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Part 4 Relational concepts in form–function mapping

1 The mosaic evolution of cognitive and linguistic ontogeny

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Before we can properly consider the relations between language and cognition from the perspective of a comparative primatology, we will need to establish some fundamental points about the similarities and differences of cognitive development in the different species. Towards the end of the chapter I shall then return to the central issue, and show that the comparative developmental data demonstrate that there can be no very intimate interaction between language and cognition in early ontogenesis – cognition leads.

A popular evolutionary theory of human cognition, neoteny, has it that we are developmentally retarded, allowing a greater period of plasticity for the acquisition of culture (e.g. Gould 1977; Montagu 1981). The comparative data, we shall see, do not support the neoteny theory. If anything, humans' cognitive development is precocious as compared to that of other primate species. Of course, this in no way denies that "changes in the relative time of appearances and rate of development for characters already present in ancestors" (the modern neo-Haeckelian definition of heterochrony proposed by Gould 1977:2) is a valid biogenetic law of the evolution of cognitive development (see McKinney & McNamara 1991; Mayr 1994; Langer & Killen 1998; and Parker, Langer, & McKinney 2000, for updated analyses). One product of such timing changes is mosaic organizational heterochrony of ancestral characters, whether morphological such as the body or behavioral such as cognition. That is, the evolution of organized characteristics is produced by a mix of changes in developmental timing of their constituent structures (see Levinton 1988, and Shea 1989, for data on and discussions of mosaic evolution). Organizational heterochrony, I have proposed, characterizes primate cognitive phylogeny and, as such, is a structural evolutionary mechanism of development (Langer 1989, 1993, 1994a, 1996, 1998, 2000; see also Parker 2000).

While Gould's definition of heterochrony focuses on phylogenetic changes in developmental onset ages and velocity, the present comparative analyses extend to changes in offset ages, extent, sequencing, and organization of primates' cognitive development. Primates' cognitive development comprises foundational physical cognition (e.g., knowledge about causality and objects), logical cognition (e.g., classificatory categorizing), and arithmetic cognition (e.g., exchange operations such as substituting to preserve a quantitative relation) reviewed in Langer, Rivera, Schlesinger, & Wakeley (in press). For expository convenience I will conflate logical and arithmetic cognition into logicomathematical cognition (while stipulating that the structures and processing of these two domains differ in important respects).

Since much of the relevant primate data comes from comparisons with my findings on young human children, I will first sketch essential features of the research methods I devised to generate them. Then I will turn to key invariant and variant features of primates' cognitive development, such as its sequencing. Most attention will be paid to the comparative extent (section 8) and organization (section 9) of the early development of different species of primate. These key features are central to my proposal of mosaic organizational heterochrony as an evolutionary mechanism of cognitive ontogeny. Also, I have already provided more details on other key features, such as the comparative developmental velocity of different primate species, elsewhere (especially in Langer 1998, 2000). The comparisons of primates' cognitive development will also provide the empirical base for hypothesizing evolutionary and developmental relations between primates' cognitive and linguistic ontogenies in the concluding section.

1 Research method

The research method was developed in the study of 6- to 60-month-old children's spontaneous constructive interactions with four to twelve objects (see the appendix of Langer 1980, for detailed description). The range of objects spans geometric shapes to realistic things such as cups (as illustrated in Figures 1.1–1.4). Some of the object sets presented embodied class structures (e.g., multiplicative classes that intersect form and color such as a yellow and green cylinder and a yellow and a green triangular column, shown in figure 1.1). However, nothing in the procedures required subjects to do anything about the objects' class structures. No instructions, training, or reinforcement were given and no problems were presented. Children played freely with the objects as they wished because my goal was to study their developing spontaneous constructive intelligence and to develop tests that could be applied across species.

With human children, this initial nonverbal and nondirective procedure was followed by progressively provoked probes. To illustrate, in one condition designed to provoke classifying, children were presented with two alignments of four objects. One alignment might comprise three rectangular rings and one circular ring while the other alignment comprised three

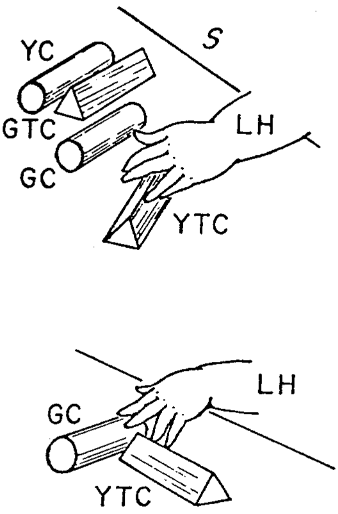

Fig. 1.1 6-month-old subject composing a set comprising a green cylinder (GC) with a yellow triangular column (YTC) using left hand (LH). S = subject.

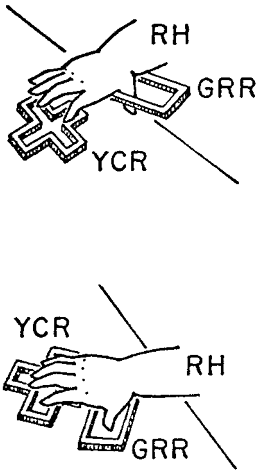

Fig. 1.2 6-month-old subject composing a set comprising a green rectangular ring (GRR) with a yellow cross ring (YCR) using right hand (RH).

