present model, ape nests are stable but unidimensional constructions extending in the vertical plane of Euclidean space. Elements are basically connected by *In* and *On* relations. Furthermore, nests are peculiar constructions in which most elements are not detached, and the detached ones (twigs and leafs added at the end) are mostly massed together or piled up. All these properties are consistent with the limits of chimpanzees' constructions observed in lab studies.

Some chimpanzees' constructional behaviors observed in captivity seem to be related to apes' natural propensity to make nests. This is the true in the case of piling blocks one atop the other, a constructional behavior that has been observed to develop spontaneously between the ages of 2 and 4 years in chimpanzees (Hayashi & Matsuzawa, 2003; Potì, 1997), or easily learned in chimpanzees in their third year of life (Hayashi & Matsuzawa, 2003). Another notable example is spontaneously stacking and crossing sticks, which was observed in a juvenile chimpanzee (Potì & Langer, 2001). Indeed, adult chimpanzees can stack and cross three blocks precisely when provided with a model (Potì *et al.*, 2009). One further peculiar behavior observed in the free play of young and adult chimpanzees may be linked to nest building, namely placing several objects all around oneself (Potì, 2005).

Comparison with primatological models of object combination and tool use

Fragaszy & Cummins-Sebree (2005) proposed a relational model of spatial reasoning that applies to object manipulation and tool use (hereinafter denoted as the F & CS model). Construction activity is an instance of spatial reasoning according to the F & CS model and implies object manipulation and combination. A comparison with this model is therefore of interest. The authors have considered several aspects of the task of putting two or more objects in spatial relation to each other and their model is a good step forward towards classifying and comparing diverse behaviors in the domain of spatial knowledge. However, the F & CS model does not fit the properties of constructional praxis very well, and it is more consistent with the properties of various forms of tool use.

A key difference between the model of constructional praxis proposed here and the F & CS model is the meaning of dynamic and static relations. In both models duration is a critical feature of the spatial relations produced by action. However, the role of constructing static or dynamic relations for spatial cognition and development depends on which of the various forms of tool use or constructions are considered. Indeed, when using tools, static relations are instantaneous, such as when banging a stone on a nut to crack it open, though the whole process can be repeated. Conversely, dynamic instrumental actions require a sustained attention over time to continuously adjust the action to the ongoing result as when pulling in an object with a stick that must be repositioned to maintain contact with the food during pulling. Therefore, in using tools, producing dynamic relations is more demanding than producing static relations. The opposite is true in the case of constructions: The ability to construct static relations is more difficult and a later achievement compared with constructing unstable dynamic relations (Langer, 1980). Static relations can endure and can be observed and internalized as elements of spatial knowledge separate from the subjective activity. Static relations also allow further elaboration, as when a subject increases the number of blocks it can stack firmly, from two to three to four and so on. Stable constructions comprise static relations and, as discussed at the beginning of this paper, producing stable constructions requires focusing on relations and an allocentric reference.

In sum, whereas more durable instances of tool use involve a continuous dynamic process in which the subject continues to act on the tool while monitoring the changing effects of the action, more durable constructions are those where non causal and non dynamic actions are used (and where the subject can add new elements to what has already been done). Incidently, this difference might explain why species that spontaneously perform tool use in the wild (like macaques and capuchins) do not show any spontaneous constructional behaviour of their own either in the wild or in the laboratory.

Another key difference is that, in a model of constructional praxis, the number of the types of relations generated in a construction must be considered, something that is different from how many objects are put together. Conversely, in the F & CS model (as in models of tool use) the term "relation" is used in a very general sense and the number of relations generated is a direct function of the number of objects put together. As a consequence, in their model the Zero Order refers to combinations of one object to the body or to a surface, the First Order refers to combinations of two objects, the Second Order refers to combinations of three objects, and so on. The same consideration applies to the Matsuzawa's model of tool use and tree-structure analysis of the cognitive processes involved in a behavioral pattern dealing with multiple objects (Matsuzawa, 1996). The tree structure analysis focuses on the objects manipulated and specifically on connections of connections of objects. It proceeds from Level 0 of an action directly performed on an object (as in the example of touching a nut), to Level 1 of two objects related or connected to form a "node" (as in the example of using a twig to fish for termites), to Level 2 of an object connected to a previous cluster of two objects to form a new higher "node" (as in the example of using a hammer stone to hit a nut placed on an anvil stone – where nut and anvil stone constitute the previous level 1 cluster), and so on. So, levels of complexity increase with the number of nesting clusters in the tree structure. The hierarchy of levels in the F & CS model or in the Matsuzawa's model corresponds to the number of objects in the present model.

