Common Territories in Comparative and Developmental Psychology: Quest for Shared Means and Meaning in Behavioral Investigations

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Comparative and developmental psychology have impacted one another for well over 100 years. Researchers have studied developmental processes of humans and nonhumans to formulate evolutionary theories and to determine the contributions of hereditary and experiential factors at ontogenetic and phylogenetic levels. We discuss current directions in comparative and developmental research that attend to micro-developmental processes and ecological contexts as sources of variability in humans and nonhumans. This research has been a segue into studies of behavior that are integrative in scope, such the family of systems theories, which cross disciplinary boundaries. We present findings from our research on instrumental manual activity in human and nonhuman primates from a systems perspective, and argue that integrative systems approaches hold promise for understanding individuals and development of behavior across species.

Historically, the fields of comparative and developmental psychology have been intertwined, using animal models as analogs in studying human developmental processes, making cross-species comparisons at different points in the lifespan, and inquiring into the evolutionary history of humans and other species. Comparative psychology originated from Darwin's theory of evolution, which yielded insights into the phylogenetic continuity of human and nonhuman life, and changed the conception of life from a static process to a dynamic one (Darwin, 1859). Studying living animals became a promising means to think about the development of the human mind, with its remarkable plasticity and coordinated functioning (Geary & Bjorklund, 2000; Hall, 1992). Noting successive changes in physical and behavioral organization occurring at the level of the individual organism (i.e., developmental changes), with their potential to serve adaptive functions for survival and reproduction, led to formulation of theories about evolutionary change in

development relevant to our own species (Gessell, 1948; Gottlieb, 1992; Gould, 1976, 1977). Indeed, discerning evolutionary origins and trends in behavior by studying developmental processes has been a prominent force in comparative psychology since the early 19th century (Gottlieb, 1984; Lehrman, 1970; Tinbergen, 1963).

G. Stanley Hall, one of the early psychologists who studied human development, integrated Darwinian biological principles into his view of humans, albeit erroneously. For instance, his theory that very early childhood corresponded to a monkey-like ancestor that had reached sexual maturity around age 6-7 years (Hall, 1904) has since been rejected. Hall's ideas rested on Haeckel's evolutionary theory that ontogeny recapitulates phylogeny, or that ontogenetic progression mirrors the phylogenetic history of the species, an idea not commonly accepted by contemporary scientists (but see Parker & Gibson, 1979; Parker & McKinney, 1999). Though at times it would appear that comparative and developmental psychology have grown apart since the days of Darwin and Hall, a substantial body of research in both fields converges on the same behavioral topics (e.g., symbolic processing including numerical and spatial reasoning and linguistic abilities, memory, perception, social responsiveness, imitation and other social learning mechanisms to name a few). It is beyond the scope of this paper to delve into all of the territories where comparative research and developmental psychological research have overlapped. Instead, we describe some of comparative and developmental psychology's noteworthy contributions in means (methodology) and meaning (theoretical frameworks) that significantly advance integrative research in both fields. That is, these contributions cross disciplinary boundaries by incorporating biology (with its focus on process) and ecology (with its focus on context) with psychology (with its focus on the individual as a whole), and thus, hold great promise for helping us to understand behavioral phenomena. Further, we argue that both comparative and developmental psychology benefit by researchers' deliberate efforts to strive for shared means and meaning with other areas in behavioral science. Contemporary investigations by those researchers working from systems perspectives, with their attention to developmental patterns of change at levels ranging from cellular to cultural (these perspectives differ slightly, but all are integrative in scope), serve as examples. Later in this article we describe our work examining instrumental manual activity from a systems perspective that speaks to both comparative and developmental questions.

Breaking Free of the Nature-Nurture Dichotomy

Inquiry in comparative and developmental psychology has long been dominated by attempts to determine the relative contribution of genetic and experiential factors to behavioral expression. The relationship between developmental outcomes and an individual's genetic endowment is an incredibly complex one that is often misunderstood (Jensen, 1969; Morage, 2001). Investigating the emergence of behavior in individuals and variability in behavior across individuals and species should not rest on nature and nurture as competing explanations, but rather, should encompass the dialectical interplay of systems external and internal to the organism (Michel & Moore, 1995; Oyama, 2000). It is not meaningful to argue that certain phenotypic characteristics are more or less genetic than others. Nor is it

meaningful to view some characteristics as more or less biological than others. Comparative and developmental psychologists propose that the possibilities of evolutionary change can be understood if we consider the developmental process of the individual in its species-typical ecological niche.

These ideas are very powerful; they can help science break free of the nature-nurture dichotomy that has been such an abiding and stifling theme in our research (see also Lickliter & Berry, 1990). For example, studies in psychobiology have revolutionized our understanding of "nature" by providing evidence that genetic influence on behavioral expression is not unidirectional, and that developmental outcomes are best conceptualized as being epigenetic, or the result of a complex confluence of genetic influence and multiple organizational systems in the individual organism, including molecular, cellular, and organismic (Gottlieb, 1998). Schneirla, who studied nonhuman animals (1957, see also Schneirla & Rosenblatt, 1961, 1963) charted new territory by providing a compelling argument that integrated organicism (i.e., the integrated structural features of individual) and contextualism (i.e., interactive relations among levels of the individual's bodily and ecological systems). Schneirla's work on the dynamic relations between learning abilities, the structure and plasticity of the nervous system, and a species' ecological niche is an elegant demonstration of applying organismic and contextualist models to behavioral development. Furthermore, the timing among interactions, or what Pepper (1942) describes as historic events (viewed as contextual influences), are crucial to developmental outcomes such that developmental trajectories do not progress in a genetically predetermined invariant fashion, but rather, show considerable individual variability (Schneirla & Rosenblatt, 1963). Thus, developmental "norms" are probabilistic as opposed to inevitable. Schneirla's probabilistic-epigenetic position emphasized the integration of multiple systems in development and was rooted in a solid empirical foundation of biology, and comparative and developmental psychology. In general, developmental psychobiology, the field founded by Schneirla, emphasizes the coordination of biological and experiential aspects of behavior and has moved beyond nature vs. nurture (see Michel & Moore, 1995 for a comprehensive treatment).

The conception that development is a self-organizing process is implicit in much contemporary research in human developmental psychology (Lerner & Walls, 1999). Viewing development as a self organizing process entails consideration of contextual factors (Cole, 1992; Parent, Normandeau, & Larivee, 2000; Rogoff, 1990). For example, the timing of locomotor development reflects a variety of culturally specific practices (e.g., Hopkins & Westra, 1988; Super, 1976) Variability in people's family, community, and culture underscores the need to conduct research in varied contexts, in addition to standard laboratory settings (Lerner & Busch-Rossnagel, 1981). For example, when studying infants and children, cross-cultural psychologists examine the integration of cognitive and socioemotional development by analyzing infant and child care, familial influences, and value characteristics of the larger culture (e.g., Berry, Poortinga, & Pandey, 1997; Keller & Greenfield, 2000; Matsumoto, 2000). The growing interest of developmental psychologists in the particulars of behavioral development rather than universals, reflects the viewpoint that variability should not be conceptualized as noise, or experimental error, but rather, as an important indicator of the organiza-

tion of the individual (Fischer & Pare-Blagoev, 2000; Harkness, Raeff, & Super, 2000).

The importance of studying studying self organization within varied contexts is evident in studies of behavioral development in other species. For example, West and King (2002, p. 98) studied the ontogeny of song and mating behavior in brown-headed cowbirds. They propose that a "social/cultural gateway" directs development by constraining the "settings and sequence of events through which [organisms] obtain access to information for learning." West and King have shown that contextual factors (e.g., social setting) work in concert with individual characteristics (e.g., age and sex) to channel variation in behavioral development (e.g., mating strategies and song development) (see also Coleman & Wilson, 1998 for an example with pumpkinseed sunfish).

The contributions that we describe next draw from scholars studying humans and nonhuman animals. Some embrace a synthetic relationship between biology and individual contexts in development, thereby forwarding an integrative systems view of development. Others embody a process-focused approach, thereby revealing the intricacies and dynamics of developmental trajectories.

Contributions in Means of Doing Research:
Capturing the Emergence of Behavior and its Adaptive Qualities

Comparative researchers studying nonhumans have devised observational methodologies for describing and measuring behavior that are distinguished for their clarity (Altmann, 1974). These observation techniques have been especially useful for psychologists whose subjects are nonverbal humans and young children whose language facility is developing (e.g., Hinde, 1987; Michel, 1991a; Savage-Rumbaugh, et al., 1993). Rovee-Collier's (1995, 1997) research is a first-rate example of the usefulness of operant paradigms, which originated in laboratory experiments with nonhumans, to study memory development in human infants. Rovee-Collier's testing situation requires that infants recognize and recall that their kicking response will activate movement of a mobile hanging above them. Interestingly, infants remember this relationship weeks later, but their memories are dependent on the testing context being the same. These are two examples of methodologies first used by comparative researchers that have proved useful in studies of human development.

Microanalysis of Problem Solving

Recent work in developmental psychology has broadened the methods by which we study problem-solving behavior. The focus of analysis is not solely on whether children can solve problems or not, or on the number of errors committed, but rather how children's solutions come about. The research methodology employed must therefore capture the emergence and organizational profile of strategies children use to solve problems (Granott & Parziale, 2002). For example, Siegler (1996, 2002) has analyzed how children approach problems requiring numerical reasoning. Central to Siegler's theoretical framework is the proposition that children's strategies are multidimensional rather than unidimensional. Gradual changes in the utilization of strategies predominate over sudden shifts in thinking.

The empirical data, Siegler argues, dictate that our research methods should capture the generation of variability as an epigenetic process that contributes to a constellation of strategies for approaching a variety of problems in a variety of contexts. Siegler's (1996, 2002) concept of "microgenetics" captures this idea (see also Siegler & Crowley, 1991). Microgenetics entail micro-developmental analysis, that is, examination of variability within individual subjects over time, producing a comprehensive picture of the developmental process. Furthermore, Siegler (1996) notes that children's variability and selection of problem-solving strategies become increasingly adaptive, an analogy consistent with the evolutionary process, where the production of new variants in behavior often reflects adaptive change.

Socio-Emotional Adjustment and the Developmental Niche

Although many comparative psychologists remain concerned with the foundations and expression of species-typical behavior, increasingly, questions of individual variation arise. For instance, comparative researchers studying monkeys (e.g., Boccia & Pedersen, 2001; Mason & Capitanio, 1988; Maestripieri, Jovanovic, & Gouzoules, 2000; Schino & Troisi, 2001; Suomi, 1987) have devised research methods to reveal the complexity of socio-emotional development. In these studies, researchers tracked hereditary relationships and experimentally manipulated rearing history and events that the monkeys experienced. Infant-maternal relationships were related to behavioral changes brought about by variations in the social group in order to isolate developmental processes contributing to attachment, temperament, and subsequent socio-emotional adjustment in the young monkeys. Soumi's (2000) finding that rhesus monkeys' behavior and brain chemistry were affected by the interaction of early rearing experience and serotonin transporter genotype is an excellent example of an animal model approach that fuses developmental and neuropsychology. This work enhances our understanding of the relationship between the young monkey's formation of attachment and its reactivity to stressful situations.