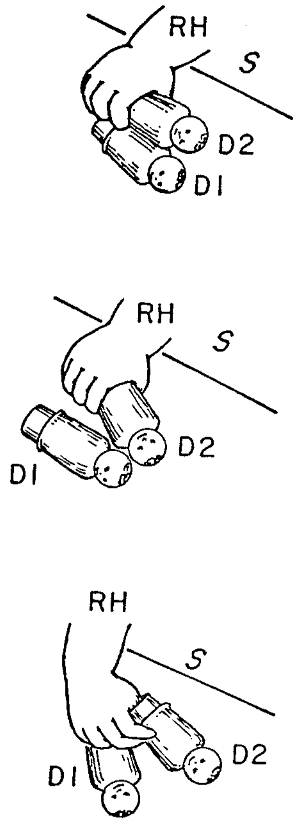

Fig. 1.3 6-month-old subject composing a set comprising two dolls (D1 and D2) using right hand (RH). S = subject.

circular rings and one rectangular ring. By age 21 months, some infants begin to correct the classificatory "mistakes" presented to them (Langer 1986); by age 36 months all children do (Sugarman 1983; Langer, in preparation). Some subjects even rebuke the tester. Thus, one 30-month-old (subject 30AP) remarked "No belongs this way" as she corrected the classificatory misplacements.

Many of the findings on humans that I will review have been replicated with 8- to 21-month-old Aymara and Quecha Indian children in Peru (Jacobsen 1984), and 6- to 30-month-old infants exposed *in utero* to crack cocaine (Ahl 1993). The Indian children were raised in impoverished conditions as compared to the mainly Caucasian middle-class San Francisco Bay Area children in my samples. Nevertheless, no differences were found in

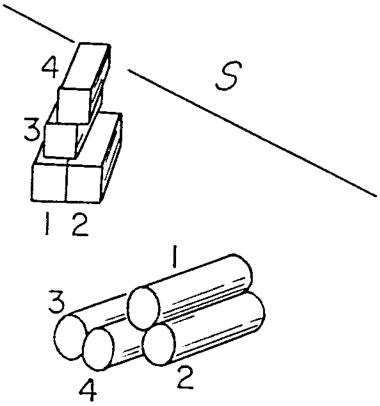

Fig. 1.4 Second-order classifying by a 21-month-old subject.

onset age, velocity, sequence, extent, or organization of cognitive development during infancy in these different human samples; though the crack cocaine babies, of course, manifest many other behavioral, especially emotional, dysfunctions.

Most of the comparisons of primates' cognitive development in the next sections are based on these studies of human children (Langer 1980, 1986, in preparation); and on parallel studies (Antinucci 1989; Spinozzi 1993; Poti 1996, 1997; Poti, Langer, Savage-Rumbaugh, & Brakke 1999; Spinozzi, Natale, Langer, & Brakke 1999) on cebus (*Cebus apella*), macaques (*Macaca fascicularis*) and common and bonobo chimpanzees (*Pan troglodytes and Pan paniscus*) using the nonverbal and nondirective methods developed to study human children's spontaneous cognitive constructions. We have yet to use provoked methods with nonhuman primates.

2 Invariant initial elements of cognition

Perhaps the most important foundational similarity (and difference, as we shall see in section 7) in primate cognition is in their composition of sets. All primates we have studied so far compose sets of objects as elements for their cognition (such as those illustrated in figures 1.1–1.4). They compose sets of objects by bringing two or more objects into contact or close proximity with each other (i.e., no more than 5 centimeters apart).

This is a fundamental similarity since combinativity structures, including especially composing sets, are foundational to constructing cognition and language, as elaborated in section 8. Thus, combinativity is a central general-purpose structure. Combinativity includes composing, decomposing, and recomposing operations (Langer 1980). (Here I focus only on composing for the sake of brevity.) These operations construct fundamental elements, such as sets and series.

Combinativity operations are foundational and fundamental because without them little if any cognition and language is possible (Langer 1980, 1986, 1993). To illustrate the generality of these combinativity structures, consider an aspect of composing. At least two objects must be composed with each other if: (a) they are to be classified as identical or different; and (b) a tool is to be used as a causal instrument to an end (e.g., one object is used to hit another). So, too, at least two symbols must be composed with each other if they are to form a minimal grammatical expression. Note, however, that the form of composing differs by domain. To illustrate, causal tool construction requires spatial composition of the objects involved (at the level of development we are dealing with here). Classificatory construction does not. Contemporaneous manipulation of objects suffices for human infants and young chimpanzees to categorize them even when they do not group them together spatially (Langer, Schlesinger, Spinozzi, & Natale 1998; Spinozzi, Natale, Langer, & Schlesinger 1998; Spinozzi & Langer 1999).

3 Invariant elementary logicomathematical and physical cognitions

It has long been recognized that all primates develop foundational physical cognitions such as notions of object permanence and of causal instrumentality (e.g. Kohler 1926; Parker & Gibson 1979). We now have evidence that human infants and juvenile chimpanzees and monkeys also develop: (1) logical operations such as classifying by the identity of objects (Ricciuti 1965; Woodward & Hunt 1972; Nelson 1973; Roberts & Fischer 1979; Spinozzi & Natale 1979; Langer 1980, 1986; Starkey 1981; Sinclair, Stambak, Lezine, Rayna, & Verba 1982; Sugarman 1983; Spinozzi 1993; Spinozzi *et al.* 1999); and (2) arithmetic operations such as substituting objects in sets to produce quantitative equality (Langer 1980, 1986; Poti & Antinucci 1989; Poti 1997; Poti *et al.* 1999). Thus, all primate species we have studied so far develop foundational logicomathematical as well as physical cognition.

