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Play as the Foundation of Human Intelligence: The Illuminating Role of Human Brain Evolution and Development and Implications for Education and Child Development.

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Play as the Foundation of Human Intelligence: The Illuminating Role of Human Brain Evolution and Development and Implications for Education and Child Development.

Abstract

Children love to play. Why do they find such a frivolous activity so pleasurable and desirable? Perhaps it is not frivolous, but instead is an adaptation designed to guide proper cognitive development in human children. To understand why, I marshal evidence from different fields to build a case for play as a central behavioral mechanism of human brain and cognitive development. I start with a discussion of human evolution, focusing on the evolution of human physiology, tool-use, the human brain, and life-history strategy, and development, and how these are all connected as an adaptive suite. The anthropological and developmental evidence suggests the existence of an extended childhood adapted to establish the skills, knowledge, and understanding necessary to become a successful hunter-gatherer. I also compare human and chimpanzee brain development, and how brain-specific genes evolved uniquely in humans to foster human brain development. I conclude with the evidence from developmental psychology that even contemporary, first-world children are born with the drive to learn and develop intellectually through play. In this framework, human play can be viewed as an adaptation that guides human brain development to produce curious, intelligent and well-adjusted adults. I close by speculating on the possibility that barriers to or constraints on play may hamper intellectual and cognitive development. I focus on the important concept of developmental *decanlization* as a mechanism of evolutionary mismatch. I argue that more empirical study is needed to better understand the importance of play compared to other forms of education for optimal intellectual and cognitive development.

Keywords

Play, Development, Psychopathology, Intelligence, Creativity, Neuropsychology, Anthropology, Education, Comparative Cognition

INTRODUCTION

Children love to play. Why do they find such a frivolous activity so pleasurable and desirable? Why do children in every corner of the world, from Western to Eastern, from urban to rural, and even among every extant hunter-gather and traditional foraging group ever studied, like to kick a ball, throw a rock or spear, play make-believe with real dolls or ones made from sticks and twigs? Why do we all enjoy the pleasures of singing and dancing, the thrill of chase and tag, or hide and seek? Why do we engage in tickling, wrestling, or more sedate coordinated games such as involving dice, game pieces, or a “hot potato”? Human universals of play include skipping and throwing stones, chase and tag, wrestling, pretend play and make believe, word games, song, and rhyme, rope games, running, climbing and jumping, dance, imitation & miming, etc. (Konner, 2010; Gray, 2013).

Perhaps play is not frivolous. Instead, perhaps play is a human adaptation through which we learn the life skills necessary to be a successful adult. Play isn't even unique to humans. There is much evidence across the Animal Kingdom that play serves an adaptive role in neural and behavioral development (see reviews by Bateson and Martin, 2013; Burghardt, 2014). Rough-and-tumble play (e.g., wrestling) has an extremely broad phylogenetic distribution, including wasps (Phylum Arthropoda; Dapporto, Turillazzi, & Palagi, 2006), though it is best characterized in Orders Rodentia (Pellis & Pellis, 2009; Trezza et al., 2010; Figure 1), Carnivora, and Primates of Phylum Chordata. Dolphins are well known for their playfulness both in social play and play with objects (Kuczaj & Eskelinen, 2014), but object play is also found in octopuses (Phylum Mollusca; Kuba, Meisel, Byrne, Griebel, & Mather, 2003) and cichlid fish (Phylum Chordata; Burghardt, Dinets, & Murphy, 2014). Non mammals, such as reptiles and birds, play, and can even be influenced to play when nearby conspecifics are playing. Indeed, the observation that play is universal in animals may point to its functional and adaptive nature for individual success and survival (Bateson, 2014). Individual

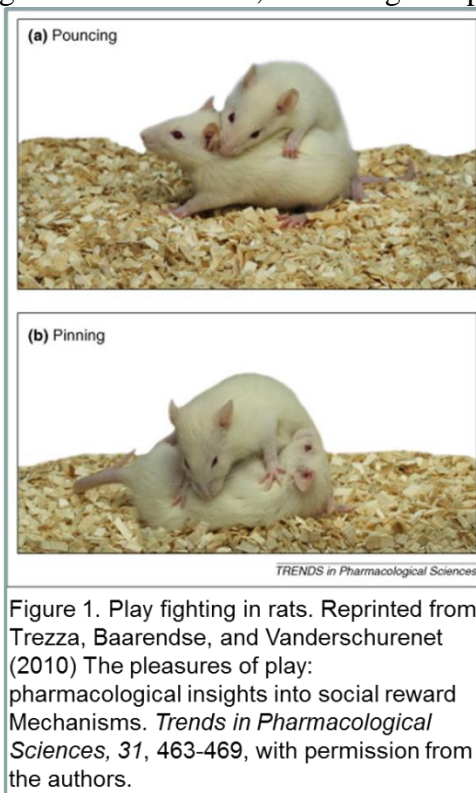


Figure 1. Play fighting in rats. Reprinted from Trezza, Baarendse, and Vanderschuren (2010) The pleasures of play: pharmacological insights into social reward Mechanisms. *Trends in Pharmacological Sciences*, 31, 463-469, with permission from the authors.

differences in juvenile play are associated with differences in success and survivorship as adults (Antonacci, Norscia, & Palagi, 2010; Blumstein, Chung, & Smith, 2013; Fagen & Fagen, 2004, 2009). The mechanistic basis of play, and how play contributes to neural development, is finally starting to receive more empirical attention (Bell, Pellis, & Kolb, 2010; Pellis & Pellis, 2009; Pellis, Pellis, & Bell, 2010; Pellis, Pellis, & Himmler, 2014; van den Berg et al., 1999; Vanderschuren & Trezza, 2014).

Among human hunter-gatherers (HG) throughout the world, play has evolved to the most advanced form that exists in the animal kingdom, and, unlike in most other animals, extends into adulthood as a major form of behavior (Bjorklund, 1997; Lorenz, 1971). There are major differences between the way modern humans play and the play of other extant great apes. The young of chimpanzees, bonobos, and gorillas engage in certain forms of play also found among humans, such as chase and wrestling, climbing, spinning and other acrobatics, and curiosity-driven playing with objects and other forms of object exploration. Young chimpanzees even enjoy and actively recruit others to tickle them (personal observation). Nevertheless, many of the more cognitive and symbolic forms of play are virtually nonexistent in apes and other animals. These include such forms of play as pretend play and make believe; play involving synchronized or coordinated social interactions, such as dance and games with rules; and of course word play, such as song, rhyme, and storytelling.

Another departure from the great apes is that humans continue to engage in play throughout their lifespan, well into adulthood and even old age, though bonobos continue to engage in social play in adulthood (Palagi & Cordoni, 2012). These differences suggest that play serves additional functions beyond those it serves in other primates and the rest of the animal kingdom. To understand these additional functions, why they evolved, and the important role of play in shaping brain development, it is important to understand key aspects of the modern human ecological niche. That is, we must first characterize the role that children and adults play in human society to understand why play might have become a fundamental adaptation serving these roles.

THE ORIGINAL SCIENTISTS

In a seminal paper, Blurton Jones and Konner (1976) report their study of the !Kung bushman, a contemporary hunter-gather society living in Southern Africa. They interviewed individuals and groups of !Kung men, investigating how detailed was their knowledge of their world. They included questions designed to probe the empirical and epistemological systems these men used in acquiring and evaluating evidence. Evidence is acquired directly through an individual's own experiences, and socially through information shared by group members. The

!Kung knowledge of animal behavior was found to equal or even exceed that of contemporary ethologists. What was particularly telling was the empirical approach adopted by the !Kung, including their skepticism of non-personal sources of information.

*“The !Kung appear to know a good deal more about many subjects than do the scientists. **The !Kung appear to separate data carefully from theory and to discriminate observed data from second-hand information** (emphasis added).*

Their procedures of data gathering, analysis, and interpretation resemble the methods of modern-day Western ethology as regards (1) attention to detail, (2) distinguishing data from hearsay, and (3) displaying a general freedom from inference. In these respects their observations are superior to those of naturalists such as Gilbert White and Aristotle and very sophisticated indeed when compared with the legions of animal behaviorists among Western hunters, gamekeepers, and pet owners.” (p. 333).

These statements reflect what others have written about the information demands and skill proficiency of hunter-gatherer subsistence ecology (Draper & Cashden, 1988; Hill & Hurtado, 1996). A hunter-gatherer lifestyle involves a long-term, lifelong development of knowledge and skill. The extended human childhood allows for the development of cognitive abilities such as planning, inference, analytic and relational cognition, and cultural acquisition and modification. Anthropologists have demonstrated that the skills and proficiencies needed to be a successful hunter-gatherer are acquired during an extended development during childhood (Bock, 2005; Konner, 2005; Tucker & Young, 2005; but see Bird & Bird, 2005, Blurton Jones & Marlowe, 2002). The intergenerational transfer of a cumulative culture and beliefs, with generation and incorporation of modifications and innovations requires a long period of R&D during an extended phase of development. Liebenberg (1990) is perhaps the most eloquent treaties documenting how childhood and child development in hunter-gather societies fosters a scientific mindset that is necessary to the hunter-gather way of life, especially the art of tracking animals. The following quote articulates clearly the special roles of play and storytelling in training the mind and transferring accumulated knowledge across generations.

“Although they receive very little formal instruction, children of Kalahari hunter-gatherers are exposed to a continuous process of learning in the form of play activities and informal storytelling.

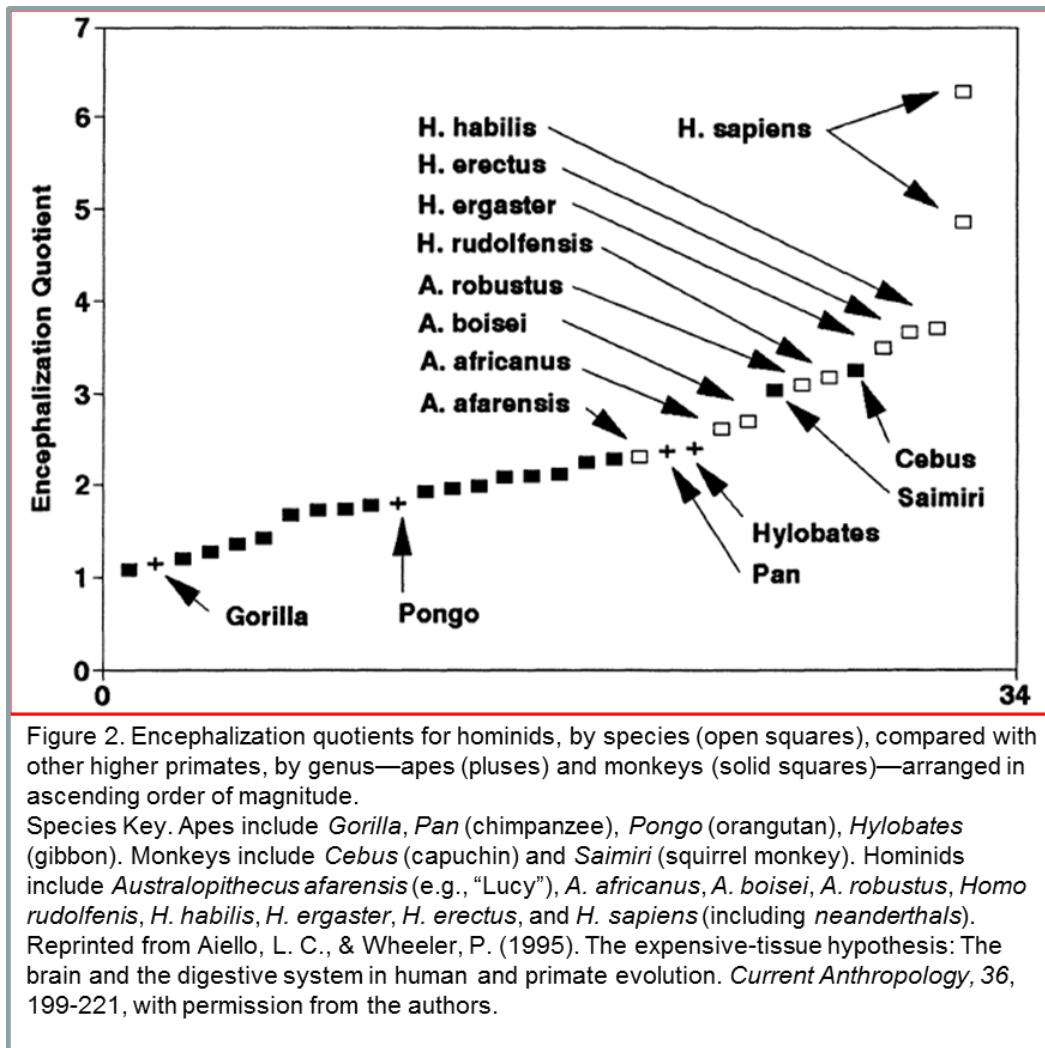
From as early as three years old, a boy plays with a little bow of wood and twine with arrows of grass stems, shooting at still targets or dung-beetles and grasshoppers. As he grows older, he will hunt lizards, mice and small birds. By stalking these small animals he studies their behavior, so that he not only gains experience in stalking but acquires knowledge which he may use later when hunting large animals. Older boys spend much time studying animal tracks. They may follow the spoor [tracks, scent, scat, etc.] of insects, scorpions, and at a later stage small mammals such as mongooses, and reconstruct their feeding patterns and habits. In this way their knowledge and tracking skills are developed through continuous study of all the animals in their environment. Throughout their growing years, children spend many hours listening intently to the conversation of their elders. Much information is also transmitted among the children themselves, from the older to the younger.