Experiments conducted by developmental psychobiologists with other mammalian orders (e.g., rodents) suggest other neural, endocrine, and immune correlates of attachment and maintenance of social bonds (Insel, 1992), and their contribution to adult behavior (Pedersen & Boccia, 2002). Leon (1992) adopted methods to identify olfactory, auditory, and visual preferences of mothers and offspring that contribute to attachment and feeding, thereby increasing the rat pups' chances for survival. The huddling niche in rats has been described as a learning milieu of rapid change where thermoregulation, olfactory and motor development, and dominance hierarchies exert influences at differing points in the rat pups' development. Research methodologies employed in studies of rodents have been particularly instructive in furthering the conception of the changing characteristics and function of the developmental niche (i.e., a concept that describes the integrative of features of a particular species and its habitat, Smotherman & Robinson, 1998; West, King, & Arberg, 1988).

All of these ideas resonate with issues in human development. For example, Thomas and Chess's (1977) analysis of children's "goodness of fit" with their respective environments is the classic analog for the concept of the developmental niche in human studies; their work showed how infant temperament impacts infant

adaptation to care-giving environments. More recently, Harkness and Super (1994), building on research ideas from behavioral ecology with nonhuman populations, have put forth three components of the child's developmental niche, including physical and social settings (e.g., climate and family, respectively), child rearing practices, and cultural customs (e.g., belief systems). Cross cultural studies have examined the child's developmental niche more closely, looking at how the unique socialization practices of different cultures affect the dynamic interaction of the child with his caregivers. For example, DeVries (1994) has reported that Masai children in East Africa display temperamental traits that Western caregivers would consider undesirable and that would put them at risk for behavioral adjustment problems in Western cultures. In the Masai culture, however, these traits, including being persistent, intense, and not easily consolable, are highly valued and would support adaptation to the harsh environmental conditions experienced by this African nomadic tribe.

This corpus of research on social adjustment in infancy has generally progressed towards achieving greater specificity and ecological validity since the seminal work on attachment by Harlow, Mason, and colleagues (Harlow & Harlow, 1965; Harlow & Zimmerman, 1959; Mason & Berkson, 1975) and Thomas and Chess (1977). Moreover, these contributions, marked by their attention to context and process, are indicative of efforts by comparative and developmental psychologists to employ research methods with foci of analyses that capture the emergence of behavior and its adaptive qualities.

Contributions in Meaning: Theories and Conceptual Frameworks to Guide Research and Interpret Findings

Developmental research with humans, generally, has been much more theory-driven compared to comparative research with nonhumans, which has tended to be more empirically driven. An example is research in "theory of mind", the attribution of mental states to others. This form of social cognition, a substantive research theme in child development research, has been theorized to be a uniquely human quality that is linked to the development of cognitive abilities, social skills, and sophisticated communicative capacities (e.g., Astington, 1993; Perner, 1991; Wellman, Cross, & Watson, 2001). Comparative researchers have addressed exhibitory aspects of theory of mind, that is whether other species attribute intentions, beliefs, and desires to others, with cleverly designed laboratory and field experiments (e.g., Cheney & Seyfarth, 1990; Gallup, 1982; Heyes, 1998; Povinelli & Giambrone, 2001; Premack & Woodruff, 1978; Whiten & Byrne, 1988). Comparative psychologists have been more conservative in their interpretations of data compared to developmental psychologists. Making inferences about the thinking of nonhumans must proceed with skepticism that it is like the thinking of humans, lest we fall into the anthropomorphism trap. Thus, to date, comparative psychologists have provided little sound evidence that monkeys and apes make inferences about mental states of others. Whether chimpanzees have a rudimentary theory of mind, a question posed by Premack & Woodruff (1978) over twenty years ago, remains open. Perhaps this is because of methodological challenges involved in doing this type of research with nonhuman animals. After all, we cannot question nonverbal nonhumans as we do human children. Virtually every experimental

paradigm used with children involves questioning children about what they believe others (including dolls, puppets, or actual people) see, know, think, or feel. Comparative researchers, one could argue, have a greater burden of proof placed on them. Hence, reporting evidence for and against mental attribution has been the predominant focus in the literature on nonhumans as opposed to emphasis on theoretical developmental discussions in the literature on children.

Nonetheless, it is certain that animals possess highly sophisticated communication systems, and nonhuman primates in particular show marked sensitivity to vocalizations, gestures, facial expressions of conspecifics and human caretakers/observers. All are indicative of highly developed forms of social cognition (Russon, Bard, & Parker, 1996; Owren & Rendall, 1997). Examining both children and nonhuman primates' sensitivity to affective displays and their abilities to engage in social negotiation in more naturalistic settings may be a fairer comparison than paradigms that require inferences about subjects' interpretations of scenarios.

Value of Integrative Developmental Systems Approaches

By adopting an integrative theoretical and methodological approach, comparative and developmental psychologists may be better able to establish the relations among individuals' characteristics and contextual variables and consequent development of behavior across species. A common means to investigate ontogenetic changes in behavior coupled with a common conceptual framework to make meaning of the data hold great possibility for advancing both comparative and developmental psychology. Some contemporary scientists, whose work is discussed in the remainder of this section, have heeded von Bertalanffy's (1968) challenge that theories in science should integrate biology, ecology, and developmental systems and evolutionary histories of organisms and have utilized analytical methods that capture complex relations.

Developmental psychobiology, which to date has typically involved studying nonhuman populations, focuses on the relationship between structure and function at ontogenetic and phylogenetic levels of analysis (Gottlieb, Wahlsten, & Lickliter, 1998; Lerner, 1991). Phylogeny is, after all, a sequential pattern of varying ontogenies. A central assumption of developmental psychobiology is that behavioral ontogeny should be thought of in the same terms as morphological ontogeny, as both are guided by epigenetic interactions. Another assumption is that the structure-function relationship, and the ontogenetic processes that bring it about, should not be assumed to be equivalent across phylogenetic levels, even if the behavioral patterns that develop are similar in different species (Reese & Overton, 1970). The intricacies of the structure-function relationship are illustrated in Gould's (1977) argument linking brain development and socio-cultural functioning at individual and intergenerational levels of analysis. Comparing individuals of different species may guide the formulation of causal questions pertaining to proximate, ontogenetic, and phylogenetic causes of behavior (Gould, 1977). This assertion, however, differs from the proposition that any *one* of these orientations can serve to explain, fully, the other (Lehrman, 1970; Snowden & French, 1979; Tinbergen, 1963). Arguments such as Gould's that pertain to the evolution of the structure-function relationship must necessarily be of a comparative and developmental nature. Gilbert Gottlieb (1992, p. 137), working from a psychobiological

perspective, asserts that "an understanding of heredity and individual development will allow not only a clear picture of how an adult animal is formed but [also] that such an understanding is indispensable for an appreciation of the processes of evolution as well" (see also Lickliter & Berry, 1990).

Developmental systems theories can succeed in providing elegant causal accounts of the relationship between the individual's design features (e.g., perceptual processes, muscle tone, movement preferences) and developmental trajectories (Kuo, 1976; Lewis, 2000; Oyama, Griffiths, & Gray, 2001). Thelen and Smith's (1994) version of a developmental systems theory, which they have termed "dynamic systems theory", assumes that development results from the continual and multiple interaction of all levels of the developing system, from the molecular level to the cultural level. Morphological and behavioral characteristics, they argue, arise not from genetic codes or environmental instructions, but from dynamic interrelations within and between the multitude of systems that comprise and surround the organism. For example, Thelen (1986, 1992; see also Thelen & Corbetta, 2002) has shown that muscle growth and postural control are hastened when infants are held upright and allowed to engage in stepping, leading to acceleration in locomotor development. Hopkins and Westra (1988) suggest that early attainment of certain milestones in locomotor development in West Indian babies reflects "formal handling practices" (e.g., stretching exercises and placing infants in positions that challenge their balance) used by West Indian mothers with their infants.

Bronfenbrenner's (1979, see also Bronfenbrenner & Evans, 2000) Bioecological theory offers an alternate integrative approach to the biological, cognitive, and socio-emotional dimensions of behavioral development. This theoretical position, like all integrative theories, advocates a dynamic, interactive model of individual-contextual relations, and ascribes a key role to temporal processes and contextual details at multiple levels of organization (i.e., systems that are internal and external to the individual). Attention to the ecology of the individual, changing relations in the individual's micro and macro systems (e.g., perceptual-motor and familial, respectively), and historical embedding of systems gives descriptive and explanatory power to this theoretical orientation (Bronfenbrenner, 1977, 1979; Bronfenbrenner & Evans, 2000; Bronfenbrenner & Morris, 1998).

Researchers studying children through this theoretical lens have examined the effects of residential crowding on children's well-being, the contributions of parental and peer support to academic performance, and the links between access to community health centers and welfare institutions on children's development (Evans & Saegert, 2000; Steinberg, 1990; Bronfenbrenner, 1993, respectively). Bronfenbrenner (1993) points out that, given the typically low proportion of variance explained by the variables under investigation in developmental research, it is necessary to focus on multiple contextual influences. This assertion underscores the argument that experimental causal analyses should not be the sole analytical strategy in an integrative approach. Where causal relations remain shrouded from analyses, as they often do when studying development, we can make use of correlational methods, asking how and how much a particular parameter influences another. Convergent correlational evidence can be a powerful analytical tool when studying development and when comparing species (Fragaszy & Perry, in press; Ross & McLarnon, 2000; Russon, 2003). All of these integrative approaches are promising candidates to investigate behavioral phenomena because they are simul-

taneously both broader and more differentiated than their predecessors with their restricted focus on innateness (e.g., Lorenz, 1957; Chomsky, 1972), stimulus-response connections in decontextualized experimental settings (e.g., Skinner, 1938), or logical mathematical thinking (e.g., Piaget, 1963).

Value of an Integrative Approach to Study the Development of Instrumental Manual Activity

We devote the remainder of this paper to instrumental manual activity, a common form of problem solving exhibited extensively by human and nonhuman primates. The specialization of the hand for fine motor movement, haptic perception, bimanual coordination, and manipulation of objects renders instrumental manual activity a distinctive feature in the evolutionary history of primates (Fragaszy, 1998; Marzke & Wullstein, 1996; Wilson, 1998). Visual-motor coordination, prehension, and bimanual dexterity affect the extent to which the individual can experience and modify its environment. Sometimes the functional outcomes of instrumental manual activity are identical across species, such as using objects as tools in feeding behavior; however, the developmental processes that brought about the behavior can be dissimilar. Examining instrumental manual activity from a comparative developmental perspective that is integrative in scope can be most informative.