4 Invariant onset age of physical cognition

Developing foundational logicomathematical as well as physical cognition does not mean that the onset age is the same for both domains of knowledge in all primate species. As far as we know, the onset age is the same in all primate species for the development of physical cognition only, which I now sketch.

Human infants begin to construct knowledge about the existence and causal relations of objects in space and time. The earliest symptoms are newborns' sensorimotor activity (e.g. tracking objects and thumb sucking). These activities maintain contact with objects, thereby constituting stage 1 of Piaget's (1952, 1954) six-stage sequence of object permanence development during infancy. So, too, these activities require (a) exerting effort ("work" or energy) and (b) taking into account spatiotemporal contact in order to maintain effective causal relations, thereby constituting the stage 1 efficacy and phenomenalism of Piaget's (1952, 1954) six-stage sequence of causal means–ends development during infancy.

Little attention has been given in comparative research to the onset age of physical cognition. The most I have been able to find is that the earliest symptoms of stage 1 object permanence begin to be manifest during their first week by macaques (*Macaca fuscata* and *fascicularis*; Parker 1977; Poti 1989), the second week by *Cebus appela* (Spinozzi 1989), and the fifth week by *Gorilla gorilla* (Redshaw 1978; Spinozzi & Natale 1989). While limited, the data suggest no or very little difference between human and nonhuman primates in the onset age for developing physical cognition. A fairly secure estimate would put onset age in the neonatal to early infancy range in all primates.

5 Invariant sequencing

The developmental stage sequences are universal, with one partial exception detailed below. The order of stage development is conserved, including no stage skipping or reversal, in all primate species and in all cognitive domains studied so far.

Universal invariance has been found for the most extensively studied developmental stage sequence of physical cognition, Piaget's (1954) six stages of object permanence. Since it therefore provides the most reliable data, it will serve as my example. Sequential invariance has been found in at least a variety of monkey species (i.e. cebus, macaques, and squirrel), gorillas, chimpanzees, and humans (e.g. Piaget 1954; Uzgiris & Hunt 1975; Parker & Gibson 1979; Doré & Dumas 1987; Antinucci 1989). Indeed, the universality of the invariant object permanence stage sequence extends to the mammal species that have been studied so far: cats and dogs (e.g. Gruber, Girgus, & Banuazizi 1971; Traina & Pasnak 1981; see Doré & Goulet 1998 for a review).

Our research has begun investigating whether within-domain stage sequences in logicomathematical cognitions are also universal in primate species. So far we are finding universality with one partial exception, Langer's (1980, 1986) five-stage sequence of logical classification in infancy.

The sequence of classifying is invariant in humans (Langer 1980, 1986) and chimpanzees (Spinozzi 1993; Spinozzi *et al.*, 1999) but not monkeys (Spinozzi & Natale 1989).

6 Variant velocity

The rate of cognitive development is accelerated in human ontogeny as compared to that of other primates. The development of classification is typical. For instance, cebus monkeys do not complete their development of first-order classifying – limited to constructing single categories of objects – until age 4 years (Spinozzi & Natale 1989). In comparison, it is already developed by age 15 months in humans (Langer 1986). So too, while chimpanzees develop rudimentary second-order classifying that extends to constructing two categories of objects, it does not originate until age 4½ years (Spinozzi 1993). In comparison, it originates at age 1½ years in humans.

This pattern of relatively precocious and accelerated cognitive development in humans supports heterochronic theories of progressive terminal extension (peramorphosis or "overdevelopment") in the evolution of primate cognitive ontogeny, and not neoteny (paedomorphosis or "underdevelopment"), as detailed in Langer (1998, 2000). Support for theories of progressive terminal extension is reinforced by findings of increasingly extended cognitive development in the primate lineage that I review in the next two sections. Fully understanding the evolutionary significance of humans' precocial, accelerated and extended cognitive development requires placing it in its full developmental context. I have already endeavored to do so in Langer (1998, 2000) and, therefore, will only allude to the core components here: relatively precocial brain maturation coupled with decelerated nonbrain physiological maturation and decelerated noncognitive behavioral development in humans. Thus, the comparative model of human development that is emerging in this proposal couples (a) nonbrain physiological and noncognitive behavioral immaturity with (b) brain and cognitive precocity.

7 Variant extent of developing elements of cognition

During their first three years, human infants already construct ever more powerful elements of cognition (Langer 1980, 1986, in preparation). Two measures permit central comparisons with the elements composed by young nonhuman primates (Antinucci 1989; Spinozzi 1993; Poti 1996, 1997; Poti *et al.* 1999; Spinozzi *et al.* 1999). I will outline the findings in turn.

With age, human infants include more objects in the sets they compose. For example, 14 percent of their sets comprise eight objects at age 30 months. The number of objects composed into sets also increases with age in chimpanzees. Up to age 5 years, the limit is about five objects. Thus, while already breaking out of the limits of the law of small numbers (defined as no more than three or four units), young chimpanzees seem to be restricted to the smallest intermediate numbers. Minimal increases are found in cebus and macaques during their first 4 years. With age, the set sizes increase from compositions of two objects to no more than three objects. They do not exceed the limits of small numbers.