*Hunters share their knowledge and experience with each other in storytelling around the campfire, in which hunts and events are described in minute detail. **Although there seems to be relatively little direct transmission of information or formal teaching, much knowledge is gained indirectly in a relaxed social context. Knowledge gained informally is assimilated more easily than knowledge gained under direct instruction, to which people generally have an adverse reaction.** Hunters take great delight in lengthy, detailed and very gripping narrations of events they have experienced, using non-verbal expression to dramatise their stories. Although they do not take licence with the facts, artistic expression is used to relate events in an entertaining way, thereby ensuring a continuous flow of information. Storytelling therefore acts as a medium for the shared group knowledge of a band.” p. 80 (emphasis added).*

Thus, the lifeway of anatomically modern humans departs dramatically from that of our closest living cousins, the great apes. This is reflected not only in *Homo sapiens*' ability to adapt through culture and technology to almost every terrestrial environment on the planet, but also by the advanced and unique forms of play expressed during human childhood, and the propensity for lifelong learning throughout adulthood. Human society has also become even more prosocial than that of our closest ape relatives, with egalitarianism and sharing as the mechanism of group cohesion and function (Sober & Wilson, 1998). Finally,

humans are unique among all animals in having a true language, which allows the interpersonal transfer of symbolic information (Bickerton, 1995).

What are the requirements of a human-specific ecology that necessitated the fundamental shift in the importance of play for human life-history strategy? And what are the human-specific developmental and evolutionary processes that brought about such a dramatic divergence from the ape template? I address these questions in the next section on the evolution of human lifespan and brain evolution. Afterward, I return to a discussion of what this implies for the role of play in human intellectual development. I end with a discussion on the implications these ideas hold for how children are raised and schooled in modern society. I will cover some evidence for evolutionary/ecological mismatch in modern education that may have some negative consequences for child development.



THE HUNTER-GATHERER FORAGING NICHE

A comparative analysis of humans and the other extant hominoids (apes) reveals many key differences (Aiello & Wheeler, 1995). First, although great apes have large brains relative to the rest of the primate clade, they are much smaller when scaled to body size than is that of a human (Aiello & Wheeler, 1995; Figure 2). Brain size did not change much during the early stages of hominid evolution, with the genus *Australopithecus* having an estimated brain size (a little over 400 cc) comparable to that of extant chimpanzees to which body size was also roughly matched. It was not until the origin of *Homo* that brain size started to increase, and to a greater extent than body size. By the time the first *Homo sapiens* remains are found in the paleontological record, roughly 200 kya (thousand years ago); human brain size had tripled compared to that of a chimpanzee or Australopithecine. This large brain is metabolically expensive, and required a shift to a diet of high nutrient density to support a brain with as many neurons as has the human brain (Fonesca-Azevedo & Herculano-Houzel, 2012).

Second, the length of the gastrointestinal tract of humans is about 60% of that of a similar-sized primate (Milton, 2003). Much of this difference is due to a reduction in the length of the lower intestines, which are responsible for microbial processing of non-digestible

carbohydrates such as resistant starch and fiber (Figure 3). The small intestine of humans where foods are broken down into their digestible constituents, however, is relatively large compared to that of a similarly-sized ape (Milton, 2003). Aiello and Wheeler (1995) theorized that the larger brain and shorter intestines reorganized away from bacterial

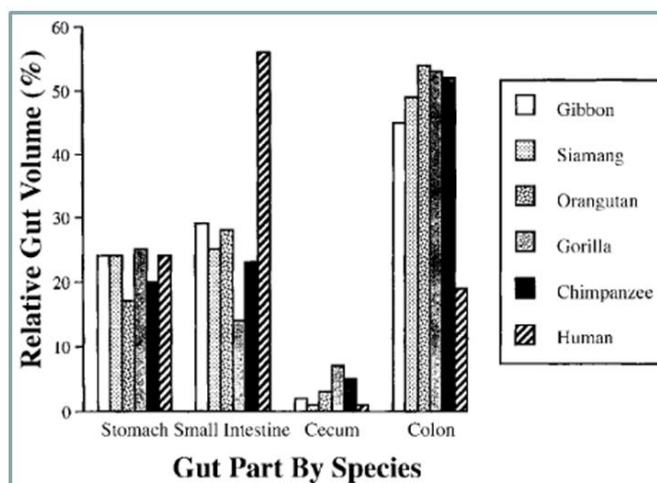


Figure 3. Relative gut proportions for extant hominoids (percentage of total gut volume). Lesser apes: gibbon (*Hylobates pileatus*), siamang (*Hylobates syndactylus*); great apes: orangutan (*Pongo pygmaeus*), gorilla (*Gorilla gorilla*), chimpanzee (*Pan troglodytes*); Western humans (*Homo sapiens sapiens*). All calculations of relative volume by K. Milton. See Milton (10) for sources of raw data. Reprinted from Nutrition Vol. 15(6), K. Milton, Nutritional characteristics of wild primate foods: do the diets of our closest living relatives have lessons for us?, pp. 488-498, 1999, with permission from Elsevier Science. Reprinted from Milton, K. (2003). The critical role played by animal source foods in human (*Homo*) evolution. *The Journal of Nutrition*, 133, 3886s-3892s., with permission from the authors.

fermentation to assimilation by enzymatic digestion necessitated a developmental and physiological tradeoff between two metabolically expensive organs (but see Navarrete, van Schaik, & Isler, 2011). In order for brain expansion to occur, the intestines had to shrink. The only way this appeared possible was for the nutrient quality of the human diet to increase so that sufficient nutrient extraction could take place during the shorter transit time through the gut. Also, our energy needs had to shift away from a substantial portion coming in the form of fermented fatty acids produced by the hind-gut microbes, and rely more on the direct

extraction in the small intestines of nutrients from high quality and readily digestible sources (Fonseca-Azevedo & Herculano-Houzel, 2012; Milton, 2003).

Another human-unique feature¹ to consider is the dexterous hand with an opposable thumb. The human hand is well-adapted to object manipulation, and was a necessary evolutionary step to allow for the development of tools (Marzke & Marzke, 2000; Susman, 1998; Figure 4).

What does this suite of traits; big brains, short intestines, and dexterous hand with an opposable thumb, tell us about our human-specific way of life? They are all adaptations that allowed humans to extract the most nutrient dense foods from the environment. These traits indicate that humans have moved to the

¹Bipedalism was also a human-unique anatomical specialization, one that defines the origin of hominids (humans and our non-ape ancestors) as separate from the hominoids (apes; White et al., 2009). Although bipedalism was a necessary precursor to the evolution of the suite of traits unique to *Homo*, it wasn't sufficient to the evolution of the *Homo*-unique life history strategy, as exemplified by the ape-like *Ardipithecus* and *Australopithecus* that were also bipedal but possessed an ape-like cranium and, presumably, cognition.

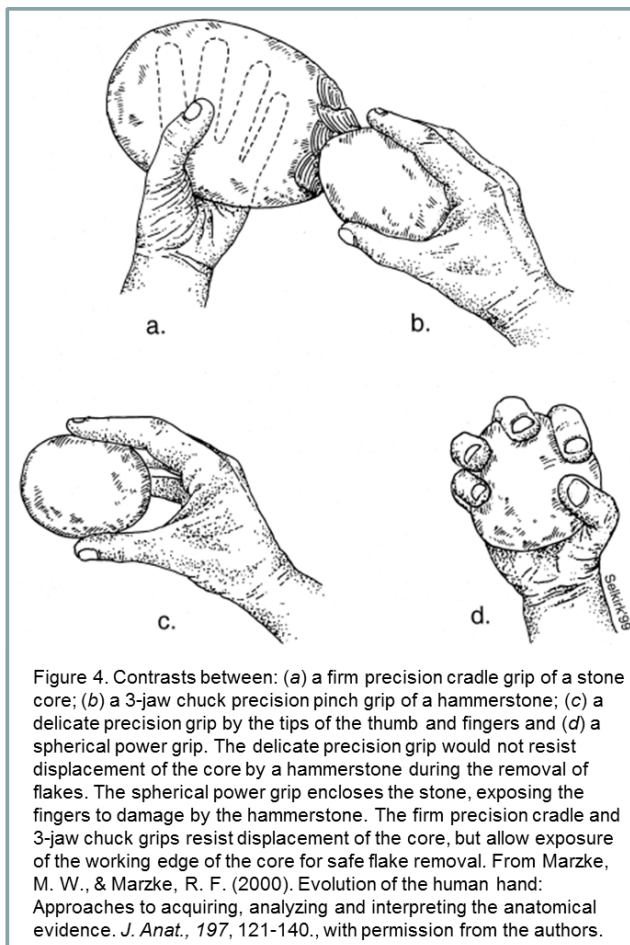
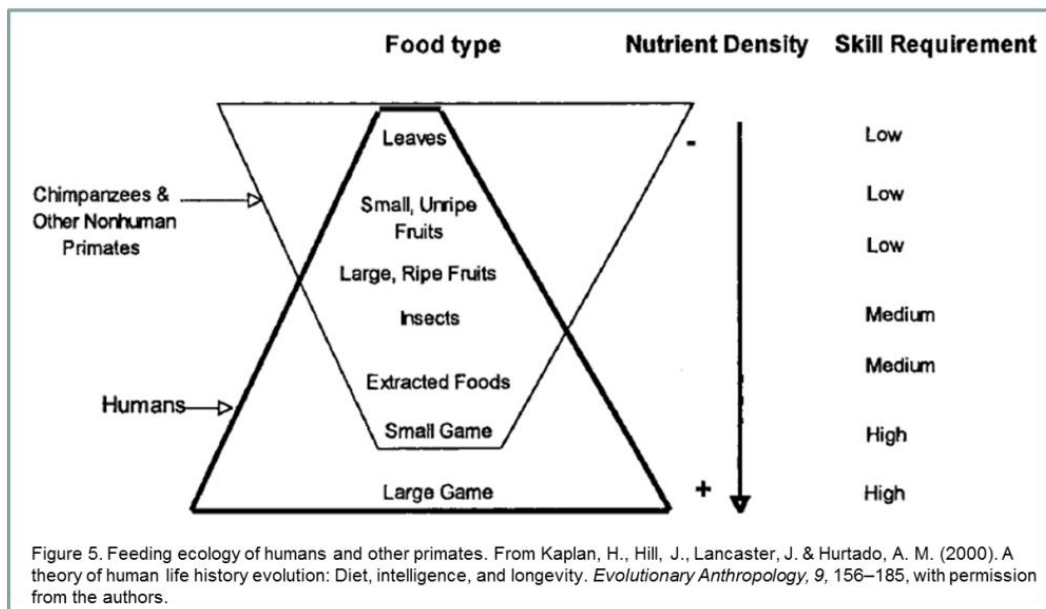
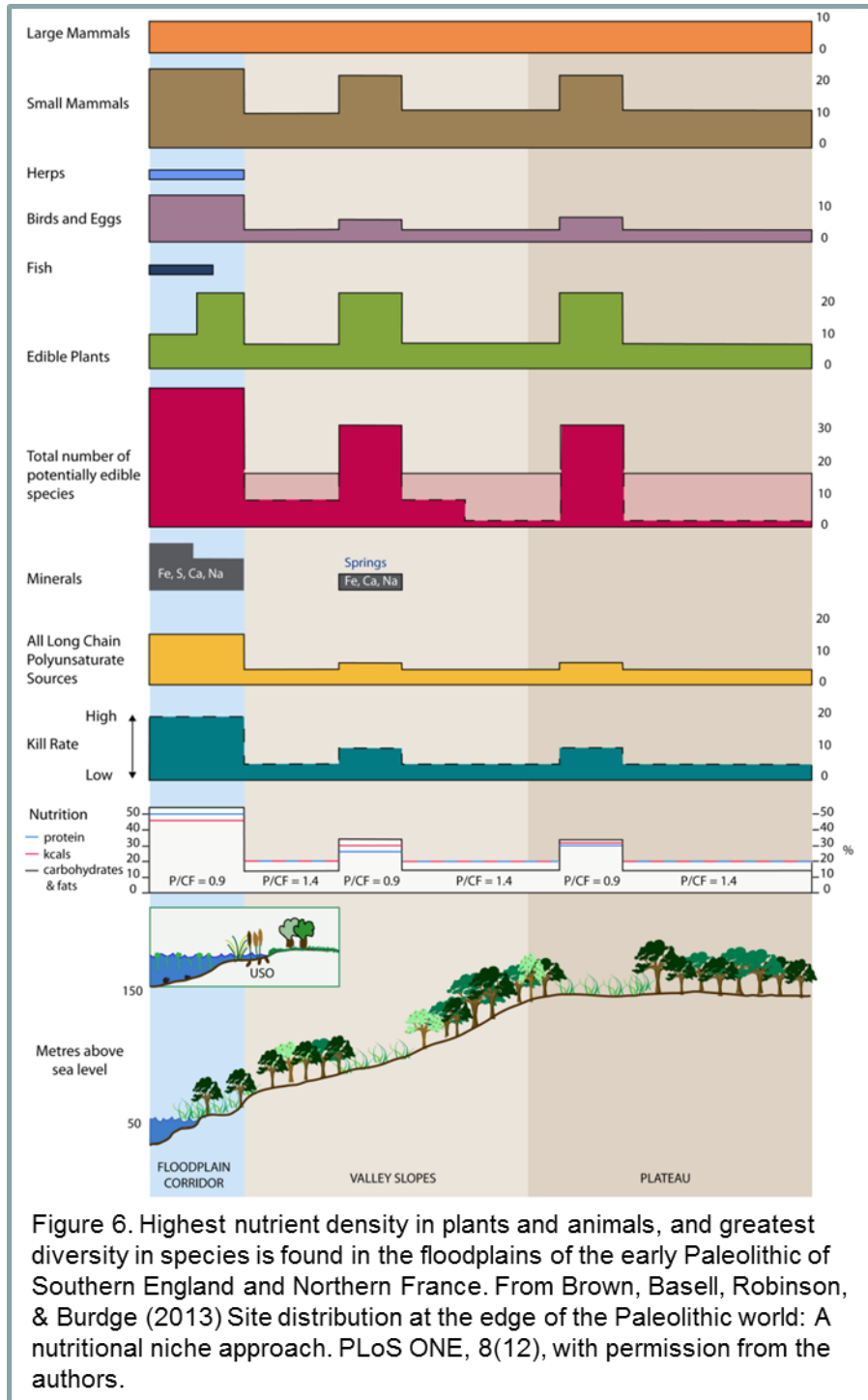