Instrumental manual activity is defined as using hands to manipulate objects or surfaces to attain a goal. Traditionally, goal-directed object manipulation of this sort has been interpreted as activity that is mediated by abstract cognitive constructs (e.g., Greenfield, 1991; Langer, 1980; Piaget & Inhelder, 1969) or is aided by causal understanding of means-end relationships (e.g., Limongelli, Boysen, & Visalberghi, 1995; Visalberghi & Tomasello, 1998). Developmental psychologists, in particular, are interested in instrumental manual activity as an expression of an individual's abstract knowledge of logical-mathematical relationships (Langer, 1980). Indeed, "logico-mathematical" ways of knowing form the basis of Piaget's (1969; see also Piaget & Inhelder, 1969) theory of cognitive development, and Piagetian theory has been the dominant theoretical approach applied to the investigation of instrumental manual activity in nonhuman animals. Piaget addressed motor behavior, but was more interested in the logical rules that children abstracted from movement: the products of thinking rather than the processes that are involved in constructing this knowledge. The Piagetian perspective has motivated some comparative psychologists to draw parallels between children's sensorimotor development and the manipulative capabilities and propensities of nonhuman primates. Piaget's scheme of the substages of sensorimotor development has been applied to the manipulative repertoire of various species of nonhuman primates (e.g., orangutans, chimpanzees, and capuchin monkeys) residing in captivity and in the wild (Antinucci, 1990; Call, 2001; Chevalier-Skolnikoff, 1989; Parker & Gibson, 1977; Poti, 1997). Parker and colleagues (Parker & Gibson, 1979; Parker & McKinney, 1999) devised an evolutionary explanation for the emergence of language and intelligence in humans employing Piagetian ontogenetic theory. Piaget's theory has been a heuristic tool to make descriptive comparisons between species. Its use, however, has not gone without criticism by developmental and comparative psychologists. Chief objections concern the conceptual

validity of Piaget's theory, which fails to account fully for individual and ecological contextual influences on behavior. Because it is a stage theory, one of the tenets is universality, which downplays individual and cultural differences in behavioral development. Developmental psychologists have modified these conceptual weaknesses in subsequent revisions of the theory (e.g., neo-Piagetian, Case, 1985; Fischer, 1980; and information-processing approaches, Bjorklund, 1997).

Furthermore, research with children has illuminated some of the methodological weaknesses in the Piagetian testing paradigms, which use particular tasks and oftentimes rely on verbal responses by subjects. The conclusion that Piaget underestimated the capabilities of children has come about largely because of a revision in research methodology used with young children that specifically addressed testing contexts, including constraints imposed by tasks. To illustrate, children have shown improved performance than predicted by Piagetian theory in manual tasks that provide perceptual and functional feedback to them (DeLoache, Sugarman, & Brown, 1985; Fragaszy et al., 2002). Tasks that afford children opportunities to detect errors in their action-based solutions to problems and to assess their progress towards goals can reveal, in dynamic systems terms, rapid assembly of skills. Effective behavior may not be evident where motoric demands are not well-suited to children's perceptual-motor developmental level. Additionally, inferring cognitive structures from actions with objects is problematic when actors cannot comment on their actions or answer questions posed by experimenters (Adams-Curtis, 1989; Brainerd, 1979). Reliance on the verbal reports of children may in fact mask the complexity of the developmental process.

Comparative psychologists are, no doubt, concerned with the very areas in which Piaget's theory has been criticized by developmental psychologists, even though a Piagetian approach continues to guide the investigation and interpretation of cognitive and perceptual-motor skills in nonhuman primates (Antinucci, 1990; Chevalier-Skolnikoff, 1983; Parker & McKinney, 1999; Poti & Spinozzi, 1994). Developmental psychologists studying young children, on the other hand, have adopted alternative approaches that integrate the converging influences of brain, body, environmental context, and behavior (e.g., Connolly & Dalgleish, 1989; Elman et al., 1996; Lockman & Thelen, 1993; Michel, 1991b; Thelen, 1992). The instrumental manual system is marked by progressive reorganization that is contingent upon self-assembled development in neural, perceptual, and muscle systems. Changing relations among the components of the individual's perceptual and motor systems and ecological context become the focus of analysis, and in that sense, the individual and his/her environment are conceptualized as dynamic rather than statically and inflexibly hierarchical. Relationships among these components are not temporally stable, and development does not follow an invariant stage-like sequence as Piaget asserted. For example, in the domain of instrumental manual activity, variables such as manual dexterity, postural control, visual acuity, supportive surfaces, understanding of the task and goal, experience with the task, and social context are all considered (Bushnell & Boudreau, 1993; Johnson-Pynn & Fragaszy, 2001; Michel & Moore, 1995). An integrative theoretical stance moves beyond the notion that a morphologically determined abstract symbol system is the driving force behind the development of instrumental manual skill and other forms of cognition (e.g., theory of mind), and it does not privilege abstract knowledge over somatic knowledge (Lockman, 2000). Studying individuals of different spe-

cies and employing a similar (or in the best case, identical) research methodology can elucidate insights into the interrelationship between the body's actions and any logical or abstract rules that might emerge to guide behavior.

We provide an overview of three lines of research in the area of instrumental manual activity with human children, chimpanzees (*Pan troglodytes*), bonobos (*Pan paniscus*), and capuchin monkeys (*Cebus apella*). Our comparative developmental studies of seriation of nesting cups, solving mazes by manipulating a joystick, and using objects as tools, have led us to adopt a specific systems interpretation, the perception-action model (Lockman, 2000), to research instrumental manual activity. The perception-action model, derived from the ecological theory of Gibson (1979), encompasses the developing systems of the individual and is a useful framework for examining the development of instrumental manual skill in humans and nonhumans alike (see also Gibson & Pick, 2000, for a general treatment).

Seriation of Nesting Cups: Considering Interactions Between the Individual's Physical System and Experiences

Our findings with children (age range 11-36 months), chimpanzees, and capuchin monkeys have raised doubts that an abstract concept of reversibility is necessary to construct a seriated set of cups by size (Fragaszy, et. al, 2002a; Johnson-Pynn & Fragaszy, 2001). Piaget purported that reversibility, the abstract knowledge of a logical relationship in which an element in a series can be simultaneously smaller than the preceding element and larger than the subsequent element, was responsible for success in seriating objects. Piaget used a series of graduated sticks to arrive at his conclusion that 5-year-olds were successful seriators because they had attained this form of abstract knowledge (Piaget, 1969; see also Inhelder & Piaget, 1964; Piaget & Inhelder, 1969). Other developmentalists studying younger children used nesting cups instead of sticks to examine seriation skill. Nesting cups, unlike sticks, provided functional feedback to children as young as 24 months of age, who were able to seriate cups into an ordered set of five (DeLoache, Sugarman, & Brown, 1985; Greenfield, Nelson, & Saltzman, 1972). Fragaszy et al. (2002a) tested an even younger sample of children (ages 11, 16, and 21 months) and compared their performance to that of chimpanzees and capuchins, both noted for their manipulative propensities and skill. Briefly, Fragaszy et al. (2002a) found that young children were successful seriators, including one 11 month-old who occasionally constructed a seriated 5-cup set. Even more surprising, chimps and capuchins generally seriated cups more often and more efficiently (i.e., using a fewer number of actions) than children between 12 and 21 months of age. These results prompted the authors to question the attribution of reversibility (a form of logical reasoning) to nonhuman subjects, but not to children, who were far less successful.

Effective instrumental manual action requires integrating thought processes and bodily systems (Bernstein, 1967; Manoel & Connolly, 1997). Perhaps the nonhuman subjects in this comparative study were better seriators because they had more practice executing the actions required by the task compared to the young children. Maintaining postural control frees the arms and hands to manipulate objects more readily, and may facilitate detection of the physical properties of

the cups. The development of postural control has been noted to be a factor affecting the development of bimanual coordination involving planning movement sequences and solving object-related movement tasks in children (Corbetta, 2001; von Hofsten, 1994). Compared to the children in our study, the apes and capuchins were not challenged in this respect. In fact, one bonobo tended to hold cups with his feet while using his hands to construct seriated sets. A capuchin, used several body parts, including his hands, feet, tail, and mouth to support and combine cups. It could also have been the case that grasping the edges of the cups in order to remove them from a nested stack and aligning the cups in order to insert them into a nested stack was more challenging for young children whose grasp patterns were not fully developed to handle the fine motor movements required by the task. The actions that the individual can and does perform support detection of physical properties, including relations between differing sized cups.

Instrumental manual activity is inextricably tied to a species' propensity to manipulate objects in exploration (Fragaszy & Adams-Curtis, 1991). Most likely the success of *Pan* and *Cebus* in the nesting cups task reflects the behavioral tendencies that these two genera show for using objects in exploratory and goal-directed ways in many settings. Such activity enables perceptual-motor learning about the physical properties of objects and the relations between them, and as important, about the actions one can perform with objects (e.g., Gibson, 1982; Lockman, 2000). Interestingly, when the nesting cups task was presented to rhesus macaques (*M. mulatta*), less known for their proclivity to manipulate objects, they did not show combinatorial behavior with the cups and resisted shaping to induce it. The most complex structure made by any of these subjects was a two-cup combination, and this occurred rarely (J. Johnson-Pynn, unpublished observation).

Our analysis of the micro-development of object combinations and responses to errors in seriation takes experience into account, and thus, portrays the dynamic nature of the emergence of seriation skill (Johnson-Pynn et al., 1999). Our subjects combined cups in a variety of ways and showed dramatic micro-developmental increases (i.e., shifting to hierarchical combinatory methods of combining cups as the dominant strategy) in the complexity of cup combinations across testing. There was no all or nothing leap from no seriation to seriation; the development of seriation was not discontinuous or highly dependent on age as Piaget's theory predicts. Subjects' strategies for constructing stable multi-cup structures do not have to be explained as driven by conceptual, abstract knowledge. If we follow Siegler's (1996, 2002) account of strategy development, it is likely that the acquisition of combinatorial strategies develop from a confluence of associative and metacognitive processes that may or may not be conscious to the individual (Siegler & Stern, 1998). Experience handling the cups, trying various combinations, and flexibly adapting to mistakes facilitates seriation skill in young children and nonhuman subjects alike.

Interpretation of children and nonhuman primates' behavior with nesting cups is consistent with the dynamic systems view of developmental psychobiologists Michel and Moore (1995, p. 354) who state that "Motor behavior is a function of the state of development of the nervous system, but the experiences generated by the behavior can also contribute to further development of the neural system." It is feasible that perceptual-motor learning enables the development of symbolic relations or abstract representational concepts such as reversibility (Johnson-

Pynn & Fragaszy, 2001; Langer, 1980). Comparing humans' with nonhumans' emergence of object manipulative skill suggests to us that a dynamic, reciprocal relationship between perceptual, conceptual, and reflective consciousness precludes isolation or superiority of any single domain.