During their first year, human infants only construct one set at a time. By the end of their first year they begin to construct two sets at a time. By the end of their second year they begin to construct three or four contemporaneous sets. More than half of their compositions comprise multiple contemporaneous sets by age 36 months. Young chimpanzees also begin to construct contemporaneous sets. But, up till age 5 years, they are limited to constructing minimal contemporaneous sets, that is, no more than two sets at a time. And their rate of production is comparatively small. Contemporaneous sets account for only 20 percent of their compositions. In stark contrast, cebus and macaques rarely if ever compose contemporaneous sets in their first 4 years.

8 Variant extent of developing cognition

The elements of cognition primates construct constrain the level of intellectual operations they can attain. Up to at least age 4 years, cebus and macaques are limited to constructing single sets of no more than three objects. Human infants already begin to exceed these limits by constructing two contemporaneous sets of increasingly numerous objects in their second year. The comparative consequence is that cebus and macaques are locked into developing no more than relatively simple cognitions, while progressive possibilities open up for children to map new and more advanced cognitions. For instance, young cebus and macaques are limited to constructing single-category classifying (Spinozzi & Natale 1989) while human infants already begin to construct two-category classifying by age 18 months (Ricciuti 1965; Woodward & Hunt 1972; Nelson 1973; Roberts & Fischer 1979; Starkey 1981; Sinclair *et al.* 1982; Sugarman 1983; Langer 1986; Gopnik & Meltzoff 1992).

Young chimpanzees, like human infants and unlike young monkeys, construct two contemporaneous sets as elements of their cognition. Unlike young monkeys they are therefore not limited to developing first-order cognitions, such as single-category classifying. Instead, like human infants, young chimpanzees begin to develop second-order cognitions, such as two-category classifying, but not until their fifth year (Spinozzi 1993; Spinozzi *et al.* 1999).

Up to at least age 5 years and unlike human infants, we have also seen, chimpanzees are limited to composing two contemporaneous sets. In their second year, human infants already begin to compose multiple contemporaneous sets. As a consequence, only chimpanzees are constrained to constructing no more than two-category classifying (Spinozzi 1993; Spinozzi *et al.* 1999). Humans already begin to develop three-category classifying during early childhood (Langer, in preparation).

This is a vital difference in the cognitive development attainable by chimpanzees and humans. The ability to construct three simultaneous sets is a precondition to building hierarchies, although it is of course not direct evidence of hierarchical ability. It determines whether hierarchically integrated cognition is possible. For example, three-category classifying opens up the possibility of hierarchization while two-category classifying does not permit anything more than linear cognition. Minimally, hierarchic inclusion requires two complementary subordinate classes integrated by one superordinate class. The capability of human infants to compose three contemporaneous sets permits hierarchization. Chimpanzees as old as age 5 years still do not compose three contemporaneous sets. As a consequence they remain limited to linear cognition.

Another vital difference in their potential cognitive development is that, unlike chimpanzees, human infants already begin to map their cognitions recursively onto each other towards the end of the second year (Langer 1986). Young chimpanzees only construct transitional recursive mappings of cognitions onto cognitions (Poti 1997; Poti *et al.* 1999). This is the reason why I have claimed that only the cognition of human children among young primates becomes fully recursive; and that recursiveness is a key to changing the rules of cognitive development (Langer 1994a). It further opens up possibilities for transforming linear into hierarchic cognition.

The elements of cognitive development are limited to contents such as actual sets of objects in all young nonhuman primates we have studied. This is never exceeded by young monkeys. It is barely exceeded by young chimpanzees. By age five years (effectively early adolescence), chimpanzees' cognition just begins to be extended beyond contents such as sets of objects. In comparison, the elements of cognitive development are progressively liberated from contents such as actual sets of objects in humans. By late infancy, the elements begin to be expanded to include forms of cognition (e.g. classifications, correspondences, and exchanges) as well as objects, sets, series, etc. Towards the end of their second year human infants begin to map their cognitive constructions onto each other (Langer 1986). For example, some infants compose two sets of objects in spatial and numerical one-to-one correspondence. Then they exchange equal numbers of objects between the two sets such that they preserve the spatial and numerical correspondence between the two sets. These infants map substitutions onto their correspondence mappings. This recursive operation produces equivalence upon equivalence relations.

Thus, in their second year human infants begin to map their cognitions onto each other. By this recursive procedure, they generate the onset of more advanced (representational) cognitions where the elements of their cognitive mappings are as much other cognitive mappings as actual things. By mapping their cognitions onto each other as well as objects, infants begin to detach their intellectual constructions from their initial concrete objects of application. In comparison, even the cognitions of young chimpanzees as old as five years remain bound to concrete objects. Detaching cognitions from their initial concrete object referents and, instead, mapping them onto other cognitions is pivotal to the formation of representational intelligence.

Representational intelligence, on this view, begins with hierarchic mappings upon mappings (Langer 1982, 1986, 1994a). Its conceptual origins in human ontogenesis are two-year-olds' recursive mappings of cognitions onto cognitions mapped onto objects, as in the above illustration of infants mapping substitution onto correspondence mapped onto two sets of objects. The referents of the substitution operations are no longer limited to the concrete objects forming the two corresponding sets. The referents can become equivalence *relations*. But relations are more abstract than objects. So the referents are becoming abstract.