Figure 4. Contrasts between: (a) a firm precision cradle grip of a stone core; (b) a 3-jaw chuck precision pinch grip of a hammerstone; (c) a delicate precision grip by the tips of the thumb and fingers and (d) a spherical power grip. The delicate precision grip would not resist displacement of the core by a hammerstone during the removal of flakes. The spherical power grip encloses the stone, exposing the fingers to damage by the hammerstone. The firm precision cradle and 3-jaw chuck grips resist displacement of the core, but allow exposure of the working edge of the core for safe flake removal. From Marzke, M. W., & Marzke, R. F. (2000). Evolution of the human hand: Approaches to acquiring, analyzing and interpreting the anatomical evidence. *J. Anat.*, 197, 121-140., with permission from the authors.

highest trophic level of the food chain (Figure 5). Successful predation of these nutrient dense foods, such as small and large game, requires a high degree of skill and knowledge (Figure 5).



Thus, we became the top predator, using wits and culture (a large brain) and an extensive array of tools (dexterous hands with precision grip) requiring high-level cognition and use of fire for production (Brown et al., 2012), to track, hunt, and capture a diverse array of animals, ranging from small invertebrates to those mega fauna beyond the reach of even top carnivores (Adler, Bar-Oz, Belfer-Cohen, & Bar-Yosef, 2006; Braun et al., 2010; Brown et al., 2013; Guil-Guerrero et al., 2014; Klein et al., 2004; Mellars, 2006; Steele, 2003; Stiner & Munro, 2011), and forage for energy-rich plants, such as underground storage organs (USOs) and large, fat-rich nuts and seeds with hard shells that were unattainable to most other animals. We hunted and gathered everything from small invertebrates such as insects, mollusks, and crustaceans, to small and large game (Kaplan et al., 2000). The ability of *H. erectus* and *H. sapiens* to bring down dangerous animals such as elephants, mammoths, and mastodons with nothing more than cooperative and coordinated hunting behavior and sharp-tipped thrusting weapons such as spears is testament to our newfound prowess. The emergence of the control of fire that occurred during the evolution of *H. erectus* provided hominids with an additional means to increase the metabolic efficiency of human foraging to the point of supporting the huge number of neurons in the human brain, well beyond what can be supported by foraging for raw foods of lower nutrient density (Fonseca-Azevedo & Herculano-Houzel, 2012). This likely allowed for the next stage of brain expansion in the hominid lineage that occurred



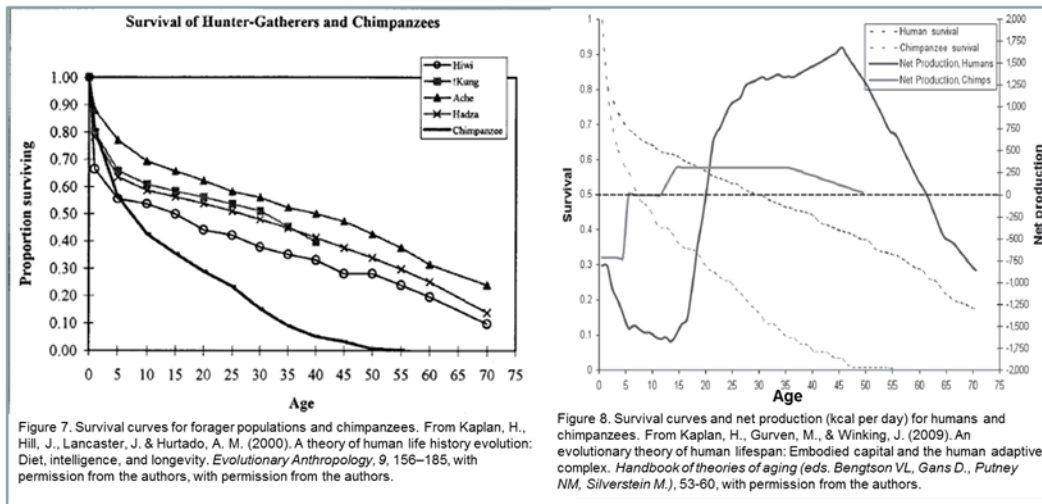
at that time, as well as the first diaspora from Africa to many parts of Europe and Asia. Even more remarkable is the ability of some groups of *H. sapiens* to use

these technologies and social traits, coupled with watercraft, to hunt and capture large sea mammals, such as whales.

These new foods, both animal and plant, provided both a quantity and quality of nutrients that were previously unavailable to our primate cousins. These nutrients include preformed fat-soluble vitamins (A, D3, K2, and E) and essential n3 fatty acids (Brown et al., 2013; Crawford et al., 1999; Cunnane, 2010; Guil-Guerrero et al., 2014; Verhaegen et al., 2007; Figure 6). Cunnane (2010) provides a compelling argument that the most recent diaspora of humans out of Africa and the colonization of the rest of the world, including Oceania and the Americas, coincided with the most recent brain expansion event and was coupled with the development of a new, sophisticated tool technology and much higher degree of cultural innovation than previously observed in the archeological record. This new technology involved a tool kit that was much more diverse, adaptable, and embodied a much greater degree of specialization than prior tool technologies (Mellars, 2006). Furthermore, many of these new tools appeared to be specially designed for extracting animal prey from shoreline environments and waterways (Mellars, 2006; Brown et al., 2012).

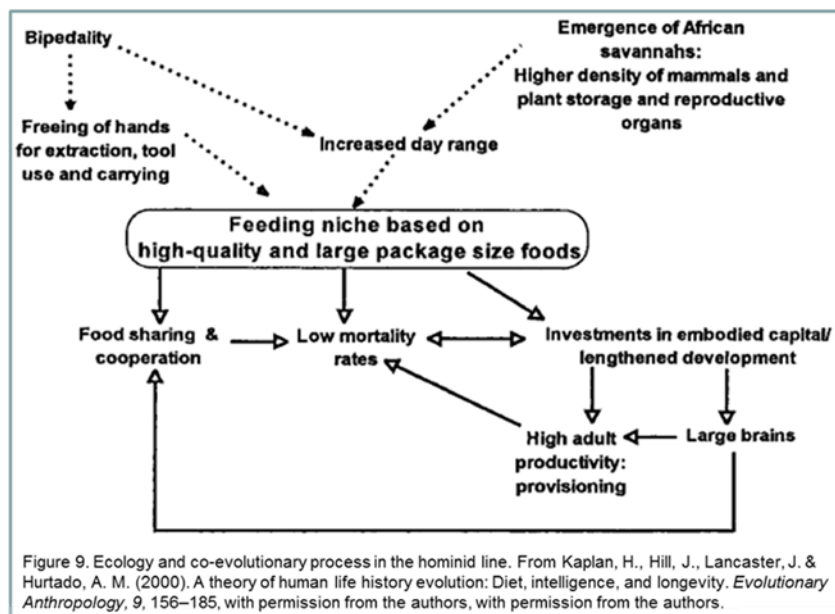
EVOLUTION OF EXTENDED HUMAN LIFESPAN

In addition to physical and cultural traits, human development and lifespan also dramatically changed from that of our most recent ape ancestors. To understand how intertwined these evolutionary changes were requires a brief discussion of how evolutionary changes often are the result of changes in developmental programs—a phenomenon called heterochrony. Compared to modern chimpanzees whose maximum life span typically reaches about 35 years old, humans can typically expect to live and be healthy well into their 70s, barring



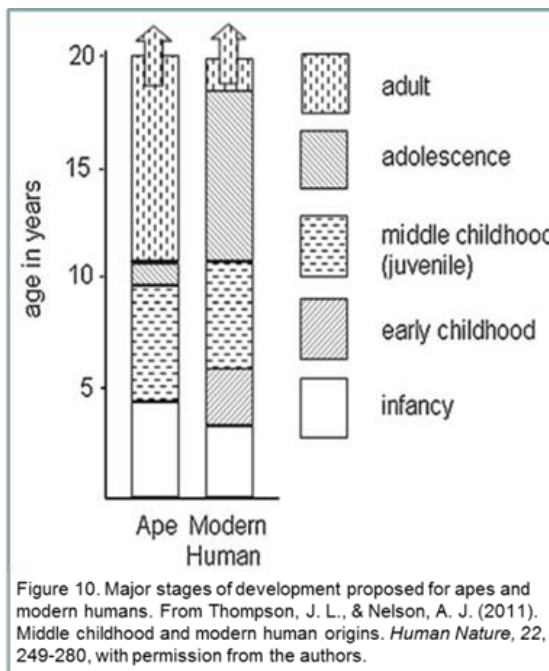
accident, trauma, or infectious disease (Caspari & Lee, 2004; Gurven & Kaplan, 2007; Kaplan et al., 2000; Figure 7). With this elongation of the human lifespan came an extended childhood—defined as the period between weaning, ranging from 3-5 years of age—and a delayed sexual maturity with the first reproductive event ranging from 14 years at the earliest to beyond 20 years of age (Reiches et al., 2009; Thompson & Nelson, 2011). Due to the lengthening of the lifespan, there is also greater inter-generational overlap, such that grandparents have become a useful resource in childrearing, providing alloparenting (Kim, Coxworth, & Hawkes, 2012). In fact, humans are different from other primates in the large degree of cooperation and distribution of activities across individuals, with both sex-specific and age-specific rolls to tackle a variety of tasks, from childcare, to foraging (hunting and gathering), and the accumulation and dissemination of shared knowledge and cultural practices (Sober & Wilson, 1998).