Using the Body to Move Objects Through Mazes in Two- and Three-Dimensional Space: Importance of Task Constraints

Psychological and ecological aspects of spatial cognition (e.g., orienting, navigating, searching) have been studied in experimental and natural settings in many tasks and situations with nonhumans (e.g., Menzel, 1999; Menzel, Savage-Rumbaugh, & Menzel, 2002; Shettleworth, 1998; for a review). We have presented computer-generated mazes, where subjects manipulated a joystick to move a cursor through a series of choice points, to assess aspects of planning by nonhuman primates (*P. troglodytes, C. apella*; Fragaszy, Johnson-Pynn et al., 2002) and pre-school-aged children (Johnson-Pynn, unpublished data) in two-dimensional space. Manipulating an object to move it through a series of paths from a start point to an end point, such as in a maze, necessitates managing multiple spatial and temporal relations. Different levels of planning are evident in this task (Bensen, 1997; Bidell & Fischer, 1994). A continuous or "on-line" form of planning involves bodily planning to control the joystick's movement, which, in turn, affects the direction that the cursor takes through the pathways on the computer screen. A memorial form of planning in this task is keeping sequences of movement decisions in mind while moving the cursor through choice points (i.e., junctures where subjects must make a directional decision about which pathway to move the cursor down). The number of mistakes made at choice points and whether subjects solved mazes provide an incomplete account of the perceptual, motor, and memorial systems that must be integrated to perform this task. On the other hand, a dynamic analysis is appropriate to understand how an individual makes and remembers decisions, while simultaneously monitoring progress towards the end of the maze.

One can infer that subjects are looking ahead (termed "forward search planning," Fabricious, 1988) of the cursor if the direction of the cursor's movement (when approaching the dead end of a pathway) is reversed to move into a pathway that may lead to the end point of the maze, what we have termed "self-correcting" an error (Fragaszy et. al, 2002b). This inference would be based on a memorial or representational view of the requirements of the task. The tendency of young children and nonhuman primates not to self-correct their mistakes, however, may reflect lack of planning or may reflect difficulty with inhibiting movements down incorrect pathways, an interpretation based on motoric constraints. Simultaneous coordination of executing and inhibiting movements is likely to impact decision-making in young children, whose inhibitory control is oftentimes weak (see Harnishfeger, 1995 for a discussion of the development of inhibition in children).

For young children (3- and 4-year olds), manipulating the joystick to control the direction of the cursor's movement appears to be especially challenging. In contrast to older children and nonhuman primate subjects, few of the young children in our sample had experience using a joystick (most 5-year olds had some experience using a keyboard or mouse with their home computer systems.). Oftentimes the movements of the cursor were not indicative of what three and four year-

olds stated was their intended cursor movement. For instance, they would often shoot beyond a correct pathway, thus failing to make the cursor take a turn. They exhibited noticeable difficulty using the joystick to stop the movement of the cursor and to make an aimed turn, even after some training in using the joystick. Their repeated attempts at maneuvering the cursor through this type of choice point were often accompanied by verbal comments such as, "I didn't mean for it to go that way" (J. Johnson-Pynn, unpublished observation). The most informed conclusion about the behavior of young children in this situation can only arise from examining the integration of multiple factors, including manipulative ability, experience handling a joystick, attention, and the type of turn dictated by the maze.

Yet another example of the confluence of task constraints, planning, and physical execution of movements to traverse a maze comes from a comparison of a capuchin's (Jobe, an adult male) performance in a two-dimensional computer version of the task to a three-dimensional version of the task. In the three-dimensional version, the subject manipulated a round ball (slightly larger than the subject's palm) along pathways that were grooved tracks in a board positioned underneath a test cage. This capuchin's performance was compromised in the three-dimensional version of the task compared to the two-dimensional version, in part, we believe, because the motor demands were greater in the three-dimensional format (Cummins-Sebree, Johnson-Pynn, & Fragaszy, 2003). It is also likely that the increased number of degrees of freedom in movement to manage in the three-dimensional version compared to the two-dimensional version of the task, taxed the monkey's memory and decision-making. An example of increased difficulty in the three-dimensional version of the maze task concerns the speed of the cursor's movement. In the two-dimensional version of the task, the speed of the cursor was constant (determined by the computer program); thus, the force with which the subject pushed or pulled on the joystick was independent of the speed of the cursor's movement along maze pathways on the computer screen. This was not the case in the three-dimensional version of the task, where the force with which the ball was moved determined the ball's speed along tracks in the board. In the three-dimensional version of the task, the capuchin subject made significantly more errors than in the two-dimensional task because it did not stop the ball in time to turn it off the incorrect path to go down the correct path. This is reminiscent of studies of the phenomenon of inhibition in human children. Planning and executing movement sequences, is contingent upon how the individual's body interfaces with the types of movement that the task dictates.

Tool Use: Learning About Affordances of Objects and Surfaces

Humans and nonhuman animals use and fashion objects adaptively in diverse contexts (Beck, 1980; Ingold, 1997; McGrew, 1992). The ability to use objects as tools has, for the most part, been studied from a Piagetian or neo-Piagetian position, resting on the assumption that comprehending a means-end relationship supports problem solving (Bates, 1979). In studies with nonhuman primates, researchers have sought to ascertain to what extent tool use is accompanied by causal reasoning (Povinelli, 2000; Tomasello & Call, 1997; Visalberghi & Tomasello, 1998). This approach has run into trouble because neither monkeys nor apes clearly evidence causal comprehension in simple tool-using tasks. In our view, this

approach is deeply flawed because interpretations of tool use as reflecting causal reasoning do not address the origins of tool use and the dynamic interplay between thought and movement of the body and objects in near space. We suggest that tool use can be more profitably investigated from a micro-developmental standpoint that addresses *how* individuals learn to use objects as tools, incorporating a variety of contexts, such as varying objects or surfaces (see Cummins-Sebree & Fragaszy, 2003).

Surprisingly, the development of tool use has received far less attention from psychologists studying children compared to those studying nonhuman primates, although this is beginning to change (Brown & Slatterly, cited in Brown, 1990; Bushnell & Bourdreau, 1993; Lockman, 2000; van Leeuwen, Smitsman, & van Leeuwen, 1994; Want & Harris, 2001). Representational thought and imitation have been two prominent themes in research on object use with children (e.g., Bates, 1979; Piaget, 1963; Want & Harris, 2000). A perception-action model shifts the focus to relational demands of the task and how the actor manages them. When individuals use an object as a tool, they coordinate multiple frames of reference between body and object, and object to surface, to produce the appropriate relations through action (Lockman, 2000). The tool user must monitor ongoing action and plan upcoming action. The body's means of affecting action (e.g., grip preferences), properties of the tool (e.g., shape), desired object (e.g., weight), and spatial frame of reference must be ascertained. Proficiency in using an object as a tool is dependent on perceiving relevant affordances of objects and surfaces and executing combinatorial actions that are appropriate to the task, such as using an appropriate degree of force on an object at a particular moment in time (Cummins-Sebree & Fragaszy, 2003) and bringing objects into proper spatial relation to one another (Lockman, 2000).

Because perception and action are inextricably linked (Gibson, 1979, Gibson & Pick, 2000), the individual's manipulative activity constrains the development of using an object in a particular way. For example, certain common action routines applied in exploration (e.g., banging) allow children to learn about the relations among objects, actions, and surfaces (Lockman, 2000; Ruff, 1984). Children who cannot execute certain movements with objects are less likely to discriminate their physical properties, and thus, may not be able to use objects effectively as tools. In contrast, those children whose actions enable the perception of information relevant to using objects as tools are at an advantage because they have a potentially broader array of object-action combinations available to them (Bushnell & Boudreau, 1993). Skill in tool use develops as action patterns build on one another, such as becoming hierarchically organized (e.g., infants learning to use a spoon, Connolly & Dalgleish, 1989; children using implements in handwriting, Greer & Lockman, 1998; infant baboons sponging liquid; Westergaard, 1993).

Guided by a perception-action model, Cummins-Sebree (1999) conducted a series of experiments in which she presented capuchin monkeys with tasks requiring use of hoe-like tools to maneuver a food treat across a platform. The design of the experiments allowed the author to determine how capuchins modulated their actions according to varying surface platform conditions (e.g., holes and barriers). Capuchins detected and moved objects past barriers on a surface, using a hoe tool, more easily than past holes on a surface. Barriers may be more visually salient than holes. Barriers also provide subjects with pronounced proprioceptive feedback

when the tool strikes the barrier compared to when it contacts the hole. Moreover, the actor can make repeated attempts at object retrieval when striking barriers with the tool, whereas with holes, an incorrect movement with the tool results in the object dropping into the hole and ending the trial. Two of the four capuchins in this study mastered using the hoe tool to retrieve the object from the other side of the hole, suggesting that, given the appropriate context and experience, capuchins can learn to avoid holes.

This conclusion is quite different from the one reached by Visalberghi and Limongelli (1994). Visalberghi and Limongelli studied capuchins' efforts to retrieve food from a tube containing a hole in the center (a "trap"). Three of the four capuchins tested were not able to avoid the trap; the fourth adopted an effective procedural rule that ignored the location of the trap. Visalberghi and Limonegelli concluded that capuchins did not understand the causal relations between the trap, movement of the food, and their actions with the stick used to push the food. Comparing the results of Visalberghi and Limongelli with those of Cummins-Sebree, points to the importance of considering contextual factors in capuchins' mastery of problems. The literature documents the tendency of capuchin monkeys to display a variety of tool-using behaviors in captivity where the context supports this form of behavioral expression. In captive environments, materials (e.g., nuts, sponges, cups, blocks, sticks) are provided, and the animals can experiment with them without the fear of predators and without the need to travel long distances to food sites. In the wild, tool use in capuchins is present, but infrequent (Boinski et al., 2003; Fragaszy et al., in press).

Other studies examining the selection and use of objects as tools further illustrate that nonhuman primates (capuchins, Cummins-Sebree, 1999, and tamarins, Hauser, 1997) are sensitive to physical properties of objects and surface features. In these experiments, capuchins and tamarins typically chose tools that resulted in solution of the task; however, capuchins occasionally chose tools that required realignment to retrieve objects and succeeded with them, whereas tamarins did not attempt realigning the tool. The difference in performance between the two species of monkeys can be explained, at least in part, by considering each species' manipulative propensities. Capuchins are well-known for their destructive foraging techniques, including pounding an object on a substrate to gain access to embedded foods (e.g., oysters, insects in woody substrates, and husked fruits, Fragaszy, Visalberghi, & Fedigan, 2003). Tamarins, on the other hand, do not act on objects in this way.