Recursive development drives progressive change in the relation between the forms and contents of cognition. This opens up the possibility of transforming forms (structures) into contents (elements) of cognition. Thus, initial simple linear cognitions (e.g. minimal classifying) become potential elements of more advanced hierarchic cognitions (e.g. comprehensive taxonomizing). On this view, recursion is a precondition for the formation of all reflective cognition which requires hierarchization, including abstract reflection (Piaget, Grize, Szeminska, & Vinh Bang 1977), cognizance or conscious understanding (Piaget 1976, 1978) and metacognition (e.g. Astington, Harris, & Olson 1989). Linear cognition is not sufficient to these attainments.

In general, with the formation of hierarchic cognition, the referents of human infants' intellectual operations are no longer limited to objects. Cognition is no longer limited to the concrete. Progressively, the referents of infants' cognitions are becoming relations, such as second-order numerical equivalence and causal dependency, that are the product of other intellectual operations mapped onto objects. By mapping cognitions onto relations, infants' intelligence is becoming abstract and reflective. Reasons why or explanations for phenomena can begin to be constructed.

Reasoned explanation is an advanced cognitive development that requires an extensive base of hierarchic conceptual integration. Conceptual integration is not truly possible without the hypotheticodeductive formal operations that are uniquely human and originate in early adolescence (Inhelder & Piaget 1958; see Langer 1969, 1994b, for reviews of the stages of human cognitive development including formal operations). Formal operational development continues through young adulthood up to about age 30 years (Kuhn, Langer, Kohlberg, & Haan 1977).

9 Evolution from asynchronic to synchronic cognitive development

Our comparative research is discovering striking divergences in the organization of cognitive development in primate species that suggest divergent evolution, specifically heterochrony in the organization of their physical and logicomathematical cognition. Figure 1.5 represents my best attempt to portray the phylogenetic evolution of early cognitive ontogeny in the primates we have studied. It tries to capture central "changes in the relative time of appearances and rate of development for [cognitive] characters already present in ancestors" found for humans as compared to chimpanzees and monkeys and for chimpanzees as compared to monkeys. (My sole addition to Gould's definition of heterochrony is to specify parenthetically that the characters under consideration here are cognitive.) Figure 1.5 should be read as part findings and part hypotheses since the research is ongoing.

Physical and logicomathematical cognition develop in parallel in human children. The onset age for constructing these cognitions is the same, very early infancy and probably the neonatal period, and they develop in synchrony. To illustrate, first-order classificatory and causal relations are constructed by infants during their first year (Langer 1980); and second-order classificatory and causal relations are constructed in their second year (Langer 1986). Neither type of cognition begins or ends before the other during childhood. Consequently, both forms of cognition are open to similar environmental influences and to each other's influence.

We find the other extreme in cebus and macaques, namely, almost total asynchrony between their development of physical and logicomathematical cognition. Since they are out of developmental phase with each other, they are not likely to be open to similar environmental influences and to each other's influence. To help grasp the significance this has for the ontogeny of cognition, it may help to sketch some representative findings.

Central physical cognitions (such as object permanence and causal rela-

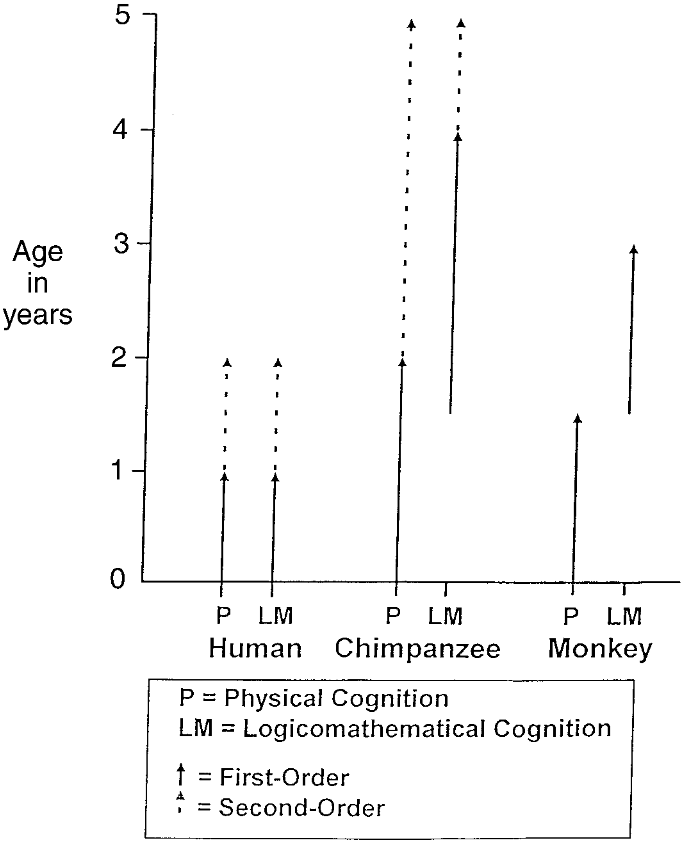

Fig. 1.5 Comparative cognitive development: vectorial trajectories of developmental onset age, velocity, sequence, and organization (but not extent or offset age).

tions) develop before central logicomathematical cognitions (such as classifying and substituting) in monkeys. The development of these physical cognitions is well underway or completed by the developmental onset of logicomathematical cognitions. To illustrate, cebus complete their development of object permanence (up to Piaget's stage 5) during their first year (Natale 1989) and only begin to develop logicomathematical cognition during their second year (Spinozzi & Natale 1989; Poti & Antinucci 1989).