Let's focus on foraging to clarify just how different are humans and great apes. In ape societies, as in most primate societies, after weaning, the individual is responsible for procuring just about all of its own food. Even though chimpanzees are known to hunt and share the meat, such events are very sporadic and infrequent, and do not provide a reliable or dependable source of calories or micronutrients (but see Stanford, 1996). In human societies, however, children contribute very little to their own nourishment and that of other group members. Figure 8 presents data from Kaplan's anthropological research showing mean individual survival rate as a function of age (left y-axis), compared to net production of calories from food as a function of age (right y-axis), for both human foragers (hunter-gatherers) and chimpanzees. It is clear that after weaning (roughly age 4-6), a chimpanzee is responsible for acquiring all of its own nourishment. Human children do not become net food producers until the about 20 years of age. In fact, unlike chimpanzee children, human children are heavily subsidized with food until they are adolescents or adults, and become net food producers through hunting and gathering (Gurven & Hill, 2009; Kaplan et al., 2000). Human adults remain major contributors, subsidizing the young and very elderly and infirm, well until old age (Kaplan, Gurven, & Winking, 2009). The necessity of this division of labor by age and gender becomes clear when we examine the skill requirement for procuring such high-density, nutritious food (Kaplan et al., 2000). As Figure 5 shows, unlike the extant apes, for which leaves and fruit provide the bulk of their nutrition supplemented only occasionally and sporadically with extracted foods and game, the bulk of nutrition in the modern human diet comes from large and small game and fish, extracted foods such as insects and other invertebrates, and extracted plants such as USOs and fat-rich nuts (e.g., the mongongo nuts that form a staple of the San, and coconuts and palm nuts that form a staple for many southeast Asians and Pacific islanders). As



we already mentioned, these foods require greater skill to acquire and process than do leaves, fruits, and some insects. Kaplan et al. (2000) has proposed a model of human life history evolution that attempts to integrate these variables into a clear picture of the *H. sapiens* ecological niche (Figure 9; but see Blurton Jones & Marlowe, 2002).

Unlike other top carnivores, such as felines, canines, hyenas, etc., humans don't have the strength, speed, and morphology (e.g., teeth and claws) needed to hunt game unaided by technology and acquired skill. Instead, we rely on skill learning, technology, causal and semantic knowledge, cleverness (relational cognition), and cooperation to forage effectively and subsidize the entire group (Kaplan et al., 2000; Kaplan et al., 2009). How did we acquire this cognitive adaptive complex? And why do we subsidize our children for such an extended period? The picture becomes clear when you reframe childhood as an extended period of research and development (R&D). Child and developmental psychologists divide

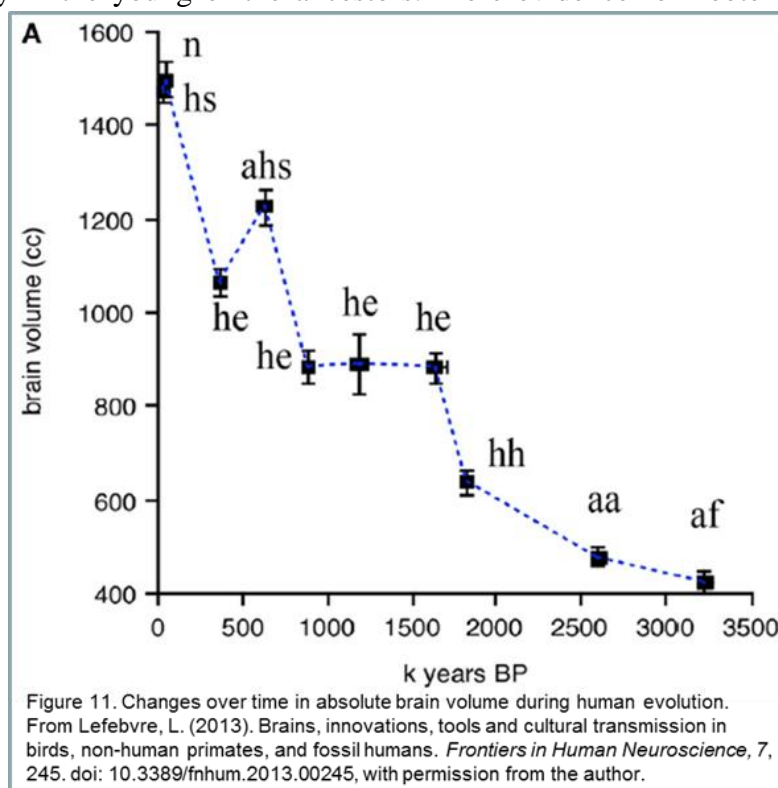


childhood into several categorical stages; infancy, early childhood, middle childhood, and adolescence² (Thompson & Nelson, 2011; Figure 10; see also Hawley, 2011 for a discussion of the biological evolution of human adolescence). From an evolutionary perspective, this extended childhood is an example of *neoteny* (the slowing down of the rate of early development; e.g., Bjorklund, 1997) and other forms of *paedomorphosis* (Shea, 1989). *Paedomorphosis* is an evolutionary-development term that describes the retention by adults of traits previously seen only in the young of the ancestors. More evidence for neoteny

comes from the retention of childhood traits of playfulness, curiosity, and laughter into adulthood and old age (Thompson & Nelson, 2011), and delayed and extended brain development (Petanjek et al., 2011; Somel et al., 2009; reviewed below). Neoteny does not, however, provide a complete picture of *heterochrony* (a developmental change in the

timing or rate of events) in human child development. There is also evidence for *hypermorphosis*—an extension of developmental processes resulting in the emergence of new traits not previously found in our closest ape relatives, and therefore by extension unlikely to have been present in our ape ancestors. Parts of the frontal cortex continue to develop until the early 20s (Liu et al., 2012; see below for more discussion on this). In addition, new cognitive traits, such as language, tool use, cooperation, imaginative play, and humor emerge. These traits are not present (or only in a very nascent form) in extant apes.

²A caveat; many ethnographers who study childhood among hunter-gatherer societies acknowledge that these categories are often not apparent in or not recognized by the members of those societies, Konner, 2010.



HUMAN BRAIN EVOLUTION

The key to why play is critical for human development comes from the study of human brain evolution. As already discussed above, the brain of modern humans, *H. sapiens*, is 3 times as large as that of our closest living ape relatives such as chimpanzees, bonobos, gorillas, and orangutans. Human brain evolution is not characterized by a gradual increase in size across evolutionary time, but through long periods of relative stasis punctuated by rapid increases in size (Lefebvre, 2013; Figure 11).

How does the human brain differ from that of the great apes?

First, it follows a different developmental course. The human brain goes through much greater postnatal expansion and development than does a chimp brain (Neubauer & Hublin, 2010). Furthermore, two gene duplication events occurred during hominid evolution, resulting in a substantial increase in the number of dendritic spines formed during *neurogenesis* (the formation of new brain cells). These spines form many more connections than are present in a chimpanzee brain during development (Dennis et al., 2012; Figure 12). The increased number and density of dendritic connections allows for a greater

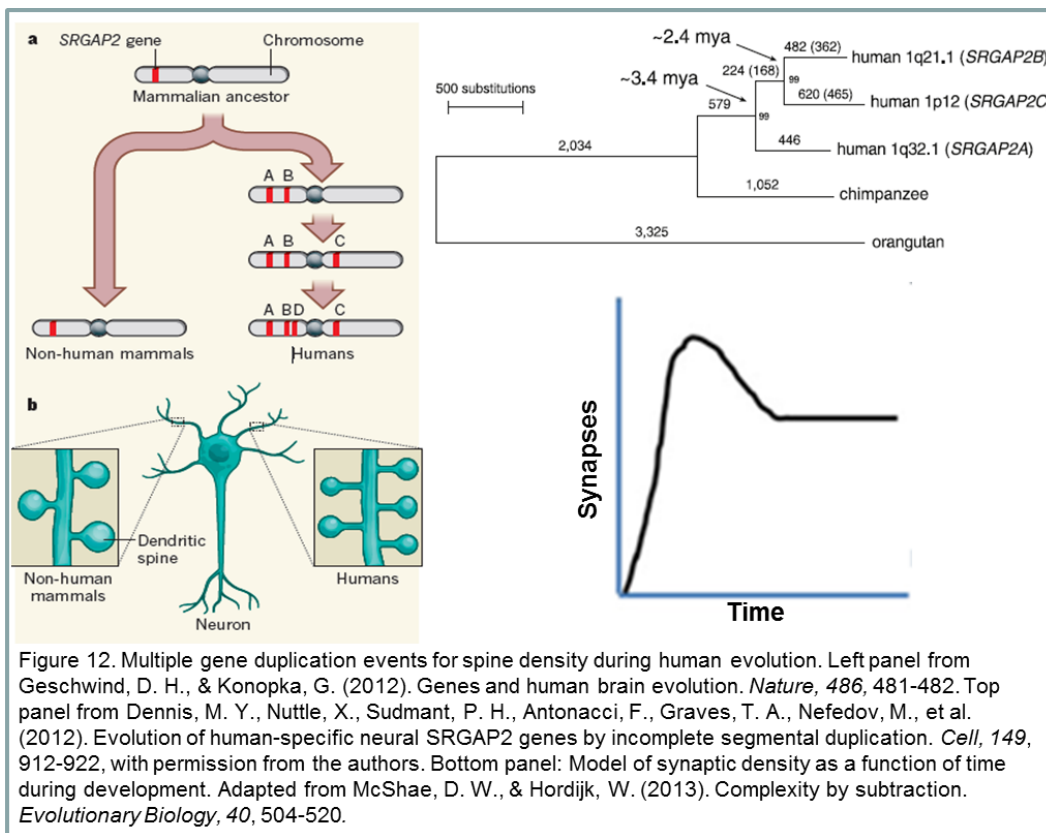
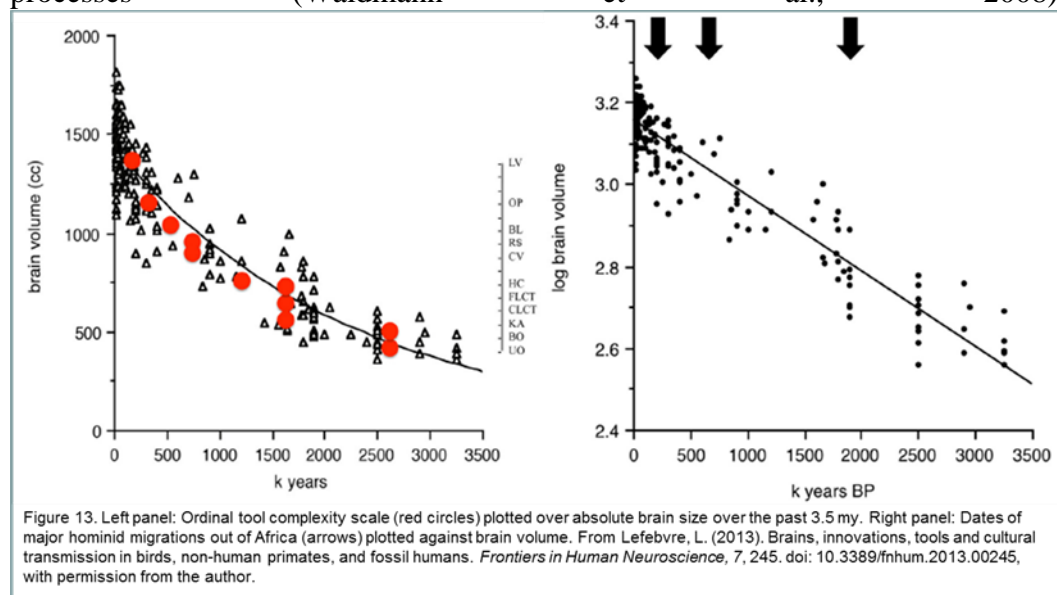


Figure 12. Multiple gene duplication events for spine density during human evolution. Left panel from Geschwind, D. H., & Konopka, G. (2012). Genes and human brain evolution. *Nature*, 486, 481-482. Top panel from Dennis, M. Y., Nuttle, X., Sudmant, P. H., Antonacci, F., Graves, T. A., Nefedov, M., et al. (2012). Evolution of human-specific neural SRGAP2 genes by incomplete segmental duplication. *Cell*, 149, 912-922, with permission from the authors. Bottom panel: Model of synaptic density as a function of time during development. Adapted from McShae, D. W., & Hordijk, W. (2013). Complexity by subtraction. *Evolutionary Biology*, 40, 504-520.