As the capuchins and tamarins could do, infants successfully used novel objects as hook tools in perceptually similar tasks (Chen, Sanchez, & Campbell, 1997; Chen & Sielger, 2000). Lockman (2000) reports that three year-olds showed sensitivity to graphic tool and surface combinations. For instance, when presented with a liquid surface, children appropriately chose a paintbrush over a pencil. When provided with multiple tool objects at a time, children (age range 2-5 years) detected and utilized the affordances of objects and performed actions appropriate to solve tool tasks (Johnson-Pynn, 2003; see also Brown & Slattery, as cited in Brown, 1990, for similar results). Children tended to select and work with objects that had physical properties that were relevant to solving tasks, and their strategies contained action patterns that were necessary for success. For example, when trying to obtain a stuffed toy that was out of reach, children selected tools that were

long rather than short and engaged in reaching and swiping more often than other movements. It was also common, however, for children to repeat actions with tool objects, even if the actions were ineffective. Sometimes these actions even continued after the experimenter called the children's attention to the reason why their actions were ineffective. It is plausible that children continued their erroneous strategies because the physical act of repetition is a means by which they could discover more about the physical and relational properties of objects. Case (1985) speculates that motoric repetition is important for children to ascertain predictability of an object-action sequence, regardless of its effectiveness in solving a problem. Actions are often repeated until consolidation of component actions is achieved. Thus, for young children, repeating actions with objects may be necessary for skill acquisition (Wood, Bruner, & Ross, 1976). It seems plausible that this interpretation could be extended to nonhuman individuals, whose behavioral repertoire with objects and surfaces also contains repetitive acts (Inoue & Matsuzawa, 1997; Takeshita, 1999; Takeshita et al., unpublished data).

Consideration of the social factors that influence the development of instrumental manual activity and studying subjects in ecologically relevant contexts will further broaden our understanding of this dimension of behavior shared by humans and nonhumans. To appreciate fully tool use, it is important to examine the organization of manipulative abilities in conjunction with the social practices that encourage and facilitate the use of objects as tools (Reed, 1993). The individual's sociocultural milieu contributes greatly to becoming proficient in the technology of one's culture (Rogoff, 1990, 2003; Vygotsky, 1978). Children participate in routine cultural activities that provide a context whereby information about the properties and functions of objects is provided along with exploratory procedures (Lockman & McHale, 1989; Rutkowska & Baines, 1997; von Hofsten & Siddiqui, 1993). Experienced and skilled individuals support novices by encouraging participation and extending their skills in order to meet task requirements (Greenfield, 1984; Johnson-Pynn & Nisbet, 2002 ; Siegler, 2001). In much the same way as adults structure social interactions with children in the context of object manipulation, Tomasello, Savage-Rumbaugh, and Kruger (1993) have proposed that humans enculturate chimpanzees in rearing environments where chimpanzees have extensive contact with their human caregivers in a variety of daily routines that involve objects. Tomasello et al. (1993) believe that the socialization of attention leads to an enhanced social cognitive orientation that has the effect of increasing enculturated chimpanzees' social learning skills relative to mother-reared chimpanzees, particularly their ability to learn via imitation (but see Bard & Gardner, 1996, for an alternative view).

Gleaning affordance information that is relevant to tool use from others is especially prominent in human communities, but it has also been documented in several communities of wild chimpanzees (e.g., termite fishing in the Gombe Stream Reserve community, Goodall, 1986; nut cracking in the Bossou community, Matsuzawa, 1994). Young chimpanzees engage in a variety of behaviors as they develop skill in using a hammer stone to crack open an oil palm nut on an anvil stone, including manipulating stones discarded by skilled conspecifics and leaning the body against a conspecific while it is nut cracking. These behaviors support detection of the properties of the stones and nuts, and the temporal and force relations that must be incorporated for success. In contrast to chimpanzees, capuchin

monkeys appear to be less likely to learn specific actions that are necessary to solve a task, but do become intensely interested in the work site and rewards when conspecifics are working (Fragaszy & Adams-Curtis, 1991; Fragaszy & Visalberghi, 1989; see Fragaszy et. al, in press for a review). Similar interpretations have been offered in observations of monkeys in provisioned non-captive settings (e.g., Japanese macaques, Hirata, Wantanabe, & Kawai, 2001).

Enhanced interest could support learning the basic association between the food site, tool, and reward. This is a distinction between *knowing that* a relationship exists versus *knowing how* to enable that relationship and why particular action-object assemblages are effective (Connolly & Dagleish, 1989; Lockman, 2000). Just because individuals understand the relations involved in using a tool, it does not follow that they can execute the actions correctly; learning by seeing is distinguished from learning by doing (Rutkowska & Baines, 1997). For example, children often reproduce nonfunctional, or irrelevant, actions with objects along with functional ones, after observing a demonstrator (Carpenter, Nagell, & Tomasello, 1998; Whiten, Custance, Gomez, Teixidor, & Bard, 1996). Thus, neither nonhuman animals or human children are likely to learn how to use objects as tools simply by observing models. It is conceivable that learning about causal relationships in tool use may require hands-on manipulation (see also Want & Harris, 2001), and we should be cautious in assuming that successful use of objects as tools reflects causal understanding (Visalberghi, Fragaszy, & Savage-Rumbaugh, 1995; Povinelli, 2000). In any case, Vygotsky's (1981) argument that the skills that individuals acquire are related to how they interact with others in problem solving situations is applicable in comparative investigations of tool use, among other types of problem solving.

Taken together, these studies suggest that learning about the properties of objects and surfaces and the relations among objects, surfaces and actions lay the foundation for a contextual understanding of the causal relations inherent in skilled tool use. The socio-cultural setting impacts how and when this learning occurs. We should conceive of variability in individuals as a potentially rich source of information about how children and nonhuman primates move towards more stable forms of tool use (Greer & Lockman, 1998) as well as other forms of problem-solving (Granott & Parziale, 2002).

Challenges in Conducting Comparative and Developmental Research

In much of the research that compares nonhumans to humans (especially humans and nonhuman primates), there are developmental differences between the subject pools; comparisons of children to subadult and adult nonhumans are the standard scenario. In contemporary research, it is unusual to be able to track the emergence of cognitive abilities in humans and nonhumans from similar starting points (but see Takeshita, 1999). Comparisons of behavior in subjects of different species and ages should be interpreted carefully. Adult animals can solve some tasks where human children cannot and vice versa. Heterochrony is common in phylogenetically related species (Gould, 1977; Parker, Langer, & McKinney, 2000). Thus, variations in task performance or an understanding of task requirements may be tied to different ontogenies of mental, physical, and social attributes, which even within the individual, do not progress at an invariant, stable pace. A

source of great controversy in developmental research has been the type of scale to employ. For example, temporal scales, such as the age of individuals, are not always appropriate variables in developmental research (Michel & Moore, 1995; Siegler, 2000) and may constrain our view of the developmental process by enforcing a false dichotomy of development as continuous or discontinuous (Fisher & Pare-Blagoev, 2000). Additionally, given that there is no single developmental endpoint in cognition, we should be wary in assuming that adult cognition is the normative or correct standard. We have evidence that human adult decision making and problem solving can differ cross-culturally, and is often wrought with biases (Coley, 2000). Technically speaking, expertise requiring particular abilities and skills can develop at any age. For example, some nonhuman primates (both adult and juvenile) develop various tool-using skills when provided with the opportunity, suitable objects, and motivation to develop the respective skill (e.g., using hammer stones to open a dense container with a highly desirable food encased in it). This same potential exists for young children. However, humans are the quintessential tool users; thus, it is difficult to find adult humans who are unskilled at the simpler tool use tasks typically provided to young children and nonhuman primates in experimental research.

Despite these methodological considerations, we contend that comparisons of nonhumans with humans of any age are indeed instructive. They have the potential to enhance our understanding of the emergence and refinement of abilities and skills and may even prompt alternative explanations of behavior or developmental trends. However, comparing developmental sequences is only a small part of what we can gain by fortifying the bridges that connect comparative and developmental psychology. A much more profound benefit will come from intense focus on explaining the sources of variability in emergent patterns and developmental trajectories in different populations.

For comparative and developmental psychologists to know only the psychological conditions of behavior that are pertinent to their specialized fields produces myopic practices in methodology, and ultimately, interpretation of data. Psychological science is prone to provincialism within its parts as are other disciplines such as biology and ecology. To be a science is to be a part of science in relation to other parts (von Bertalanffy, 1968). As Karl Jaspers (1986, p. 369) points out, science "comprises a systematic whole in which everything is connected with everything else." If science concerns the unity of what can be known, then a particular science, including psychology, must necessarily be in contact with other sciences. Systems theories already have shown great promise in integrating a variety of scientific disciplines, including comparative and developmental psychology (Lewis, 2000).

References

Adams-Curtis, L. E. (1989). Does a Piagetian description work? *Behavioral and Brain Sciences,* **12**, 588.

Altmann, J. (1974). Observational study of behavior: sampling methods. *Behaviour,* **49**, 227-267.

Antinucci, F. (1990). The comparative study of cognitive ontogeny in four primate species. In S. Parker & K. Gibson (Eds.), *"Language" and intelligence in monkeys and apes: Comparative developmental perspectives* (pp. 151-171) New York: Cambridge University Press.

Astington, J. W. (1993). *The child's discovery of the mind*. Cambridge, MA: Harvard University Press.

Bard, K., & Gardner, K. (1996). Influences on development in infant chimpanzees: Enculturation, temperament, and cognition. In A. Russon, K. Bard, & S. T. Parker (Eds.), *Reaching into thought: The minds of the great apes* (pp. 235-256). Cambridge, UK: Cambridge University Press.

Bates, E. (1979). *The emergence of symbols: Cognition and communication in infancy.* New York: Academic Press.

Beck, B. B. (1980). *Animal tool behavior: The use and manufacture of tools by animals.* New York: Garland Press.

Bensen, J. (1997). The development of planning: It's about time. In S. Friedman, E. Kofsky Scholnick (Eds.), *The developmental psychology of planning: Why, how, and when do we plan?* (pp. 43-75). Hillsdale, NJ: Erlbaum.

Bernstein, N. (1967). *The control and regulation of movement*. London, UK: Pergamon.

Berry, J. W., Poortinga, Y. H., & Pandey, J. (1997). *Handbook of cross cultural psychology: Vol. 2, Theory and method.* Boston, MA: Allyn & Bacon.

Bidell, T., & Ficsher, K. (1994). Developmental transitions in children's early on-line planning. In M. M. Haith, J. B. Bensen, R. J. Roberts, Jr., & B. F. Pennington (Eds.), *The development of future-oriented processes* (pp. 141-175). Chicago, IL: Chicago University Press.

Bjorklund, D. F. (1997). In search of a metatheory for cognitive development (or, Piaget's dead and I don't feel so good myself). *Child Development, 68*, 142-146.

Boccia, M. J., & Pedersen, C. A. (2001). Brief vs. long maternal separations in infancy: Contrasting relationships with adult maternal behavior and lactation levels of aggression and anxiety. *Psychoneuroendocrinology, 26*, 657-672.

Boinski, S., Quatrone, R. P., Sughure, K., Selvaggi, L., Henry, M., Stickler, C. M., & Rose, L. M. (2003). Skilled foraging actions by brown capuchins in Suriname: Are these socially supported and transmitted behaviors? In D. Fragaszy, & S. Perry (Eds.), *The biology of traditions: Models and evidence* (pp. 365-390). Cambridge, UK: Cambridge University Press.

Brainerd, C. J. (1979). Further replies on invariant sequences, explanation, and other stage criteria. *Behavioral and Brain Sciences, 2,* 149-152.