The development of causal cognition also antedates logicomathematical cognition. Simple first-order causality (such as using a support as a tool to get a goal object) develops by age 9 months in cebus and 15 months in macaques (Spinozzi & Poti 1989). More advanced first-order causality (such as using a stick as an instrument to rake in a goal object) develops by age 18 to 20 months in cebus, and may never develop in macaques (Natale 1989). Thus, simple first-order causality is well developed by macaques or completely developed by cebus by the onset of their logicomathematical cognition. Advanced first-order causality is well developed by cebus or nonexistent in macaques by the onset of their logicomathematical cognition.

In chimpanzees' ontogeny, physical and logicomathematical cognition constitute partially overlapping developmental trajectories. While already well underway, chimpanzees' development of physical cognition (e.g. Spinozzi & Poti 1993) is not completed before the onset of logicomathematical cognition (Spinozzi 1993; Poti 1997). Physical and logicomathematical cognition constitute partially asynchronic developmental trajectories. We can therefore expect that these two cognitive domains may eventually begin to be partially open to similar environmental influences and to each other's influence, but beginning relatively late in chimpanzee ontogeny as compared with humans.

From the start of human ontogeny, physical and logicomathematical cognition constitute contemporaneous developmental trajectories that become progressively interdependent. Synchronic developmental trajectories permit direct interaction or information flow between cognitive domains. Mutual and reciprocal influence between logicomathematical and physical cognition is readily achievable since humans develop them simultaneously and in parallel. Thus, we have found that, even in infancy, logicomathematical cognition introduces elements of necessity and certainty into physical cognition (Langer 1985). At the same time, physical cognition introduces elements of contingency and uncertainty into logical cognition.

These findings of information exchange between *structural domains* indicate that physical and logicomathematical cognitions are not modular during human infancy; nor are they in later childhood under at least partially specifiable conditions (e.g. Inhelder, Sinclair, & Bovet 1974, chs. 7 and 8). Nor are they modular in much of the history of science (e.g. Bochner 1966). Different domains of knowledge can inform each other as long as they develop in parallel, as they do in much of human ontogeny.

The present expectation, then, that these different cognitive domains can only inform each other partially in chimpanzees is based upon their partially asynchronic development, not on the premise that they are modular structures that are mentally segregated from each other. If the domains were truly modular then they could not inform each other at all. Similarly, the present expectation that these cognitive domains can inform each other even less in monkeys is based upon their predominantly asynchronic development, not structural modularity.

On the other hand, aspects of cognitive *processes* are more prone to being modular in human ontogeny (see Langer 1998, for a fuller discussion). Accordingly, in the domain of logical cognition we have found that, in the main, infants' action construction of classes by composing objects does not influence their perceptual categorizing (in a standard habituation preparation); nor does their perceptual categorizing influence their action classifying (Schlesinger & Langer 1993). Insofar as there is any information exchange, it is one-way and age-dependent: action classifying enhances perceptual categorizing at age 6 months but no longer does so at ages 10 and 12 months. So too in the domain of physical cognition we are finding that, in the main, infants' action construction of causal relations does not influence their perception of causal relations, and vice versa (Schlesinger & Langer 1994; Schlesinger 1995).

In primate evolution, unilinear growth of physical *followed by* logicomathematical cognition evolved into multilinear growth of physical *at the same time as* logicomathematical cognition. The sequential pattern of physical followed by logicomathematical cognition in the ontogeny of cebus and macaques became "folded over" and, hence, concurrent developments: (a) first to form descendant partially multilinear development midway in chimpanzee ontogeny; and (b) eventually to form fully multilinear development from the start in human ontogeny (as illustrated in figure 1.5). The onset age for beginning to develop physical cognition is roughly the same in all primates studied so far (as noted in section 4). In cebus and macaque monkeys the onset age for logicomathematical cognition is retarded such that its development does not overlap with the development of physical cognition. In chimpanzees the onset age for logicomathematical cognition is accelerated such that its development partly overlaps with the development of physical cognition. In humans the onset age for logicomathematical cognition is further accelerated to the point that it becomes contemporaneous with the onset age of physical cognition.

Phylogenetic displacement in the ontogenetic onset or timing of one cognitive development relative to another within the same organism causes a disruption in the repetition of phylogeny in ontogeny. Such heterochronic displacement involves a dislocation of the phylogenetic order of succession. It produces a change in the velocity or timing of ancestral processes. Thus, heterochrony is an evolutionary mechanism by which ancestral correlations between growth, differentiation, centralization and hierarchic integration are disrupted and new descendent correlations are established. This entails cascading ontogenetic change, as proposed in Langer (1998, 2000).

The comparative organizations of primates' cognitive development are consistent with the hypothesis that heterochrony is a mechanism of its evolution. On this hypothesis, heterochronic displacement is a mechanism whereby consecutively developing ancestral cognitive structures were transformed in phylogenesis into simultaneously developing descendant cognitive structures in human ontogenesis. Heterochrony produced the reorganization of nonaligned ancestral cognitive structures in cebus and macaques into the partly aligned descendant structures in chimpanzees and the fully aligned descendant structural development of cognition in human infancy. Figure 1.5 depicts this phylogenetic trend towards a shift in intellectual dominance from physical cognition to equipotentiality between logicomathematical and physical cognition.