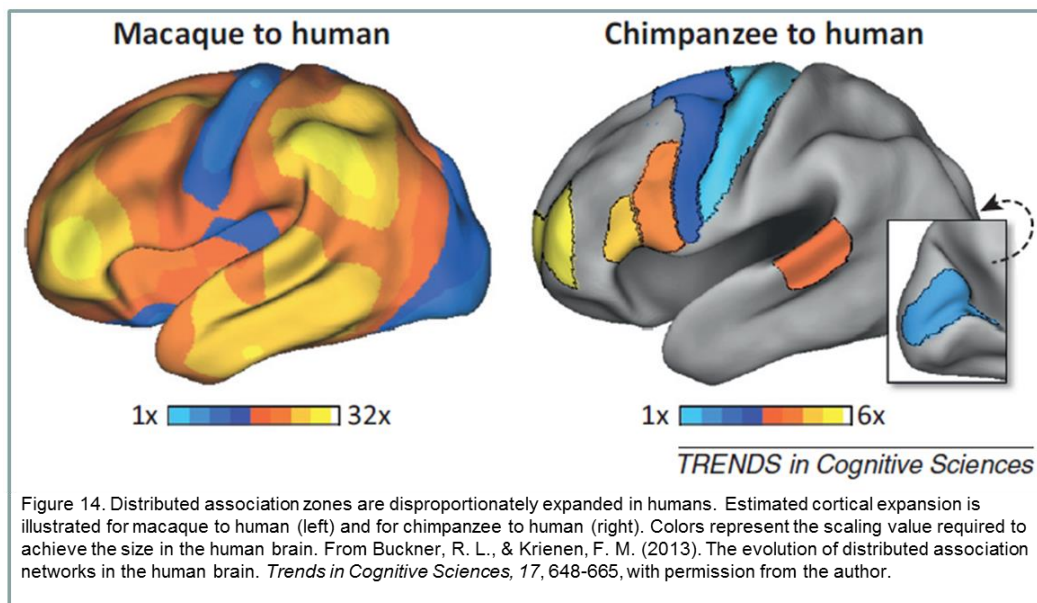
amount of *synaptic pruning* (removal of synaptic connections) to shape the final neural network established in adulthood (Figure 12, lower right panel). The synaptic pruning process is driven by experience (McShae & Hordijk, 2013), and can be likened to the way a sculpture emerges from a block of marble through the removal of overlaying material. By removing material, form and structure emerge. In an analogous fashion, the removal of unnecessary synaptic connections results in the emergence of representational content in the brain's neural networks. It is this combination of a highly-connected network, winnowed during an extended period of experience-driven synaptic pruning that has been argued to be at the core of human intelligence, and driving the acquisition of ever more abstract knowledge and representations of the world (Garlick, 2010). The more pruning that occurs during childhood, the more abstract are the representations of the world the individual is capable of understanding. In fact, some developmental psychopathologies (e.g., autism spectrum disorder) are characterized by an arrested development of the pruning process (Belmonte et al., 2004; McGrath et al., 2011).

What are the experiences that drive the synaptic pruning process that in turn shapes the development of human intelligence? Curiosity-driven and self-directed play and exploration, along with social games and communication, put the individual in contact with more information about the properties and regularities of the physical and social environments. From these experiences, the individual acquires a world knowledge that is both deep and broad, and forms the causal rules and patterns that reduce the complexity of the world into representations that are more coherent, efficient, and that define the world and its processes (Waldmann et al., 2008).

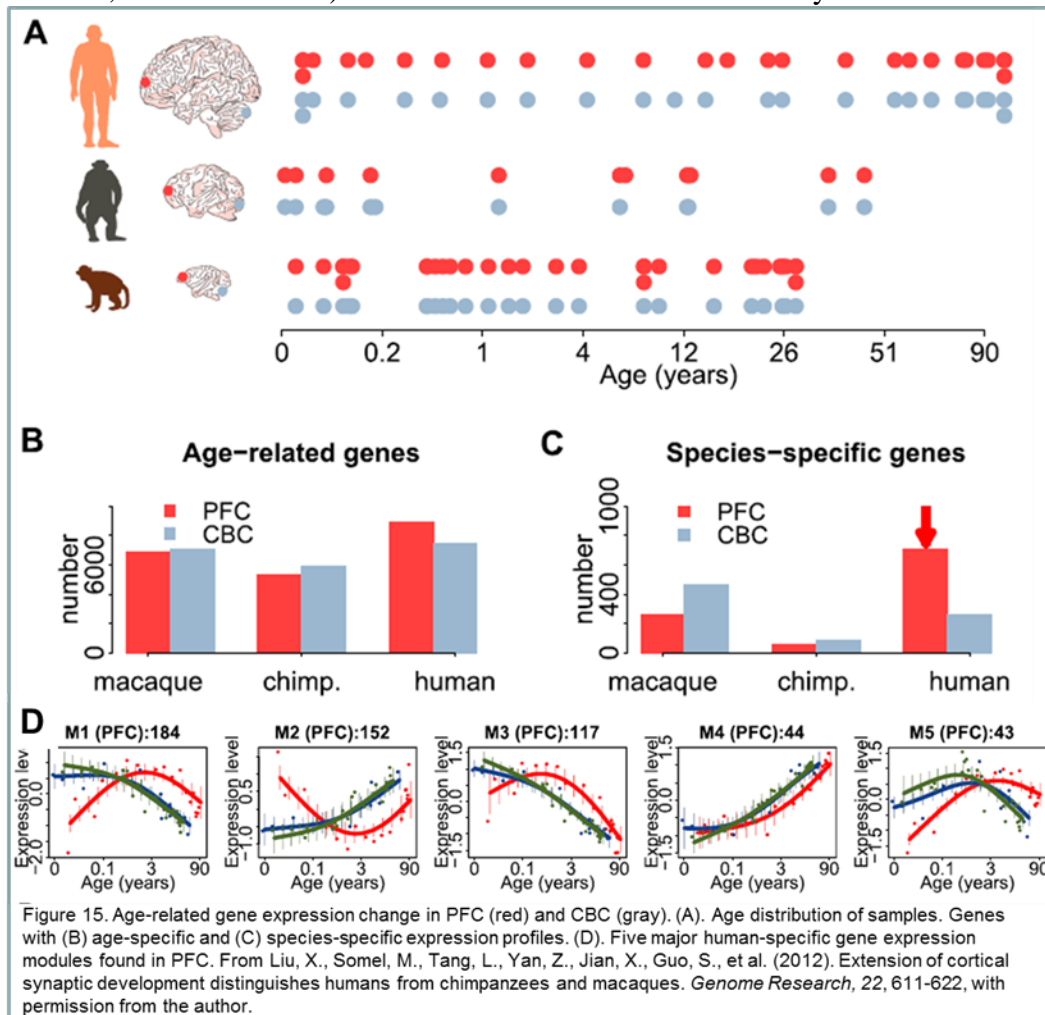


A strong piece of evidence suggesting that the genus *Homo* experienced a qualitative increase in intelligence is the strong positive relationship between the evolution of tool complexity and brain size (Figure 13, left panel; Lefebvre, 2013). The temporal pattern of evolution of tool complexity also corresponds with three separate waves of migration out of Africa, the first involving *H. erectus*, and the second and third involving *H. sapiens* (archaic *H. sapiens* and *H. sapiens neanderthalensis* first, followed later by a second wave of anatomically modern *H. sapiens*, Figure 13, right panel). These changes mark a deeper level of understanding, insight, and flexibility in adult behavior (see Liebenberg, 2013, for an in-depth discussion of the rich knowledge and sophisticated intelligence needed for hominid subsistence, especially tracking game).

A second way that human brains differ from those of the apes is in the neuroanatomy. Compared with chimps (and macaque monkeys) the human *cerebral cortex* (outer layer of the brain) is disproportionately expanded. The expansion resulted not in a change in primary sensory regions, which scale as expected with body size and are almost equivalent in size between human and chimpanzee, but in the addition of *association cortex* (cortical regions involved in higher-order processing and sensory integration) in both the anterior and posterior cortical regions (Figure 14). The addition of large regions of association cortex allowed the development of more distributed associative networks. These more extensive and distributed networks created new functional circuits that are integral to human cognition (Barrett, 2012).



Buckner and Krienen (2013) have argued that “*The rapid expansion of the cortical mantle may have untethered large portions of the cortex from strong constraints of molecular gradients and early activity cascades that lead to sensory hierarchies*” (p. 648, Buckner & Krienen, 2013). “*What fill the gaps between these hierarchies are distributed, interconnected association networks that widely span the cortex, develop late, and are preferentially more dependent on protracted activity-dependent influences*” (p. 650, Buckner & Krienen, 2013; emphasis added). The phrase “protracted activity-dependent influences” may best be translated as “a long developmental period of play.” It is important to emphasize that these brain specializations likely do not require large-scale additions or changes to genetics or wholesale *canalization* (the process by which adult traits are formed during development) of psychological and neural traits, but may result from processes that accompany rapid brain expansion (Barrett, 2012; Striedter, 2005).



more flexible brains, like the ones humans possess, by “*proliferating specialized brain regions that carve up computational problems via specialized division of labor*” (p. 10739, Barrett, 2012). Indeed, in contrast to other radiations of large-brained mammals, such as elephants and whales, that experienced a reduction in neuronal densities with increases in brain size, humans experienced a dramatic increase in neuronal density (Buckner & Krienen, 2013). That is, human brain evolution did not follow the typical allometric relationship between brain size and neuronal density.

Finally, gene expression during development of the human brain differs dramatically from gene expression during brain development in other primates (Geschwind & Konopka, 2012). For example, Liu et al. (2012) measured the expression of *synaptic* genes (genes that regulate development of synapses) in the prefrontal cortex (PFC) of humans, chimpanzees, and macaque (an old world monkey in the superfamily Catarrhini). These genes regulate the development of synaptic connections between neurons, which serve as a critical substrate for plasticity and learning from experience. They report a 12-fold increase in human-specific genes expressed in human *Prefrontal Cortex* (PFC, and cortical region involved in behavioral regulation and inhibition), but not *cerebellar cortex* (CBC, a region involved in motor learning and control), compared to chimpanzees (Figure 15). Moreover, gene expression in PFC onset at birth and showed its highest expression in most gene modules during the first year of life in chimpanzees and macaques. In humans, however, onset started at a low level in most gene modules following birth and increased throughout childhood to a peak expression at between 3-10 years of age (Figure 15, panel D). Moreover, unlike in chimpanzees and macaques for which PFC gene expression declined rapidly after the first postnatal year, expression remains high in humans throughout adulthood, only to decline modestly with the onset of old age (after 60 years age). This *hypermorphic* (extended development) neuro-developmental trait is another signature of the *heterochronic* (changes in timing of development in the descendent relative to the ancestor) changes unique to human development.