Bronfenbrenner, U. (1977). Toward an experimental ecology of human development. *American Psychologist, 32*, 513-531.

Bronfenbrenner, U. (1979). *The ecology of human development*: *Experiments by nature and by design.* Cambridge, MA: Harvard University Press.

Bronfenbrenner, U. (1989). Ecological systems theory. In R. Vasta, (Ed.), *Six theories of child development* (pp. 187-250). Greenwich, CT: JAI Press.

Bronnfenbrenner, U. (1993). The ecology of cognitive development: Research models and fugitive findings. In R. H. Wozniak, & K. W. Fischer, (Eds.), *Development in context: Acting and thinking in specific environments* (pp. 3-44). Hillsdale, NJ: Erlbaum.

Bronfenbrenner, U., & Evans, G. W. (2000). Developmental science in the 21st century: Emerging questions, theoretical models, research designs, and empirical findings. *Social Development, 9*, 115-125.

Bronfenbrenner, U., & Morris, P. (1998). The ecology of developmental process. In W. Damon (Series Ed.) and R. M. Lerner (vol. Ed.), *Handbook of child psychology: Vol 1. Theoretical models of human development* (5th ed., pp. 993-1028.). New York: Wiley.

Brown, A. L. (1990). Domain specific principles affect learning and transfer in children. *Cognitive Science, 14*, 107-133.

Bushnell, E. W., & Boudreau, J. P. (1993). Motor development and the mind: The potential role of motor abilities as a determinant of aspects of perceptual development. *Child Development, 64*, 1005-1021.

Call, J. (2001). Object permanence in orangutans (*Pongo pygmaeus*), chimpanzees (*Pan troglodytes*), and children (*Homo sapiens*). *Journal of Comparative Psychology, 115*, 159-171.

Carpenter, M., Nagell, K., & Tomasello, M. (1998). Social cognition, joint attention and communicative competence from 9 to 15 months of age. *Monographs of the Society for Research in Child Development, 63*, 1-255.

Case, R. (1985). *Intellectual development: Birth to adulthood.* Orlando, FL: Academic Press.

Chen, Z., Sanchez, R. P., & Campbell, T. (1997). From beyond to within their grasp: The rudiments of analogical problem solving in 10 and 13-month olds. *Developmental Psychology, 33*, 790-801.

Chen, Z., & Sielger, R. (2000). Across the great divide: Bridging the gap between understanding of toddlers' and older children's thinking. *Monographs for the Society of Research in Child Development, Serial No. 261, Vol. 65, No. 2*. Malden, MA: Blackwell.

Cheney, D. L., & Seyfarth, R. M. (1990). *How monkeys see the world: Inside the mind of another species*. Chicago, IL: University of Chicago Press.

Chevalier-Skolnikoff, S. (1983). Sensorimotor development in orang-utans and other primates. *Journal of Human Evolution, 12*, 545-561.

Chevalier-Skolnikoff, S. (1989). Spontaneous tool use and sensorimotor intelligence in Cebus compared with other moneys and apes. *Behavioral and Brain Sciences, 12*, 561-627.

Chompsky, N. (1972). *Languge and mind*. New York: Harcourt Brace.

Cole, M. (1992). Culture in development. In M. H. Bornstein, & M. E. Lamb (Eds.), *Developmental psychology: An advanced textbook* (3rd ed., pp. 731-789). Hillsdale, NJ: Erlbaum.

Coleman, K., & Wilson, D. S. (1998). Shyness and boldness in pumpkinseed sunfish : Individual differences are context specific. *Animal Behaviour, 56*, 927-936.

Coley, J. D. (2000). On the importance of comparative research: The case of folkbiology. *Child Development, 71*, 82-90.

Connolly, K., & Dalgleish, M. (1989). The emergence of tool-using skill in infancy. *Developmental Psychology, 25*, 894-812.

Corbetta, D. (2001). Dynamic interactions between posture, laterality, and bimanual coordination in human infants: Why stone knapping might be a uniquely hominid behavior. In V. Roux & B. Bril, *Laterality and bimanual coordination in human and nonhuman primates*. Symposium conducted at the international workshop Knapping Stone: A Uniquely Hominid Behavior, Pont-á-Mousson, France.

Cummins-Sebree, S. E. (1999). Detection of environmental constraints in a tool-use task by tufted capuchin monkeys (*Cebus apella*). Unpublished Master's Thesis, University of Georgia, Athens.

Cummins-Sebree, S. E., & Fragaszy, D. M. (2003). *Discovering affordances in tool-use tasks by capuchin monkeys (Cebus apella)*. Unpublished Manuscript.

Cummins-Sebree, S. E., Johnson-Pynn, J., & Fragaszy, D. M. (2003). *A capuchin's navigation through two- and three-dimensional mazes*. Unpublished manuscript.

Darwin, C. (1859). *On the origin of species by means of natural selection*. London, UK: John Murray.

DeLoache, J., Sugarman, S., & Brown, A. (1985). The development of error correction strategies in young children's manipulative play. *Child Development, 56*, 928-939.

DeVries, M. W. (1994). Kids in context: Temperament in cross-cultural perspective. In W. B. Carey, & S. C. Devitt (Eds.), *Prevention and early intervention: Individual differences as risk factors for the mental health of children* (pp. 126-139). New York: Brunner/Mazel.

Elman, J. L., Bates, E. A., Johnson, M. H., Karmiloff-Smith, A., Parisi, D., & Plunkett, K. (1996). *Rethinking innateness*. Cambridge, MA: MIT Press.

Evans, G. W., & Saegert, S. (2000). Residential crowding in the context of inner city poverty. In S. Wapner, J. Demick, T. Yamamoto, & H. Minami (Eds.), *Theoretical perspectives in environment behavior research* (pp. 247-267). New York: Kluwer Academic/Plenum Publishers.

Fabricius, W. V. (1988). The development of forward search planning in preschoolers. *Child Development, 59*, 1473-1488.

Fischer, K. W. (1980). A theory of cognitive development: The control and construction of hierarchies of skills. *Psychological Review, 87*, 477-531.

Fischer, K. W., & Pare-Blagoev, J. (2000). From individual differences to dynamic pathways of development. *Child Development, 71*, 850-853.

Fragaszy, D. M. (1998). How nonhuman primates use their hands [Monograph]. *Clinics and Developmental Medicine, 147*, 77-96.

Fragaszy, D. M., & Adams-Curtis, L. E. (1991). Generative aspects of manipulation in tufted capuchin monkeys (*Cebus apella*). *Journal of Comparative Psychology, 105*, 387-397.

Fragaszy, D. M., Galloway, A. T., Johnson-Pynn, J., & Brakke, K. (2002a). The sources of skill in seriating cups in children, monkeys, and apes. *Developmental Science, 5*, 118-131.

Fragaszy, D. M., Johnson-Pynn, J., Brakke, K., & Hirsh, E. (2002b). Strategic navigation of two-dimensional alley mazes: Comparing capuchin monkeys and chimpanzees. *Animal Cognition*, Retrieved September 1, 2002, from http://athene.em.springer.de/cgi/view

Fragaszy, D. M., & Perry, S. (Eds.). (2003). *The biology of traditions: Models and evidence*. Cambridge, UK: Cambridge University Press.

Fragaszy, D. M., & Visalberghi, E. (1989). Social influences on the acquisition of tool-using behaviors in tufted capuchin monkeys (*Cebus apella*). *Journal of Comparative Psychology,* **103**, 159-170.

Fragaszy, D. M., Visalberghi, E., & Fedigan, L. (2003). *The complete capuchin.* Cambridge, UK: Cambridge University Press.

Gallup, G. G. (1982). Self awareness and the emergence of mind in primates. *American Journal of Primatology,* **2**, 237-248.

Geary, D. C., & Bjorklund, D. F. (2000). Evolutionary developmental psychology. *Child Development,* **71**, 57-65.

Gessell, A. L. (1948). *Studies in child development.* Westport, CT: Greenwood.

Gibson, E. J. (1982). The concept of affordances in perceptual development: *The renascence of functionalism.* In W. A. Collins (Ed.), *Minnesota symposium on child psychology, Vol. 15* (pp. 55-80). Hillsdale, NJ: Erlbaum.

Gibson, E. J., & Pick, A. D. (2000). *An ecological approach to perceptual learning and development.* New York: Oxford University Press.

Gibson, J. J. (1979). *The ecological approach to visual perception.* Boston, MA: Houghton Mifflin.

Goodall, J. (1986). *The chimpanzees of Gombe.* Cambridge, MA: Harvard University Press.

Gottlieb, G. (1984). Evolutionary trends and evolutionary origins: Relevance to theory in comparative psychology. *Psychological Review,* **91**, 448-456.

Gottlieb, G. (1992). *Individual development and evolution: The genesis of novel behavior.* New York: Oxford University Press.

Gottlieb, G. (1998). Normally occurring environmental and behavioral influences on gene activity: From central dogma to probabilistic epigenesis. *Psychological Review,* **105**, 792-802.

Gottlieb, G., Wahlsten, D., & Lickliter, R. (1998). The significance of biology for human development: A developmental psychobiological systems view. In W. Damon (Series Ed.), & R. M. Lernder (Vol. Ed.), *Handbook of child psychology: Vol. 1. Theoretical models of human development* (5th ed., pp. 233-273). New York: Wiley.

Gould, S. J. (1976). Grades and clades revisited. In R. B. Masterton, W. Hodos, & H. Jerison (Eds*.), Evolution, brain, and behavior: persistent problems* (pp. 115-126). Hillsdale, NJ: Erlbaum.

Gould, S. J. (1977). *Ontogeny and phylogeny.* Cambridge, MA: Harvard University Press.

Granott, N., & Parziale, J. (2002) (Eds.). *Microdevelopment: Transition processes in development and learning.* Cambridge, UK: Cambridge University Press.

Greenfield, P. M. (1984). A theory of the teacher in the learning activities of everyday life. In B. Rogoff & J. Lave (Eds.), *Everyday cognition: Its development in social context* (pp. 117-138). Cambridge, MA: Harvard University Press.

Greenfield, P. M. (1991). Language, tools, and the brain: The ontogeny and phylogeny of hierarchically organized sequential behavior. *Behavioral and Brain Sciences,* **14**, 531-595.

Greenfield, P., Nelson, K., & Saltzman, E. (1972). The development of rulebound strategies for manipulating seriated cups: A parallel between action and grammar. *Cognitive Psychology,* **3**, 291-310.

Greer, T., & Lockman, J. L. (1998). Using writing instruments: Invariances in young children and adults. *Child Development,* **69**, 888-902.

Hall, B. K. (1992). *Evolutionary developmental biology.* London, UK: Chapman & Hall.

Hall, G. S. (1904). *Adolescence: Its psychology and its relations to physiology, anthropology, sociology, sex, crime, religion and education* (Vols. 1 and 2). New York: Appleton.