This heterochronic reorganization opened up the possibility for full information flow between logicomathematical (e.g. classificatory) and physical (e.g. causal) cognition in human infancy (making it possible, e.g., to form a "logic of experimentation"). These cognitive domains are predominantly segregated from each other in time and, therefore, in information flow in the early development of cebus and macaque monkeys. They are partially segregated from each other in time and, therefore, in information flow in the early development of chimpanzees.

The possibilities opened up for further development vary accordingly and, I propose, reciprocally constrain the "direction" of progressive cognitive ontogeny in primate phylogeny (with the stipulation that directional processes are probabilistic, not deterministic). As we have seen, cognitive development is already quite substantial in the youth of cebus and macaque monkeys. However, their asynchronic early cognitive development hampers much further progress with age. The partially synchronic and relatively advanced early cognitive development of chimpanzees multiplies the possibilities for substantial, if still limited, information exchange and further progress with age. Humans' synchronic and still more extensive early cognitive development opens up comparatively unlimited, permanent, and unique possibilities for further intellectual progress, such as a history of science (see Langer 1969: 178–180, for five criterial features of progressive cognitive development).

10 Cognition and language: phylogenetic dissociation, ontogenetic asynchrony

Unlike cognition, where the relation between developing domains in phylogeny evolves from asynchrony to synchrony, cognition and language are dissociated in phylogeny with one exception. Cognition and language only become associated developmentally in human ontogeny. But their ontogenetic trajectories are asynchronic (as illustrated in figure 1.6).

Cognition and language are dissociated in phylogeny until we get to human ontogeny, as was pointed out a long time ago (e.g. Vygotsky 1962).

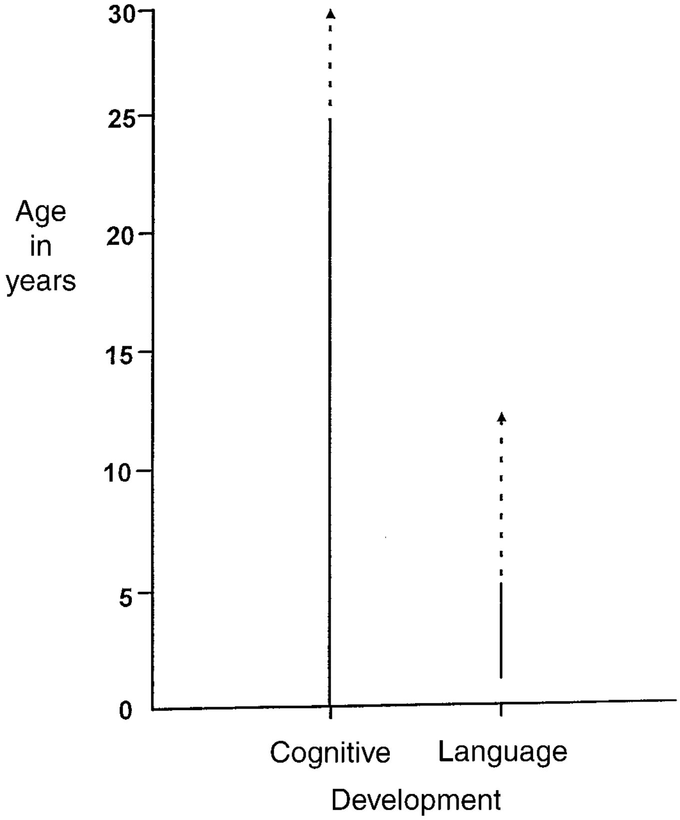

Fig. 1.6 Cognition and language: ontogenetic asynchrony.

In primates, we have seen, first-order cognition develops without the benefit of any language in young monkeys and chimpanzees. Young chimpanzees develop further, to at least rudimentary second-order cognition without the benefit of any language. In logicomathematical cognition this includes, for example, two-category classifying. In physical cognition this includes, for example, searching for nonvisibly displaced objects; thereby constituting stage 6 of Piaget's (1954) six-stage object permanence sequence.

In phylogeny, language does not originate until around the end of the first year of human ontogeny with the onset of the one-word stage (Brown 1973). By then, we have seen, humans are already in transition to second-order cognition. So, the ontogenetic onset and initial developmental stages of human cognition precede the onset of language by about a year.

On the other hand, the offset of language precedes the offset of human cognition by decades. The offset of cognitive development is around age 30 years in humans (Kuhn *et al.* 1977). The offset of language development is between age 5 years and puberty. (I use this large age spread because I don't know a consensually agreed-upon measure for determining the offset age of language development.) As compared to cognitive ontogeny, then, the velocity of language ontogeny is accelerated by a factor of 2 to 6. Thus, the initial lag in linguistic development is overcome rapidly.

In both phylogeny and ontogeny, then, cognition originates and develops prior to and without any language. Conversely, language does not originate prior to and without cognition. The phylogenetic dissociation proves that language is not a necessary condition for the origins of cognition and for its development up to at least second-order cognition. While it has long been recognized that language is not necessary for the evolution and development of elementary physical cognition (e.g. Kohler 1926; Vygotsky 1962; Parker & Gibson 1979), our research is showing that language is also not necessary for the evolution and development of elementary logicomathematical cognition such as classifying.

Language is not necessary for the *origins* of classifying. Single-category classes are constructed by monkeys, chimpanzees, and very young human infants (as outlined in section 8). Language is also not necessary for the subsequent *development* of logical classifying. Two-category classes are constructed by chimpanzees who have no language, as well as language-trained chimpanzees and older human infants. So it is not clear in what sense the foundations of concept formation might be related to language acquisition in evolution and development even if two-category classifying is correlated with a naming burst in American infants (Gopnik & Meltzoff 1992; Mervis & Bertrand 1994; but see Gershkoff-Stowe, Thal, Smith, & Namy 1997, for a nonreplication).