What is the functional significance of this change in gene expression in the PFC? Such developmental hypermorphosis suggests a novel phase of human ontogeny from 3-7 years of age related to the development of and plasticity in the PFC. This stage of child development coincides with the period of cognitive maturity, specifically in the development of self-regulation (e.g., inhibitory control of behavior and behavioral organization over longer time horizons—that is, planning), the emergence of abstract thinking, and social behavior including what developmental psychologists describe as the emergence of *theory of mind* (e.g., perspective taking and empathy) (Thompson & Nelson, 2011). Notably, individuals diagnosed with autism spectrum disorder experience a lack of synaptic

pruning, have larger brains as a result, and show deficits in PFC-related cognitive traits (Belmonte et al., 2004).

Following the increase in the expression of synaptic genes in humans, chimpanzees, and macaques, all three species experience a decline in mRNA abundance which is evidence of the synaptic pruning process. Nevertheless, despite the similar onset, the decline starts later and is slower in humans relative to the other two primate species on which there is comparable data (Liu et al., 2012). This suggests the operation of both *neoteny* (Somel, Liu, & Khaitovich, 2013) and *hypermorphosis* (cf. Bogin, 1997) in synaptic gene expression. Hyermorphosis is a process by which a developmental process in a descendant species (in this case humans) remains on beyond when it would normally terminate in the ancestral species (e.g., the last common ancestor of the Genus *Homo* and *Pan*). The early termination relative to in humans is the *pleisiomorphic* (ancestral) state of the trait found in extant apes and monkeys.

Cortical gray matter in the “social brain” decreases in volume by 15% during adolescence (between ages 10 and 20, Blakemore, 2012; Giedd et al., 1999), providing further evidence of the importance of synaptic pruning in cortical development related to human-specific cognitive specializations, such as social behaviors critical for the success of an altruistic species living in an egalitarian society (Sober & Wilson, 1998).

Geschwind and Konopka (2012) discuss recent discoveries that reveal more genetic evidence supporting the *heterochrony model* of human brain evolution. They report the discovery by Dennis et al. (2012) and Charrier et al. (2012) of three duplication events involving the SRGAP2 gene. These derived forms of the duplicated gene are uniquely found in humans among all mammals, and regulate an increased production of immature *dendritic spines* (neural connections between adjacent cells; Figure 12). By dramatically increasing the number of immature spines, many more connections are formed, allowing for a much greater degree of synaptic pruning. This provides a greater potential for building the sparse, distributed neural networks thought to underlie abstract representation and intelligence (Garlick, 2010). The evolution of developmental and neuronal-gene regulatory processes produced a modern human brain adapted to the unique ecological niche occupied by modern humans, hunter-gatherer and civilized alike (Neubauer & Hublin, 2010). We next turn to the implications this evolutionary transformation holds for childhood and human development.

THE ROLE OF PLAY IN CHILD DEVELOPMENT

What is play? All scholars of play agree that a universal definition of play is difficult to agree upon (Bateson, 2014; Bateson & Martin, 2013; Burghardt, 2005, 2014). Nevertheless, it is generally recognized that a comparative analysis of play

has produced a list of fundamental characteristics. Bateson (2014, page 100) defines the five defining features of play as follows (see also Burghardt, 2005):

1. *The behavior is spontaneous and rewarding to the individual; it is intrinsically motivated and its performance serves as a goal in itself. Play is “fun.”*
2. *The player is to some extent protected from the normal consequences of serious behavior. The behavior appears to have no immediate practical goal or benefit. Social forms of the behavior may be preceded or accompanied by specific signals or facial expressions indicating that the behavior is not serious. Play is the antithesis of “work” or “serious” behavior.*
3. *The behavior consists of actions or, in the case of humans, thoughts, expressed in novel combinations. Social forms of the behavior may be accompanied by temporary changes in social relationships, such as role reversals, in which a normally dominant individual may become temporarily subordinate while playing, and vice versa. Play is a generator of novelty.*
4. *Individual actions or thoughts are performed repeatedly (though they do not resemble stereotypes such as the circular pacing seen in animals kept in impoverished conditions); they may also be incomplete or exaggerated relative to non-playful behavior in adults. Play looks different.*
5. *The behavior is sensitive to prevailing conditions and occurs only when the player is free from illness or stress. Play is an indicator of well-being.*

These criteria feature play as an activity that is purposeless in that it tends to be detached from the outcome, is imperfect from the goal-directed form of the activity, and that tends to occur when the individual is in a non-stressed state. Despite this detachment from an immediate outcome related to the individual's basic needs (e.g., feeding, mating, protection and safety, seeking shelter, etc.), there has been much discussion and speculation as to play's function in the Animal Kingdom. **The likely function of play is to bring the individual into contact with experiences that shape its knowledge of the world and its properties.** This applies to both the physical and social worlds an individual inhabits. Playing with an object is very informative as to the object's functional properties and affordances. Playing with individuals allows for practice of social behaviors that are necessary for proper communication and socialization. Practicing actions improves on their execution and flexible use. Play has been shown to correlate positively with brain mass (Byers, 1999), suggesting that play

has an important function in brain development, with the implication that larger brains require more play for proper development.

I have spent a large part of my career as a comparative psychologist documenting and dissecting the cognitive processes of animals. In my research, I have discovered that nonhuman animals, such as rats, acquire highly detailed and flexible representations of the spatial, temporal, and causal organization of their environment (Blaisdell, 2009). Indeed, rats even appear to understand that the effects of their actions on the world are attributable to themselves, that is, that they have a sense of agency (Blaisdell et al., 2006; Leising et al., 2008). This sense of agency contributes to causal inferences similar to those that underlie the scientific method (Blaisdell, 2008; Blaisdell & Waldmann, 2012; Waldmann et al., 2008). It is still a mystery, however, as to where this sense of agency comes from either in the nervous system or developmentally. Also, the ability to form abstract representations of environmental relationships and to derive novel inferences from these abstractions is poorly understood mechanistically. It is likely that play forms a crucial internally-motivated behavior that shapes the nervous system to acquire abstractions that sub serve inferences.

I have also shown that the environment plays an important role in modulating behavioral variability, which may serve an important function in driving new learning about the environment (Stahlman et al., 2010a, 2010b; Stahlman & Blaisdell, 2011a; 2011b). Interestingly, the conditions under which variability in behavior is highest mirror those in which play behaviors are most likely to occur, when there is little expectation of an immediate outcome relevant to the individual's basic needs. The generation and control of behavioral variability may be an important substrate of play behavior seminal for new learning (Roberts, 2014) and creativity (Stahlman et al., 2013). Processes of creativity and innovation depend on a continuous source of behavioral variability (Bateson & Martin, 2013). Play provides one important source of variability upon which learning, development, and adaptation can act (Avital & Jablonka, 2000; Bateson & Martin, 2013).

Play in humans. Though the study of play is still in its infancy (Byers, 1998), current evidence suggests that play serves a seminal role in child development in contemporary hunter-gatherer societies (Gray, 2013; Kamei, 2005). Play fosters knowledge acquisition, guides the development of short-term and long-term planning abilities, establishes the skills necessary for hunter-gatherer subsistence (food provisioning, shelter, predator defense, tool manufacture and use, & etc.), fosters social development, guides acquisition and modification of cultural beliefs and practices, and hones the cognitive processes of inference and counterfactual reasoning (Barker et al., 2014; Buchsbaum et al., 2012; Kiser, 2015). Counterfactual reasoning consists of asking “what if” questions, making hunter gatherers the original scientists and philosophers. These

abilities form the core of a successful hunter gatherer, whose task is to thrive in the original human ecological niche and contribute as a productive member of society. As we discussed at the beginning of this paper, Blurton-Jones and Konner (1976) revealed that adult male San demonstrate the same analytic abilities and skepticism as contemporary scientists in their treatment of data versus conjecture, and in the derivation of inferences.

Science is an important epistemological tool in both contemporary foraging and hunter-gather societies on the one hand, and modern industrialized societies on the other. Nevertheless, science education differs dramatically between the two. Barnhardt and Kawagley (2005) eloquently contrast science education between Western and Indigenous cultures.

“Although Western science and education tend to emphasize compartmentalized knowledge that is often decontextualized and taught in the detached setting of a classroom or laboratory, Indigenous people have traditionally acquired their knowledge through direct experience in the natural world. For them, the particulars come to be understood in relation to the whole, and the “laws” are continually tested in the context of everyday survival. Western thought also tends to differ from Indigenous thought in its notion of competency. In Western terms, competency is often assessed based on predetermined ideas of what a person should know, which is then measured indirectly through various forms of “objective” tests. Such an approach does not address whether that person is actually capable of putting that knowledge into practice. In the traditional Native sense, competency has an unequivocal relationship to survival or extinction—if one fails as a caribou hunter, the entire family is in jeopardy. One either has or does not have requisite knowledge, and it is tested in a real-world context” (p. 11).

Beyond the anthropological evidence for the importance of play in child development, there is increasing recognition of its importance in early child development in contemporary, industrialized society coming from the fields of child and cognitive development. Xu and Kushnir (2013) report that studies in their lab reveal infants to be *rational constructivist* learners in which learning is seen as rational (logical), statistical, and inferential (see also Gopnik & Wellman, 2012). They marshal the rapidly growing empirical evidence for the existence of a set of domain-general statistical and inferential mechanisms that can explain why infants and young children learn quickly, efficiently, and effectively. Rational learning based on causal and inferential mechanisms has strong support in both

humans and nonhuman-animals (Cheng, 1997; Waldmann, Hagmayer, & Blaisdell, 2006; Waldmann, Cheng, Hagmayer, & Blaisdell, 2008). Thus, *rational constructivism* provides a framework for how such processes emerge during development. Infants are *rational* in the sense that they integrate prior beliefs, knowledge, and biases with new evidence provided by the environment. They use their updated beliefs and knowledge to follow the principles of logic to make predictions and guide actions. Infants can be viewed as *constructivist* from the evidence that they engage in hypothesis testing. They appear to entertain multiple possible hypotheses derived from prior knowledge and beliefs, plan interventions to test hypothetical causal models, and notice anomalous data, and finally engage in *inductive inference* whereby they induce new conceptual understanding and abstract, higher-order relations when their prior conceptual knowledge and level of representation is insufficient to account for the statistical data they gather through observation and experimentation (e.g., Sim & Xu, 2014). Toddlers also appear to infer more abstract, higher-order relational principles from minimal observational data during causal learning (Walker & Gopnik, 2014).

Children are born with the adaptation to act like scientists and philosophers. Buchsbaum et al. (2012) summarize this best by stating

“We hypothesize that...the change in the developmental program that led to the uniquely long period of human childhood...allowed immature proto-humans to enjoy longer protected periods of learning and, in particular, to engage more extensively in the free exploration found in play.

*We propose that this developmental change created the context for the application of more powerful learning mechanisms. In particular, these learning mechanisms included a newly sophisticated and general ability and motivation to **learn about causation** and to **construct causal models**. Those models, in turn, support **sophisticated inference and planning** by allowing organisms to **consider a wide range of alternative possible future outcomes**. The result was a set of new abilities including more sophisticated tool use for foraging and more sophisticated social intelligence for cooperative child-rearing. Those abilities, in turn, allowed for still greater caregiving investment and a still longer childhood and so on...”* (p. 2202. emphasis added)

“Play is a form of exploratory learning. The immature animal can explore and practice alternative actions in a low-risk setting, without the pressure of achieving a particular goal. Indeed, a

striking recent program of research shows that a distinctive kind of exploratory play that involves informal experimentation helps human children learn causal models, supporting the idea of an evolutionary connection between childhood play and causal learning... Human children...unlike any other immature anima..., engage in a particularly distinctive kind of pretend or symbolic play. Children go beyond simply practicing actions they will require later or manipulating objects to discover their causal features. Instead, they work out quite elaborate unreal scenarios, often with the aid of language, props and gestures.” (p. 2204. emphasis added)

To reconnect with the discussion on the evolution of an extended human childhood, Buchsbaum et al. (2012) suggest that “*Investment in an extended childhood, with its many opportunities for free exploration and causal learning, may have allowed human beings to turn from simply making the same ecological widgets to developing our staggeringly wide variety of strategies for adaptive success.*” (p. 2210). These same innate neurocognitive developmental mechanisms that allowed humans to thrive as hunter-gatherers and spread across the globe, are the ones that can allow our own children to develop into independent, intelligent, creative, and passionate adults. Such a child will have a greater chance of becoming an adult that can both thrive in and contribute to society, with a reduced risk of cognitive, social, or emotional maladjustment.