Harkness, S., & Super, C. M. (1994). The developmental niche: A theoretical framework for analyzing the household production of health. *Social Science Medicine,* **38**, 217-226.

Harkness, S., Raeff, C., & Super, C. M. (2000). Variability in the social construction of the child. *New directions for child and adolescent development #87.* San Francisco, CA: Jossey-Bass.

Harlow, H., & Harlow, M. (1965). The affectionate systems. In A. M. Shrier, H. F. Harlow, & F. Stollintz (Eds.), *Behavior of nonhuman primates,* Vol. 2 (pp. 287-334). New York: Academic Press.

Harlow, H., & Zimmerman. (1959). Affectionate responses in the infant monkey. *Science,* **130**, 421-432.

Harnishfeger, K. K. (1995). The development of cognitive inhibition: Theories, definitions, and research evidence. In F. Dempster, & C. Brainerd (Eds.), *New perspectives on interference and inhibition in cognition* (pp. 176-204). New York: Academic Press.

Hauser, M. D. (1997). Artifactual kinds and functional design features: What a primate understands without language. *Cognition, 64*, 285-308.

Heyes, C. M. (1998). Theory of mind in nonhuman primates. *Behavioral and Brain Sciences, 21*, 101-148.

Hinde, R. A. (1987). *Individuals, relationships and culture: Links between ethology and the social sciences.* Cambridge, UK: Cambridge University Press.

Hirata, S., Wantanabe, K., & Kawai, M. (2001). "Sweet-potato washing revisited." In T. Matsuzawa (Ed.), *Primate origins of cognition and behavior* (pp. 487-508). Tokyo, Japan: Springer.

Hopkins, B., & Westra, T. (1988). Maternal handling and motor development: An intracultural study. *Genetic, Social, and General Psychology Monographs, 14*, 377-420.

Ingold, T. (1997). Eight themes in the anthropology of technology. *Social Analysis, 41*, 106-138.

Inhelder, B., & Piaget, J. (1964). *The early growth of logic in the child: Classification and seriation.* New York: Norton.

Inoue-Nakamura, N., & Matsuzawa, T. (1997). Development of stone tool use by wild chimpanzees (*Pan troglodytes*). *Journal of Comparative Psychology*, **111**, 159-173.

Insel, T. (1992). Oxytocin: a neuropeptide for affiliation- evidence from behavioral, autoradiographic, and comparative studies. *Psychoneuroendocrinology*, **17**, 3-35.

Jaspers, K. (1986). *Basic philosophical writings, selections.* L. H. Ehrlich, E. Ehrlich, & G. B. Pepper (Eds. and translators). Athens, OH: Ohio University Press.

Jensen, A. R. (1969). How much can we boost IQ and scholastic achievement? *Harvard Educational Review, 39*, 1-123.

Johnson-Pynn, J. (2003). *Scaffolding improves preschoolers' performance in tool-using tasks.* Unpublished manuscript.

Johnson-Pynn, J., Fragaszy, D. M., Hirsh, E. M., Brakke, K. E., & Greenfield, P. M. (1999). Stratagies used to combine seriated cups by chimpanzees (*Pan troglodytes*), bonobos (*Pan paniscus*), and capuchins (*Cebus apella*). *Journal of Comparative Psychology, 133*, 137-148.

Johnson-Pynn, J., & Fragaszy, D. M. (2001). Do apes and monkeys rely upon conceptual reversibility? *Animal Cognition, 4*, 315-324.

Johnson-Pynn, J., & Nisbet (2002). Preschoolers effectively tutor novice classmates in a block construction task. *Child Study Journal, 32*, 241-255.

Keller, H., & Greenfield, P. M. (2000). History and future of development in cross-cultural psychology. *Journal of Cross-Cultural Psychology, 31*, 52-62.

Kuo, Z. Y. (1976). *The dynamics of behavioral development: An epigenetic view.* New York: Plenum.

Langer, J. (1980). *The origins of logic: 6 to 12 months.* San Diego, CA: Academic Press.

Lehrman, D. S. (1970). Semantic and conceptual issues in the nature-nurture problem. In L. R.Aronson, E. Tobach, D. S. Lehrman, & J. S. Rosenblatt (Eds.), *Development and evolution of behavior: Essays in memory of T. C. Schneirla* (pp. 17-52). San Fransisco, CA: W.H. Freeman.

Leon, M. (1992). The neurobiology of filial learning. *Annual Review of Psychology, 43*, 377-398

Lerner, R. M. (1991). Changing organism-context relations as the basic process of development: A developmental contextual perspective. *Developmental Psychology, 27*, 27-32.

Lerner, R. M., & Busch-Rossnagel, N. A. (Eds.). (1981). *Individuals as producers of their development: A life-span perspective.* New York: Academic Press.

Lerner, R. M., & Walls, T. (1999). Revisiting individuals as producers of their own development: From dynamic interactionism to developmental systems. In J. Brändtstadter & R. M. Lerner (Eds.), *Action and self-development: Theory and research through the life-span* (pp. 3-36). Thousand Oaks, CA: Sage.

Lewis, M. D. (2000). The promise of dynamic systems approaches for an integrated account of human development. *Child Development, 71*, 36-43.

Lickliter, R., & Berry, T. D. (1990). The phylogeny fallacy: Developmental psychology's misapplication of evolutionary theory. *Developmental Review, 10*, 348-364.

Limongelli, L., Boysen, S. T., & Visalberghi, E. (1995). Comprehension of cause-effect relationships in a tool-using task. *Journal of Comparative Psychology*, **109**, 18-26.

Lockman, J. J. (2000). A perception-action perspective on tool use development. *Child Development, 71*, 137-144.

Lockman, J. J., & McHale, J. P. (1989). Object manipulation in infancy: Developmental and contextual determinants. In N. L. Hazen & J. J. Lockman (Eds.), *Action in social context: Perspectives on early development* (pp. 129-167). New York: Plenum Press.

Lockman, J. J., & Thelen, E. (1993). Developmental biodynamics: Brain, body, behavior connections. *Child Development, 64*, 953-959.

Lorenz, K. (1957). The conception of instinctive behavior. In Schiller, C. H. (Ed. and Trans.), *Instinctive behavior* (pp. 129-175). New York: International Universities Press.

Maestripieri, D., Jovanovic, T., & Gouzoules, H. (2000). Crying and infant abuse in rhesus monkeys. *Child Development, 71*, 301-309.

Manoel, E., & Connolly, K (1997). Variability and stability in the development of skilled actions. In K. Connolly, H. Forssberg (Eds.), *Neurophysiology and neuropsychology of motor development* (pp. 286-318). Cambridge, UK: Cambridge University Press.

Marzke, M. W., & Wullstein, K. L. (1996). Chimpanzee and human grips: A new classification with a focus on evolutionary morphology. *International Journal of Primatology, 17*, 117-139.

Mason, W. A., & Berkson, G. (1975). Effects of maternal mobility on the development of rocking and other behaviors in rhesus monkeys: A study with artificial mothers. *Developmental Psychobiology, 8*, 197-211.

Mason, W. A., & Capitanio, J. P. (1988). Formation and expression of filial attachment in rhesus monkeys raised with living and inanimate mother substitutes. *Developmental Psychobiology, 21*, 401-430.

Matsumoto, D. (2000). *Culture and psychology: People and the world*. Belmont, CA: Wadsworth.

Matsuzawa, T. (1994). Field experiment on use of stone tools by chimpanzees in the wild: In R. Wrangham, W. McGrew, F. de Waal, & P. Heltne (Eds.), *Chimpanzee cultures* (pp. 350-370). Cambridge, MA: Harvard University Press.

McGrew, W. (1992). *Chimpanzee material culture*. Cambridge, UK: Cambridge University Press.

Menzel, C. R. (1999). Unprompted recall and reporting of hidden objects by a chimpanzee (*Pan troglodytes*) after extended delays. *Journal of Comparative Psychology, 113*, 426-434.

Menzel, C. R., Savage-Rumbaugh, E. S., & Menzel, E. W., Jr. (2002). Bonobo (*Pan paniscus*) spatial memory and communication in a 20-hectare forest. *International Journal of Primatology, 23*, 601-619.

Michel, G. F. (1991a). Human psychology and the minds of other animals. In C. A. Ristau (Ed.), *Cognitive ethology: The minds of other animals* (pp. 253-272). Hillsdale, NJ: Erlbaum.

Michel, G. F. (1991b). Development of infant manual skills: Motor programs, schemata, or dynamic systems? In J. Fagard, & P. H. Wolff (Eds.), *The development of timing control and temporal organization in coordinated action* (pp. 175-199). New York: Elsevier.

Michel, G. F., & Moore, C. L. (1995). *Developmental psychobiology: An interdisciplinary science*. Cambridge, MA: MIT Press.

Morage, M. (2001). *The misunderstood gene*. Cambridge, MA: Harvard University Press.

Owren, M. J., & Rendall, D. (1997). An affect-conditioning model of nonhuman primate vocal signaling. In D. H. Owings, & D. Beecher (Eds.), *Perspectives in ethology, Vol. 12 : Communication* (pp. 299-346). New York: Plenum Press.

Oyama, S. (2000). *The ontogeny of information: Developmental systems and evolution*. Durham, NC: Duke University Press.

Oyama, S., Griffiths, P. E., & Gray, R. D. (Eds.). (2001). *Cycles of contingency*. Cambridge, MA: MIT Press.

Parent, S., Normandeau, S., & Larivee, S. (2000). A quest for the holy grail in the new millennium: In search of a united theory of cognitive development. *Child Development, 71*, 860-861.

Parker, S. T., & Gibson, K. R. (1977). Object manipulation, tool use, and sensorimotor intelligence as feeding adaptions in Cebus monkeys and great apes. *Journal of Human Evolution, 6*, 623-641.

Parker, S. T., & Gibson, K. R. (1979). A developmental model for the evolution of language and intelligence in early months. *Behavioral and Brain Sciences, 2*, 367-408.

Parker, S. T., Langer, J., & McKinney, M. L. (2000). *Biology, brains, and behavior: The evolution of human development*. Santa Fe, NM: School of American Research Press.

Parker, S. T., & McKinney, M. L. (1999). *The evolution of cognitive development in monkeys, apes, and humans*. Baltimore, MD: Johns Hopkins University Press.

Pedersen, C. A., & Boccia, M. L. (2002). Oxytocin links mothering received, mothering bestowed and adult stress responses. *Stress: The International Journal on the Biology of Stress,* **5**, 259-267.

Perner, J. (1991). *Understanding the representational mind.* Cambridge, MA: MIT Press.

Pepper, S. C. (1942). *World hypotheses: A study in evidence.* Berkeley, CA: University of California Press.

Piaget, J. (1963). *The origins of intelligence in children.* New York: W. W. Norton.

Piaget, J. (1969). *The child's conception of number.* London, UK: Routledge & Kegan Paul.

Piaget, J., & Inhelder, B. (1969). *The psychology of the child.* New York: Basic books.

Poti, P. (1997). Logical studies of young chimpanzees spontaneous object grouping. *International Journal of Primatology,* **18**, 33-59.