Cognitive operations generate knowledge. Symbols, including language, express meaning (a subset of the knowledge generated by cognition). Symbolic processes complement cognitive processes. Symbolic processes express or represent meaning based upon the knowledge generated by cognitive processes. The symbolic media used to express meaning range from gestural and iconic to linguistic and mathematical notation.

On the present view, cognition provides axiomatic properties necessary for any grammatical symbolic system, including language and mathematics. But symbolic systems also have special-purpose properties not found within cognition *per se*. For example, semantic rules of selection and representation are autonomous and vary from one symbolic medium to another, such as from language to mathematical notation (see Langer 1986, ch. 19, for a fuller discussion). Language and mathematical notation are powerful heuristic media that multiply new phenomena (i.e., possibilities, considerations, problems, contradictions, gaps, etc.) upon which cognition may operate.

Determining the relations between cognition and language is a central problem for all major theories of cognitive development (Piaget 1951; Vygotsky 1962; Werner & Kaplan 1963). Unlike these theories, however, our proposals are not based upon ontogenetic data that confound cognitive with linguistic data. They are based upon data on the development of cognitive operations that are independent of the data on the development of symbol formation, such as pretend routines and verbal utterances.

These data sets led us to conclude that the pace and depth of cognitive development is equal to or greater than linguistic development during most of human infancy. This proposition takes into account our data on cognitive development (Langer 1980, 1986) and the data on symbolic and linguistic development generated in our studies (Langer 1980, 1982, 1983, 1986) and that reported in the literature (e.g. Braine 1963; Bloom 1970; Brown 1973; Bowerman 1978; and Maratsos 1983). It is, of course, impossible to compare quantitatively cognitive with symbolic development since there is no common developmental metric that can measure both. Nevertheless, the data are rich enough to extract a set of qualitative generalizations:

1. First-order cognition is well developed during the second half of infants' first year when their symbolic behavior is extremely rudimentary. Symbolization involves little more than the transition between stages 3 and 4, signalling and indexing in Piaget's (1951) six-stage sequence of symbol formation.
2. Second-order cognition originates towards the end of infants' first year when their symbolic and linguistic productions begin to be substantial. Symbolizing progresses to well-articulated stage 5 indexing of nonvisible referents in Piaget's (1951) six-stage symbol-formation sequence.
3. Second-order cognition is well developed by the second half of infants' second year when their linguistic production is beginning to develop some power. Symbolizing is becoming protogrammatical, and includes initial forms of stage 6 arbitrary and conventional signing in Piaget's (1951) six-stage symbol-formation sequence.

To the extent that they may inform each other's development during human infancy when concept formation outstrips symbol formation, the predominant potential influence would therefore be from cognition to language. Since language lags behind ontogenetically during most of infancy, it is less possible for it to affect cognition. Indeed, infants develop second-order cognition before they begin to develop fully grammatical language marked by supple syntax and complex semantics towards the middle of their third year (Bickerton 1990; Lieberman 1991). Second-order cognition is a necessary condition for young children to produce and comprehend arbitrary but conventional rules by which symbols stand for and communicate referents in grammatical forms. Second-order cognitions may well be axiomatic to grammatical formations in which linguistic elements are progressively combinable and interchangeable yet meaningful. For example, this is not possible without the second-order operation of substituting elements within and between two compositions (or sets) that, as we have seen, develops towards the end of infants' second year. The hypothesis is that second-order operations (of composing, decomposing, matching, commuting, substituting, etc.) provide the rewrite rules without which grammatical constructions are not possible.

Infants' developing cognition provides the foundational grammatical abilities for generating progressive syntactic as well as semantic symbolic forms. In this way, they have implications for or provide the necessary developing parameters of and constraints upon the development of syntactic linguistic production, comprehension, and, for that matter, appreciation. The developing grammars governing the generation of syntactic forms within each symbolic medium are autonomous and unique (e.g. the generative grammar proposed for language by Chomsky 1965). As language catches up with cognition by late infancy and early childhood, the influences between cognition and language may become more mutual. Then, symbolic development may begin to have implications for concept formation. Symbolization may be exploited by young children to facilitate and expand the foundations of cognition once their construction is already well underway, perhaps beyond the level of second-order cognition. For instance, playful routines permit substitution of present and arbitrary (e.g. a wooden triangular column) for nonpresent and prototypic objects (e.g. a brush). Symbolization thereby extends the range of cognitive elements.

This begins to be particularly true of language around age 24 months. At this age, infants begin to use language as a notational medium in relatively powerful ways to symbolize the nonpresent, comparative values, amounts, etc. (see also the Bowerman & Choi, Gentner & Boroditsky, and Spelke & Tsivkin chapters, this volume). Thus, language begins to expand the range of thought in at least three ways: by multiplying the constant given elements of cognition; by increasing the problem space to which cognitions apply; and by providing cognition with a progressively abstract and flexible notational symbolic system of elements that are increasingly detached from their objects of reference.

Symbolic, including linguistic, development does not cause infants' concept formation. This is made plain by the ontogenetic facts, some of which I have reviewed here. During their first two years, infants' conceptual development generally outstrips their symbolic development (see Langer 1980, 1986, for a detailed presentation). Some symbolic productions are