Other distinctions put forward in the F& CS model may not be relevant for constructions or are perhaps relevant to a different extent. First, the distinction between direct and indirect relations: a relation is indirect when there is an intermediate object between the action and the object on which the action is effective as in the case of pushing food out of a tube with a stick. In the case of tool use this might be telling because a tool is an extension of an arm or other organ of the subject, and if the subject focuses on more distal effects of its action, then it goes in the direction of constructing a relation between the tool and another object independently of the specific characteristics of its action and thus in the direction of using allocentric reference. However, in the case of constructions, generating relations independently of the properties of the action, or focusing on object relations, is best revealed by other aspects of combining objects together, such as what type of procedures are used (the shifting procedure being more indirect or allocentric than the sequential one, and the sequential procedure being more allocentric than the simultaneous one), and what type of relation is generated (*Next-to* relations being more indirect than *On* relations). Common to both models is the idea that to pinpoint the ability to focus on object relations at least three objects must be put together.

Another distinction proposed in the F & CS model is that between specific and permissive relations. In specific relations, at least one object is oriented or aligned with another object. This is an important aspect also for constructions. However, it may not be decided in advance whether a relation is permissive or specific. For example, when an object is put into a cup the relation may be quite permissive, as when a block or a stick is put into a relatively large cup, but in the F & CS model it is considered as specific.

Still another distinction proposed in the F & CS model has quite a different meaning in the two models. It concerns the procedures used to combine at least three objects together, that is whether object relations are *produced* concurrently or sequentially. In the F & CS model, producing relations concurrently is considered more advanced. This might be true for the dynamic events which the F & CS model mostly considers. Given the changing impermanent nature of such events, to simultaneously manage more than one relation at a time, it is necessary to *produce* the relations simultaneously, rather than sequentially. If however a relation is produced that is stable, as is possible in the case of constructions, then a sequential procedure might be more advanced than a simultaneous procedure. For example, using similar and simultaneous actions with the two hands on two separate constructions is the simplest way to match them, but a sequential shifting procedure is more advanced, because it indicates true coordination and planning of the object relations within and between the constructions (see discussion in paragraphs above).

To say it differently, in causal or dynamic combinations of objects, object relations strictly depend on the ongoing actions and the distinction between product and process is less clear cut. Differently, in constructions, what relations are represented and managed simultaneously is best indicated by the number of dimensions along which a construction extends and by the type and number of relations constructed. For example, as discussed in previous sections, when producing e.g., lines (repeated *Next-to* relations) with more than two objects it is necessary to consider the position of each object to all objects at each step, *unless* a simultaneous procedure is (repeatedly) used that reduces the degree of freedom of the construction.

To give an idea of the difference between a model of tool use and a model of construction, we would like to compare the ways in which the different models analyze the most complex case of tool use ever observed in the wild by chimpanzees, that is, the use of a stone as a wedge to stabilize an anvil stone, before using the anvil to put a nut on it and then hitting the nut with a hammer stone to crack the nut open. Only three instances in which three separate individuals made such a "metatool" were observed in all by Matsuzawa (1996). Interestingly, the youngest chimpanzee was 6.5 years old. This behaviour can be classified as Level 3 of the tree structure analysis: First cluster or "node" is given by the wedge and the anvil (Level 1); the second node connects the nut to the first anvil-wedge node (Level 2); and the third node connects the hammer stone to the nut, and thus also to the anvil wedge (Level 3). Similarly, in terms of the F & CS model, one object is related to three others through three sequential actions, so the behaviour is at the third level of the relational category. Moreover, the behaviour is complex because when the nut is cracked open only one relation is direct, and all three relations qualify as specific. However, in terms of a model of construction, a wedge-anvil-nut-hammer combination is a partly stable (with 2 objects) and partly unstable/dynamical (with 2 other objects) construction which corresponds to Level 1b because it extends in only one dimension (the vertical one) and involves only one type of relation (the *On* relation indeed), though applied to four objects.