Poti, P., & Spinozzi, G. (1994). Early sensory development in chimpanzees (*Pan troglodytes*). *Journal of Comparative Psychology,* **108**, 93-103.

Povinelli, D. J. (2000). *Folk physics for apes: The chimpanzee's theory of how the world works.* Oxford, UK: Oxford University Press.

Povinelli, D. J., & Giambrone S. (2001). Reasoning about beliefs: A human specialization? *Child Development,* **72**, 691-695.

Premack, D., & Woodruff, G. (1978). Does the chimpanzee have a theory of mind? *Behavioral and Brain Sciences*, **4**, 515-526.

Reed, E. S. (1993). The intention to use a specific affordance: A conceptual framework for psychology. In R. H. Wozniak, & K. Fischer (Eds.), *Development in context: Acting and thinking in specific environments* (pp. 45-76). Hillsdale, NJ: Erlbaum.

Reese, H. W., & Overton, W. F. (1970). Models of development and theories of development. In Goulet, L. R., & P. B. Blates (Eds.), *Life-span developmental psychology: Research and theory* (pp. 115-145). New York: Academic Press.

Rogoff, B. (1990). *Apprenticeship in thinking.* Oxford, UK: Oxford University Press.

Rogoff, B. (2003). The *cultural nature of human development.* Oxford, UK: Oxford University Press.

Ross, C., & McLarnon, A. (2000). The evolution of non-maternal care in anthropoid primates: A test of hypotheses. *Folia Primatologica,* **71**, 93-113.

Rovee-Collier, C. K. (1995). Time windows in cognitive development. *Developmental Psychology,* **31**, 147-169.

Rovee-Collier, C. K. (1997). Dissociations in infant memory: Rethinking the development of implicit and explicit memory. *Psychological Review,* **104**, 467-498.

Ruff, H. (1984). Infants' manipulative exploration of objects: Effects of age and object characteristic. *Developmental Psychology,* **20**, 9-20.

Russon, A. E. (2003). Developmental perspectives on great ape traditions. In D. Fragaszy & S. Perry (Eds.), *The biology of traditions: Models and evidence* (pp. 329-364). Cambridge, UK: Cambridge University Press.

Russon, A. E., Bard, K. A., & Parker, S. T. (1996). *Reaching into thought: The minds of the great apes*. Cambridge, UK: Cambridge University Press.

Rutkowska, J. C., & Baines, E. (1997). Perceiving, discovering, and constructing affordances. In M. A. Schmuckler, & J. M. Kennedy (Eds.), *Studies in perception and action IV* (pp. 161-164). Hillsdale, NJ: Erlbaum.

Savage-Rumbaugh, E. S., Murphy, J., Sevcik, R. A., Brakke, K. E., Williams, S. L., & Rumbaugh, D. M. (1993). Language comprehension in ape and child. *Monographs of the Society for Research in Child Development,* 58(3-4), Serial No. 233.

Schino, G., & Troisi, A. (2001). Relationship with the mother modulates the response of yearling Japanese macaques (*Macaca fuscata*) to the birth of a sibling. *Journal of Comparative Psychology,* **115**, 392-396.

Schneirla, T. C. (1957). The concept of development in comparative psychology. In D. B. Harris (Ed.), *The concept of development: An issue in the study of human behavior* (pp. 78-108). Minneapolis, MN: University of Minnesota Press.

Schneirla, T. C., & Rosenblatt, J. S. (1961). Behavioral organization and genesis of the social bond in insects and mammals. *American Journal of Orthopsychiatry,* **3**, 223-253.

Schneirla, T. C., & Rosenblatt, J. S. (1963). Critical periods in behavioral development. *Science,* **139**, 1110-1114.

Shettleworth, S. J. (1998). *Cognition, evolution, and behavior*. New York: Oxford University Press.

Siegler, R. S. (1996). *Emerging minds: The process of change in children's thinking*. New York: Oxford University Press.

Siegler, R. S. (2000). The rebirth of children's learning. *Child Development,* **71**, 26-35.

Siegler, R. S. (2002). Microgenetic studies of self explanation. In N. Granott and J. Parziale (Eds.), *Microdevelopment: Transition processes in development and learning* (pp. 31-58). Cambridge, UK: Cambridge University Press.

Siegler, R. S., & Crowley, K. (1991). The microgenetic method: A direct means for studying cognitive development. *American Psychologist,* **46**, 606-620.

Siegler, R. S., & Stern, E (1998). A microgenetic analysis of conscious and unconscious strategy discoveries. *Journal of Experimental Psychology: General,* **127**, 377-397.

Skinner, B. F. (1938). *The behavior of organisms*. New York: Appleton.

Smotherman, W. P., & Robinson, S. R. (1998). The uterus and environment: The ecology of fetal behavior. In E. M. Blass (Ed.), *Developmental psychobiology and behavioral ecology: Handbook of behavioral neurobiology, Vol. 9* (pp. 149-196). New York: Plenum Press.

Snowden, C. T., & French, J. A. (1979). Ontogeny does not always recapitulate phylogeny. *Behavioral and Brain Sciences,* **2**, 397-398.

Steinberg, L. (1990). Interdependence in the family: Autonomy, conflict, and harmony in the parent-adolescent relationship. In S. S. Feldman, & G. L. Elliott (Eds.), *At the threshold: The developing adolescent* (pp. 255-275). Cambridge, MA: Harvard University Press.

Suomi, S. J. (1987). Genetic and maternal contributions to individual differencesin rhesus monkey biobehavioral development. In N. A. Krasnagor, E. M. Blass, M. A. Hofer, & Smotherman (Eds.), *Perinatal development: A psychobiological perspective* (pp. 397-420). New York: Academic Press.

Suomi, S. J. (2000). A behavioral perspective on developmental psychopathology: Excessive aggression and serotonergic dysfunction in monkeys. In A. J. Sameroff, M. Lewis, & S. Miller (Eds.), *Handbook of developmental psychopathology, 2nd edition* (pp. 237-256). New York: Plenum.

Super, C. (1976). Environmental effects on motor development: The case of "African infant precocity." *Developmental Medicine and Child Neurology,* **18**, 561-567.

Thelen, E. (1986). Treadmill-elicited stepping in seven-month-old infants. *Child Development,* **57**, 1498-1506.

Thelen, E. (1992). Development of locomotion from a dynamic systems approach. In H. Forssberg, & H. Hirschfield (Eds.), *Movement disorders in children* (pp. 169-173). Basel, Switzerland: Karger.

Thelen, E., & Corbetta, D. (2002). Microdevelopment and dynamic systems: Applications to infant motor development. In N. Granott, & J. Parziale (Eds.), *Microdevelopment: Transition processes in development and learning* (pp. 59-79). Cambridge, UK: Cambridge University Press.

Thelen, E., & Smith, L. (1994). *A dynamic systems approach to the development of cognition and action*. Cambridge, MA: MIT Press.

Thomas, A., & Chess, S. (1977). *Temperament and development*. New York: Brunner/Mazel.

Tinbergen, N. (1963). On aims and methods of ethology. *Zeitschrift für Tierpsychologie*, **20**, 410-433.

Tomasello, M., & Call, J. (1997). *Primate cognition*. New York: Oxford University Press.

Tomasello, M., Savage-Rumbaugh, S., & Kruger, A. C. (1993). Imitative learning of actions on objects by children, chimpanzees, and enculturated chimpanzees. *Child Development,* **64**, 1688-1705.

van Leeuwen, L., Smitsman, A., & van Leeuwen, C. (1994). Affordances, perceptual complexity, and the development of tool use. *Journal of Experimental Psychology,* **20**, 174-191.

Visalberghi, E., Fragaszy, D. M., & Savage-Rumbaugh, S. (1995). Performance in a tool-using task by common chimpanzees (*Pan troglodytes*), bonobos (*Pan paniscus*), an orangutan (*Pongo pygmaeus*), and capuchin monkeys (*Cebus apella*). *Journal of Comparative Psychology,* **109**, 52-60.

Visalberghi, E., & Limongelli, L. (1994). Lack of comprehension of cause-effect relations in tool-using capuchin monkeys (*Cebus apella*). *Journal of Comparative Psychology,* **108**, 15-22.

Visalberghi, E., & Tomasello, M. (1998). Primate causal understanding in the physical and psychological domains. *Behavioural Processes,* **42**, 189-203.

von Bertalanffy, L. (1968). *General systems theory*. New York: Braziller.

von Hofsten, C. (1994). Planning and perceiving what is going to happen next. In M. Haith, J. Besen, R. Roberts, Jr., & B. Pennington (Eds.), *The development of future-oriented processes*, (pp. 63-85). Chicago, IL: University of Chicago Press.

von Hofsten, C., & Siddiqui, A. (1993). Using the mother's actions as a reference for object exploration in 6- and 12-month-old infants. *British Journal of Developmental Psychology,* **11**, 61-74.

Vygotsky, L. S. (1978). *Mind in society: The development of higher psychological processes*. Cambridge, MA: Harvard University Press.

Vygotsky, L. S. (1981). The genesis of higher mental functions. In J. V. Wertsch (Ed.), *The concept of activity in soviet psychology* (3-36). New York: Sharpe.

Want, S. C., & Harris, P. L. (2000). Social learning: Compounding some problems and dissolving others. *Developmental Science,* **5**, 39-41.

Want, S. C., & Harris, P. L. (2001). Learning from other people's mistakes: Causal understanding in learning to use a tool. *Child Development,* **72**, 431-443.

Wellman, H. M., Cross, D., & Watson, J. (2001). Meta-analysis of theory-of-mind development: The truth about false belief. *Child Development,* **72**, 655-684.

West, M. J., & King, A. P. (2002). The ontogeny of competence in D. Lwekowicz, & R. Lickliter (Eds.), *Conceptions of development* (pp. 77-103). New York: Taylor & Francis.

West, M. J., King, A. P., & Arberg, A. A. (1988). The inheritance of niches: The role of ecological legacies in ontogeny. In E. M. Blass (Ed.), *Developmental psychobiology and behavioral ecology* (pp. 41-62). New York: Plenum Press.

Westergaard, G. C. (1993). Development of combinatorial manipulation in infant baboons (*Papio cynocephalus anubis*). *Journal of Comparative Psychology*, **107**, 34-38.

Whiten, A., & Byrne, R.W. (1988). Tactical deception in primates. *Behavioral and Brain Sciences,* **11**, 233-273.

Whiten, A., Custance, D. M., Gomez, J. C., Teixidor, P., & Bard, K. A. (1996). Imitative learning of artificial food processing in children (*Homo sapiens*) and chimpanzees (*Pan troglodytes*). *Journal of Comparative Psychology,* **110**, 3-14.

Wilson, F. R. (1998). *The hand: How its use shapes the brain, language and human culture*. New York: Random House.

Wood, D., Bruner, J. S., & Ross, G. (1976). The role of tutoring in problem-solving. *Journal of Child Psychology and Psychiatry,* **17**, 89-100.