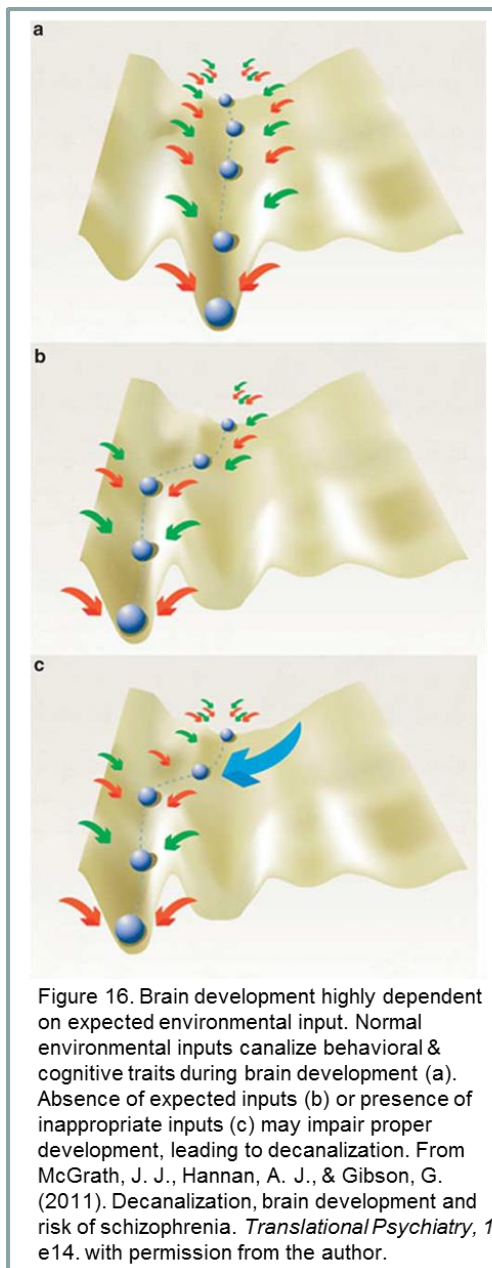
THE ROLE OF PLAY IN EDUCATION

To recap: Human evolution dramatically transformed a human econiche quite different from that of the great apes. This new econiche required new and greater cognitive abilities in reasoning and abstract thought (such as long-term planning, social development, general intelligence, abstract/relational learning, causal, and counterfactual reasoning), and a larger and more connected brain to support these new cognitive phenotypes. Along with human longevity, longer and additional stages of child development emerged to allow the necessary time for human neurocognitive development. Finally, anthropological ethnography and developmental psychology both suggest that *play* has been heavily adapted to serve a fundamental role in human neurocognitive development. Thus, the *ontogenetic niche* (the environmental context specific to a particular developmental period) of human development was shaped by evolution to achieve these goals in the ancestral type environment, such as that experienced by contemporary hunter-gatherer society. This suggests that play ought to serve a foundational role in child development in modern society as well. This

supposition begs the question of whether the ontogenetic niche of human development as it exists in modern, post-industrial societies adequately mimics the ancestral one. Evolutionary mismatch has become a useful framework from which to analyze health and disease in modern society (e.g., Cordain et al., 2005; Eaton & Conner, 1985; Lindeberg, 2010). This holds not just for our understanding of diet and exercise, but for all facets of modern human life.

For example, it is increasingly being recognized that a mismatch between ancestral and modern environments is a source of poor mental health and even psychopathology. Specifically, when expected inputs from the ancestral environment are absent (Figure 16, panel b), or when unexpected inputs are present (Figure 16, panel c), this can *decanalize* (impair proper phenotype formation) development, shifting the path of development away from the optimum of health (Figure 16, panel a), and towards more pathological states (Gibson, 2009; McGrath, Hannan, & Gibson, 2011, see also Dahl, 2004).

When thinking about the modern context of schooling, especially early childhood education (preschool and elementary school), we must consider whether the needs of the developing child are being adequately met for optimal and healthy mental and emotional development. While there aren't many data yet to strongly support a positive or negative conclusion regarding the role of modern schooling on early child development, there is a nascent yet growing literature suggesting that it is less than ideal.



Evolutionary psychologist Peter Gray has been among the most outspoken opponents to the modern methods of educating children. He has made the bold though still largely unsubstantiated claim that the modern educational system is likely driving many of the social ills like violence and bullying, cognitive disorders such as Attention Deficit/Hyperactivity Disorder (ADHD), poor self-esteem, lack of initiative and creativity, and even depression and anxiety at subclinical and clinical levels of expression (Gray, 2011). A recent survey found that high school students that reported doing more homework each night showed greater behavioral engagement in school, yet they also reported more academic stress, physical health problems, and lack of balance in their lives (Galloway, Conner, & Pope, 2013). This association supports Gray's thesis, but nevertheless is weak given that it is only an observational study. More empirical work needs to be done to determine the causality between time spent in academic instruction and practice on the one hand, and academic performance, intellectual and cognitive development, and psychological well-being on the other.

Moreover, he has discussed empirical evidence that, despite having initial academic advantages, directed academic training has no lasting effect on academic performance (Gray, 2015a). Moreover, children in more play-based preschools catch up and ultimately surpass by grade 4 the academic performance of children that attended more academically-focused preschools. Exposure to a direct-instruction preschool program was also associated with later outcomes of high violence than exposure to a play-based preschool program.

Why might early academic training paradoxically have so little benefit in future academic performance? Gray (2015b, <https://www.psychologytoday.com/blog/freedom-learn/201506/how-early-academic-training-retards-intellectual-development>) discusses the distinction raised by Katz (2015) between academic skills and intellectual skills.

“Academic skills are, in general, tried and true means of organizing, manipulating, or responding to specific categories of information to achieve certain ends. Pertaining to reading, for example, academic skills include the abilities to name the letters of the alphabet, to produce the sounds that each letter typically stands for, and to read words aloud, including new ones, based on the relationship of letters to sounds. Pertaining to mathematics, academic skills include the ability to recite the times tables and the abilities to add, subtract, multiply, or divide numbers using learned, step-by-step procedures, or algorithms. Academic skills can be and are taught directly in schools, through methods involving demonstration, recitation, memorization, and repeated

practice. Such skills lend themselves to objective tests, in which each question has one right answer.

***Intellectual skills**, in contrast, have to do with a person's ways of reasoning, hypothesizing, exploring, understanding (c.f. Garlick, 2010), and, in general, making sense of the world. Every child is, by nature, an intellectual being--a curious, sense-making person, who is continuously seeking to understand his or her physical and social environments. Each child is born with such skills and develops them further, in his or her own ways, through observing, exploring, playing, and questioning. Attempts to teach intellectual skills directly inevitably fail, because each child must develop them in his or her own way, through his or her own self-initiated activities. But adults can influence that development through the environments they provide. Children growing up in a literate and numerate environment, for example—such as an environment in which they are often read to and see others read, in which they play games that involve numbers, in which things are measured and measures have meaning—will acquire, in their own ways, understandings of the purposes of reading and the basic meaning and purposes of numbers.”*

Gray (2015b) argues that teaching academic skills to children before they have developed the requisite motivational and intellectual foundations can do more harm than good. He suggests this harm stems from both the lack of motivation to learn academic skills before the child understands them, and because academic skills are necessarily procedure-based, and that the procedures won't *consolidate* (form) into long-term memory if they have no meaning to the child. Instead, he argues that by allowing children to first engage in self-directed and self-motivated play and exploration, they will form the intellectual skills of knowledge, understanding, and analytic cognition. Once these skills have formed, it is only then that instruction in academic skills can be successful. While Gray's position is viewed by some as contentious and weakly supported empirically, it is consistent with the framework of the role of play in human evolution and brain development outlined in this paper. More empirical research and methodologies are certainly called for to test Gray's suppositions.

Beyond failing to acquire academic skills when they are introduced into curricula too early, certain types of educational practices, when introduced at an early age, might even impair the development of problem-solving, analytic abilities in children. For example, Kamii and Dominick (1997) studied children's acquisition of math concepts and algorithm teaching (see Benezet, 1935/1936 for

TABLE 1
Answers to $7 + 52 + 186$ Given by Three Classes of Second Graders

	Algorithms <i>n</i> = 17	Some Algorithms <i>n</i> = 19	No algorithms <i>n</i> = 20
	9308		
	1000		
	989		
	986		
	938	989	
	906	938	
	838	810	
	295	356	617
		
			255
245	(12%)	(26%)	246
			(45%)
			243
			236
			235
		
	200	213	138
	198	213	—
	30	199	—
	29	133	—
	29	125	—
	—	114	—
	—	—	—
		—	—
		—	—
		—	—

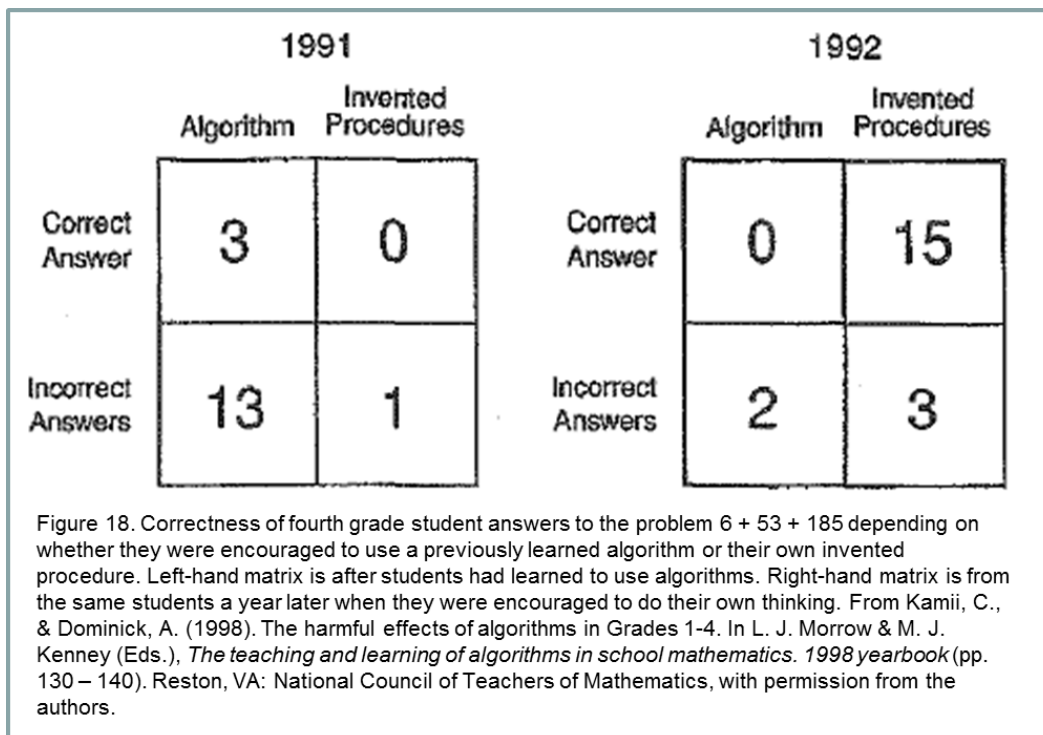
Dashes indicate that the child declined to try to work the problem.