Hypotheses regarding the evolution of constructional praxis in primates

The common ancestor of Old and New World monkeys probably possessed some rudimentary constructional abilities, which must not have been higher than those spontaneously shown by macaques today. The common ancestors must have been able to combine detached objects with reference to their body and action, which could include undifferentiated placement procedure, and/or the body as support, and/or combining a small number of objects, and/or causal and dynamic combinatorial actions. Construction abilities must then have separately evolved in *catarrhini* and *platyrrhini*, and must have evolved more rapidly in the *hominini*. Evolution went in the direction of focusing on the relations between objects and on coordinating their positions in space independently of the body reference. This may have included increasing the stability of constructions, and/or the number of the objects combined together, and/or the types of relations per construction, the number of dimensions along which to construct, and the development of new flexible procedures. The evolutionary process may not have been linear and different aspects of construction may have evolved separately. The jump to a *Homo* pattern however probably included developing several aspects simultaneously and must have consisted in the ability to coordinate multiple cognitive relations simultaneously. Its origin was possibly a domain specific ability or a domain general ability applied to the spatial domain. In the evolutionary process the capacity for nest building in the pongid line may have played a role (see above, Fruth & Hohman, 1996) possibly in combination with the development of tool using capacities (Matsuzawa, 2001). In any case, the development of multidimensional construction may require (possibly domain general) abstract abilities. Let us now turn to what the archaeological record can tell us about the spatial and abstract abilities of the various species of *Homo*.

The situation and difficulties of the archaeological record

How could we work out some realiable hypothesis about spatial human abilities in remote past? Archaeology has basically two kinds of sources at its disposal: direct, as objects, assemblages or structures and indirect ones as scientifically robust inferences from the context of archaeological sites. Among the first, since a long time we surely include stone tools, the most durable and easy recovered signature of human behavior. "Fossilized" gestures on stone tools, however, are typically subtractive ones and need a technical analysis of their making (*chaînes operatoires*) in order to say something about mental processes that originated them.

Although few enlighted scholars from mid-XIX century onward had already outlined some useful concepts about technical skills of our ancestors (Groenen, 1994), it was only a century later that the main goal of artefact analysis shifted from the study of their forms to that of their making or use, this last being much more useful conceptual tool for generating inferences about past behaviors. Just quoting the most important, we remember that F. Bordes identified cultural and ethnic traditions in morphological and technical differences in palaeolithic assemblages (Bordes, 1969), L. H. Binford and "processual" archaeologists outlined the role of each assemblage or site in the context of their landscape (Binford, 1973), S.A. Semenov founded the study of tool function (Semenov, 1964), D. Crabtree (Crabtree, 1972) and J. Tixier (Tixier *et al.*, 1980) put the experimental reproduction of tools on solid scientific basis. Grahame Clark in 1969 proposed a clear model of technical skillfulness increase with the nowadays popular subdivision in Modes 1-4 for stone tool complexes of ancient world (Clark, 1969). From the seventies onward, archaeologists have pointed out the relevance of ethological studies on primate instrumental behavior for the understanding of the oldest human technology (syntheses in Toth *et al.*, 1993; Wynn, 2002). Among these, T. Wynn has developed a tool-based *cognitive* archaeology, proposing the hypothesis that only with the achievement of a clear symmetry and volumetric regularity of stone tools an evolutionary benchmark has been achieved by the genus *Homo*, leaving the core-tool (Mode 1) technology within the realms of a generalized man-primate behavior or, at least, neurological possibility (Wynn, 1989, 2002; Wynn & McGrew, 1989; Wynn *et al.*, 2011). Other authors, however, have questioned the "primitiveness" of pre-Acheulean (Mode 1) toolkits both on behavioral (Gowlett, 1984, 1986) or technical ground (Toth, 1985, 1987; Toth & Schick, 1986). More recently, Wynn's approach has been robustly overtaken by technical analysis of 2.3 my lithic industry of Lokalelei, Kenya (Delagnes & Roche, 2005).

But if stone tools, for obvious reasons of conservation, have attracted the bulk of debate about cognitive capabilities of early *Homo*, some more "difficult" items of daily archaeological work can provide perhaps useful insights about the spatial competence of Lower Palaeolithic groups. First of all, also in the history of archaeological thought, is the controlled use of fire. This subject, not directly concerned with the goal of this work, is of the maximum ethological relevance because true fire control needs some arrangement of the space immediately surrounding heating chamber, whatever the goals of combustion. If controlled fire is highly ambiguous in African and Asian Lower Pleistocene sites (James, 1989), it is firmly documented at least from the end of Lower Pleistocene in Near East (Alperson-Afil, 2008), but - strangely - virtually absent in colder phases of Pleistocenic Europe (Roebroeks & Villa, 2011). Grossly speaking, we can affirm that from an half million year onward in Old World, fire has been fully domesticated or produced, implying at the same time – in most cases – several abilities by its makers: planning (collecting fuel), construction of borders (*i.e.,* placing stones around fire) or digging (fire is fully controlled only if combustion is protected) or both. It is worth noting that in many sites, hearth structures (usually heavily perturbed both for the lightening of base ground due to combustion and for the displacement of boarding stones) have been only indirectly detected, which is possible today only with the strong support of geomagnetic and micro-morphological techniques (Fontanals *et al.* 2010; Valleverdu *et al.*, 2010; Courty *et al.*, 2012).

Dwelling structures in old archaeological sites suffer the same dramatic conservation biases of combustion ones, as demonstrated by countless "debates" on lower Pleistocene purported structures from many African (Binford *et al.*, 1988), Asian (Fang *et al.*, 2004; Dennell, 2009) or European sites (Lumley & Boone, 1976; Villa, 1983). It is only from Upper Pleistocene onward, *i.e.*, from the final middle Palaeolithic in Eurasian prehistory, that true and well conserved structures are recorded, showing full control of three dimensional space and documenting complex behavioral sequences in construction domain (Peretto *et al.*, 2004; Iakovleva *et al.*, 2012; Otte, 2012). Both for artefacts as for structures, in most cases, the core problem from a palaeoanthropological point of view is that we cannot know exactly who was responsible for that: although intensely looked for, human remains are very rare in mammalian palaeontological record, so we can state no much more than generic landmarks as that *Homo erectus* is the first sure candidate to possess a true "human" control of space, well beyond the range of possibilities documented for the apes. But *Homo erectus* itself is notoriously a long lasting and all-embracing *taxon*, specially in the Asian context (Dennel, 2009), so we cannot go much beyond the safer strict chronological domain in assigning this or that behavior to a specific form. For these reasons, we can only sketch a kind of "minimum age" in some areas of prehistoric research all over the old world.

The third important direct evidence of spatial competence in prehistory is mobiliary art as a mark of symbolic expression, an endless issue in scientific literature (recent synthesis in D'Errico *et al.*, 2003). Elaborate cave and parietal paintings, till now a phenomenon known only for the last 40.000 years, probably for thaphonomic reasons (Guthrie, 2005), have the peculiarity of have been disposed mainly on two-dimensional surfaces, with the consequent problem of identification of third dimension control. Mobiliary "art" or clearly not functional objects, on the other hand, have been discovered at least since the second half of Middle Pleistocene in Near East, North and South Africa, although some authors refer much older finds, as the high number of rock engravings (*cuppellae*) in several lower Palaeolithic Acheulean sites in India (Bednarik, 2003b).

Among the indirect evidence of sophisticated and organized spatial competence we shall, obviously, remind the diffusion and movements of human species or groups. Once the origin of a determined *taxon* has been reasonably identified in a specific area, diffusion by land is more a matter of biogeography, palaeontology or palaeoclimatology than archaeology itself, as in the case of peopling of western Europe, whether African or Asian it be (synthesis in Bar-Yosef & Belfer-Cohen, 2011). But when the ancient peopling of isolated land-masses is concerned, wayfinding and navigation abilities can be at stake as the main cognitive tool (Golledge, 2003; Kelly, 2003). Such is the case for some debated crucial episodes of human diffusion in Palaeolithic times as that of Flores (at least 800,000 year old), Australia (at least 60,000 year old) or – may be – the southern route for the peopling of Europe: Gibraltar and Sicily at the end of lower Pleistocene (synthesis in Bednarik, 2003a; for a more skeptical view see Derricourt, 2005).

On the background of these coarse-grained standpoints, the most relevant peculiarities and difficulties of the oldest archaeological record shall be – once again – stressed, as methodological caveats:

1) Because the above mentioned limits of lithic tools for the understanding of spatial abilities, some remains as complex structures and organic material become of maximum relevance, so their scanty conservation is clearly the most obvious obstacle; therefore planning research in this field shall consider the distribution and taphonomy of most favourable contexts: open-air sites in low-energy deposits of alluvial plains are generally better than caves, but are more difficult to detect.
2) At the lowest level of involved spatial competence as crudest stone tools or simple structures, intepretative ambiguity is the unavoidable fellow of any research. The old and enduring debate on the anthropic origin of "simplest" lithic industries on the background of natural agencies (Grayson, 1986) has now been replaced by the ambiguity between man and other primates concerning stone tools,

simple structures or small sites (Wynn *et al.*, 2011; Hernandez-Aguilar, 2009).

Finally, we should consider the possibility that some technical or spatial improvements we observe in the archaeological record and tend to insert it into a quite linear progression from "simple" to "complex" behavior could be the result of exaptation phenomena, as described by Gould & Vrba (1982) in the sense of re-organizing preexisting skills in the context of the faster and ever more dominant evolution of cultural capabilities of early man.

In conclusion, on the basis of the archeological record we can say that the constructional abilities of the *Homo* species improved very much from the first half of Middle Pleistocene, that is, at least half a million years ago, but initially in a patchy differentiated manner and then in substantial and diffused manner with the modern *Homo*, 100,000 years ago.

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