Figure 17. Answers given by three classes of second graders to the problem $7 + 52 + 186$, for students that had three levels of training on arithmetic algorithms (No, Some, or Standard amount of training). From Kamii, C., & Dominick, A. (1997). To teach or not to teach algorithms. *Journal of mathematical behavior*, 16, 51-61, with permission from the authors.

a similar, early example). 2nd, 3rd, and 4th graders were tested for effects of teaching computational algorithms such as those of “carrying.” Importantly, children differed in the amount of prior training on the use of algorithms they had received. Some children had been encouraged to invent their own procedures and had not been taught any algorithms in grades 1 and 2, or in grades 1-3. Others had been taught the conventional algorithms prescribed by textbooks. In the study, the children were asked to solve multi-digit addition and multiplication problems and asked to explain how they got their answers. Students who had not been taught any algorithms produced significantly more correct answers than did those children who had formal training on algorithms (Figure 17). Moreover, when the children made errors, the incorrect answers of those children who had *not* been taught any algorithms were much more reasonable (i.e., closer to the correct answer) than the answers of the children who had received formal training on algorithms. Kamii and Dominick argue that their data show that training to use

algorithms “unteach” the concept and use of place value, and hinder children’s development of number sense. This echoes the nonhuman animal work discussed below showing impairments in the ontogeny of learning.

Figure 18 provides another example from Professor Kamii’s research. A fourth grade teacher was asked to present her class with the addition problem $6 + 53 + 185$ at two time points. In 1991, they had just learned to use algorithms to solve these types of arithmetic problems. Most of the students applied the algorithm but answered incorrectly. Only one student applied his/her own invented procedure (and also answered incorrectly). Almost a year later, the teacher asked the students to solve the same problem again, but this time they were encouraged to use their own invented method. Most of the students followed her instruction to use their own procedure, and most students answered correctly. What is interesting is that while some students who used their own procedure answered incorrectly, a great majority answered correctly. Only two students continued to apply the algorithm, and both provided an incorrect answer. This provides a nice example that formal instruction does not necessarily lead to improved performance or understanding, and in some cases may even hinder the proper development of thinking skills that underlie mathematical reasoning and number sense (Kamii, 2013). Kamii and Dominic (1997) eloquently express a fundamental problem with formalized instruction:



“It is clear that through history, and even today in different parts of the world, people have used different procedures, or algorithms, to solve problems. When we try to teach children to make relationships between numbers (logico-mathematical knowledge) by teaching them algorithms (social-conventional knowledge), we redirect their attention from trying to make sense of numbers to remembering procedures” (p. 59).

“Many educators recognize that children invent their own methods for solving problems, but their goal is still to teach the conventional algorithms in the end. We think, however, that the time has come to stop teaching the algorithms and, instead, encourage children to make the mental relationships necessary to build number sense. When children think in their own ways, they become more confident in their mathematical ability and go on to construct increasingly higher levels of thinking that are rooted in their own knowledge” (p. 60).

The seemingly radical position against formal instruction has been challenged by others (<http://www.wgquirk.com/kamii.html>; <http://wisemath.org/resources/articles/the-harmful-effects-of-kamii-and-dominicks-study-the-harmful-effects-of-algorithms-in-grades-1-4/>). Furthermore, there is empirical support for the positive role of directed instruction on problem solving, such as math equations (Star & Rittle-Johnson, 2008). Directed instruction can teach children efficient methods for solving problems. Clearly direct academic instruction is incredibly important for much of academic learning and intellectual development. What is uncertain, though, concerns the timing and amount of directed instruction. Is it possible to introduce directed instruction too early during development, and is there an optimal amount that must be balanced with all of the other factors that contribute to cognitive development, such as play, emotional and social learning, motivation, and even day dreaming?

There exists an older literature providing evidence that formal schooling is sometimes detrimental to cognitive development (Ashton, 1975). For example, Ashton discusses cases in which Piagetian perceptual invariance, such as *conservation of quantity* (recognizing that the volume of liquid remains the same when poured from a short, wide container into a tall, narrow one) or of other physical transformations, is delayed or even declines in children due to formal schooling. Some examples include a decline in conservation from 62% at age ten to 40% at ages twelve and thirteen in Chinese schools (Goodnow & Bethon, 1966); a drop in understanding of *weight conservation* (recognizing that the weight of an object remains the same despite transformation in its physical

appearance, such as shape or color) in older Zambian children following schooling as compared to younger children showing higher rates of conservation before formal schooling (Heron, 1971). A study of Hong Kong children found direct evidence that formal schooling resulted in a suppression of conservation (Goodnow, 1962). Such delays or declines are likely attributable to an overreliance on non-concrete forms of instruction, such as textbooks and lectures, and not enough time spent in concrete learning experiences, during which the learner actively engages with and manipulates the subject matter. From her review, Ashton (1975) infers that “*the opportunity for active manipulation is crucial for the development of concrete operations.*” (p. 494).

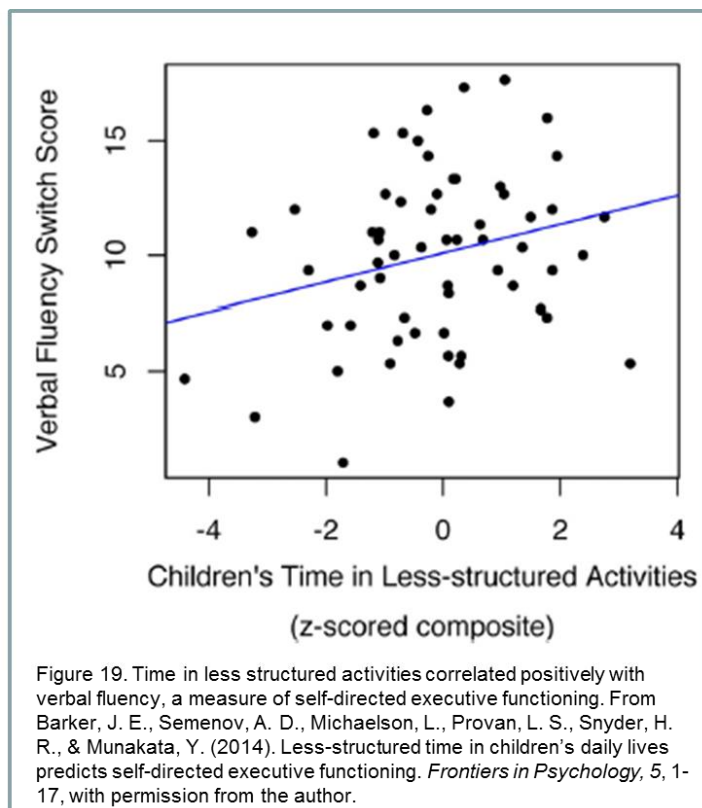
It is important to note, however, that in many cases schooling was not found to have a detrimental effect on cognitive development, and in some cases has been shown to foster the development of symbolic thought, relational cognition, formal thinking, and metacognition (e.g., Greenfield, 1966; Philip & Kelly, 1974; Prince, 1968). Indeed Ashton states “*emphasis upon concrete experience in the development of logical thinking does not imply that the importance of experiences in symbolic representation is being de-emphasized.*” (p. 494). Nevertheless, she goes on to assert “*However, the dependence of representational thought upon concrete activity must be recognized.*” (p. 494). That is, formal thought and symbolic representations only emerge from a foundation of concrete understanding acquired through actively manipulating objects, such as through play. Given the recent resurgence in the study of play in cognitive development in the fields of child development and child psychology, this older literature is in need of revisiting to bring it up to date.

What is interesting is that detrimental effects of experience provided too early may be a more general developmental phenomenon in the Animal Kingdom. For example, introducing certain types of learning, such as Pavlovian conditioning or instrumental discrimination learning, at an early age can impair later learning in rats. Spear and Hyatt (1993) discuss experiments from their lab in which rat pups exposed to audiovisual stimuli at an early age, as early as 12 days old, show impairments in Pavlovian conditioning to those stimuli when the rats are older. In another study, they showed that rats that received active-avoidance training at 15 days old took longer to relearn the task at 75 days old compared to rats that had only received the task for the first time at 75 days old. In similar research, Harlow (1959) trained rhesus monkeys on an object-discrimination procedure. Different monkeys began to learn the discrimination at different ages, ranging from 60 to 366 days old. Those monkeys that started learning the task at 60 or 90 days old were still performing at chance (i.e., showing no evidence of learning the discrimination) by the time they were 250 days old, despite the fact that monkeys that started learning the task at 150 days old were showing very strong discrimination learning by the time they were 250 days old. Thus, in both

rodents and primates it is found that early learning, that is, a learning task that is started before the individual is maturationally ready for such learning, can impair future learning involving the same learning process. While the animal research involves lower-level learning and perceptual processes, and not higher-level cognitive processes that we have been discussing in humans, the evolutionary-developmental principles are the same. A developmental process may be hindered when inputs are inappropriately timed (McGrath et al., 2011). A fascinating and important area of research would be to develop animal models, such as the rat, to study the effect of timing of experiential inputs on the developmental processes of higher-level cognition, such as causal reasoning and inference (https://www.cogneurosociety.org/rats_reasoning_cns2015_pr/).

WHY PLAY?

What is it about play, in contrast to directed academic instruction, that is beneficial for optimal cognitive and intellectual development? One factor is that the child chooses what, when, where, how, and with whom to play. Could it be that the self-directed nature of play is critical for its beneficial effects? A recent study found that 6-7 year-old children who spent more time in less-structured (and self-directed) activities were better at self-directed executive functioning; whereas more time spent in structured activities predicted poorer self-directed executive functioning (Barker et al., 2014; Figure 19; medium effect size of $\eta^2p = 0.07$; $F(1, 44) = 4.46$; $p < 0.05$). Executive functioning is a cognitive control process that regulates thought and action in support of goal-directed behavior. Executive functioning provides the basis for self-regulating processes such as



planning, decision-making, information seeking, and flexible shifting among tasks. While attempts to train executive-functioning in children have been successful, the success tends to be restricted to a formal school setting with less generalizability to other contexts. Time spent in less-structured activities, however, seems to establish an executive-functioning that



Figure 20. The author's children engaged in pretend play.

generalizes broadly across contexts, and that is more adaptable to novel situations. One need look no further than one's own children to observe how naturally they impose self-generated structure (i.e., temporary rules and scenarios) during free and imaginary play (Figure 20). This self-directed hypothesis states that self-initiated, self-directed cooperative play serves as the platform and mechanism by which the human brain develops many of their cognitive and reasoning skills (c.f., Buchsbaum et al., 2013).

Another important aspect of play is that it provides intrinsic rewards that are more powerful than extrinsic rewards provided in the context of instruction. While adults are able to learn efficiently and effectively through instruction from others, children appear to benefit much more from experiential feedback during learning in a probabilistic task (Decker et al., 2015). This developmental difference appears to be mediated by the recruitment of different neural systems in adults versus children and adolescents. Instructional control of learning recruits the prefrontal-striatal brain circuitry in adults. This circuitry is not fully developed in children, or even adolescents, thus their motivated actions are less influenced by explicit instruction. As a result, children benefit more from unbiased evaluation of their own actions through direct experience.

THE FUTURE OF CHILDHOOD

While there are many competing approaches to modern education, each with its staunch advocates, I am merely trying to show that there may be some cases where conventional educational approaches that neglect or minimize self-directed play might be counterproductive towards the goal of raising a happy, healthy, and intelligent child. There is not nearly enough long-term empirical research to adequately evaluate the different approaches to childhood education, but the

developmental and anthropological literatures certainly suggest that play is a human adaptation designed by natural selection to guide proper human cognitive, social, and emotional development.

Dr. Constance Kamii, who has studied the role of physical experience in early childhood cognitive and rational development summarizes this best in a recent chapter (Kamii, 2013):

“Physical-knowledge activities are a type of play, and I conclude by urging early childhood educators to think about play with more theoretical rigor and clarity. By documenting babies’ construction of logico-mathematical knowledge from the first day of life, Piaget (1937/1954) suggested the central role of logico-mathematical knowledge in the construction of all knowledge. He (Piaget, 1971/1974) also pointed out that children build logicomathematical knowledge in everyday situations by thinking. Children indeed like to think, and we will do well to study how they think while they play.” (p. 72).

This conclusion, if valid, leads to the recommendation that play not be ignored or minimized, but should instead be recognized as serving a foundational, critical, and central role in any program of child education. How this is to be achieved in modern society is still an open question that cannot be accommodated in the scope of this or any chapter. It will certainly pose great challenges, but in theory is achievable (e.g., Bernhard, 1988). This is a dialog that needs to take place at increasingly higher levels of decision-making regarding child education in modern society. The future of childhood is inevitably the future of the world.

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