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S. Dehaene · Y. Christen (Eds.)

Characterizing Consciousness: From Cognition to the Clinic?

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Characterizing Consciousness: From Cognition to the Clinic?

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Introduction: Recent Advances in Consciousness Research

Consciousness was long considered as the "holy grail" of cognitive psychology and neuroscience: a vague and uncertain goal, so remote as to seem almost entirely out of reach. Today, however, the perspective has changed. Characterizing the computational architecture and neurobiological mechanisms underlying consciousness remains a major unsolved problem in cognitive neuroscience, but it has become an area of intense research. Thanks to new advances in stimulation paradigms, brain imaging techniques, and neuronal theorizing, the issue now appears to be empirically addressable. Yet a major challenge still confronts these novel empirical and theoretical proposals: will they be able to help clinicians confronted with patients in coma or vegetative state? Can they help define novel diagnostic or even therapeutic tools?

In the present book, which is the outcome of a Fondation Ipsen meeting held in Paris on May 3rd 2010, 13 renowned neuroscientists and clinicians examine whether consciousness research is ripe for applications, from cognition to the clinic. The diversity of empirical research is impressive, and the theoretical convergence is quickly growing. At the cognitive level, paradigms such as backward masking, binocular rivalry or change blindness, together with quantitative probing of the subject's introspective state of mind, are helping understand the extent of subliminal processing and the point where conscious processing starts. Brain imaging techniques, combined with novel analysis tools such as the new method known as multi-voxel pattern analysis, provides a window into the underlying brain state. A coordinated state of synchronized activity, emerging relatively late after the stimulus was presented and involving cardinal nodes in 'associative' cortical areas including prefrontal and parietal cortices, is frequently associated with conscious-level perception. Similar long-distance networks emerge spontaneously in the awake resting state, although whether they are necessarily associated with conscious experience remains debated. Many of these results appear compatible with the theory of a global neuronal workspace, which proposes that a distributed set of neurons with long-distance axons are involved in the global information broadcasting underlying reportability and what is experienced as a conscious state.

Most novel perhaps is the possibility to study consciousness in non-human primates. The ability of global networks to enhance their communication through phase synchronization is increasingly understood at the electrophysiological level.

Furthermore, new paradigms now ask whether animals possess meta-cognitive abilities, such as a self-monitoring of their competence in a task, and electrophysiologists now examine the underlying neuronal networks.

Turning to clinical applications, brain imaging in the resting state or in carefully crafted stimulation paradigms holds the potential to address three questions of central importance: Is a given patient conscious? Will he ever recover consciousness? And what will be his cognitive state if he does? Brain stimulation paradigms, whether cortical or in deep-brain nuclei, can alter the state of consciousness and may improve communication in some ‘minimally conscious’ patients.

In summary, consciousness research appears to be on the verge of concrete clinical applications. We hope that the present book will serve as an up-to-date survey of this exciting field.

Gif sur Yvette, France — Stanislas Dehaene
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Missing Links in the Evolution of Language

H.S. Terrace

Abstract The evolution of language is an intractable problem if it is assumed (a la Chomsky) that language emerged full-blown at some point during the ~ 6,000,000 year period that elapsed between the divergence of the hominid line from chimpanzees, our closest living ancestor. It is intractable because it fails to recognize the role played by the evolution of conversation, and its antecedent, non-verbal conversation, a uniquely human phenomenon. For that we have to go back to the time when bipedalism replaced knuckle walking. Bipedalism resulted in a reduction in the size of the pelvis and the consequent reduction in the size of the birth canal, a birth canal that could not accommodate an infant with a brain larger than ~1,000 cc. As a result, human infants were born with a brain and skeletal system that were much less developed than those of non-human primates. To survive, the human infant required support from her mother for a period of time that was considerably longer than that needed by the offspring of other non-human primates. As a result, the human infant spent lots of face-to-face contact time with her mother, sharing eye gaze, another uniquely human activity. I hypothesize that those interactions allowed the infant to perceive and consciously compare the contents of her and her mother's mind. From there it is a relatively small step to joint attention, yet another uniquely human activity, which provided a basis for the assignment of names to events and objects.

It's not the same thing to talk of bulls, as it is to be in the bullring

Spanish proverb

All animals communicate, but only humans communicate with language. Animal communication is limited to a small number of inflexible, involuntary and predictable signals about basic needs and emotions, e.g., signals that communicate anger,

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a foraging site, the appearance of a predator, fear, a desire to mate, etc. (Searcy and Nowicki 2005). Those signals cannot be modified by substituting and existing one for another or by inventing a new one. By contrast, human languages enable its practitioners to communicate voluntarily about any imaginable topic, e.g., politics, the fourth dimension, plans for the weekend, childhood memories, a recent novel, beauty, truth, the latest gossip, etc. (Jackendoff 2002; Pinker 2007).

The origin of language, the most recently evolved and the most complex form of communication, remains a mystery. Here, I will argue that there are two major obstacles to a viable theory of the evolution of language. One assumes a discontinuity between language and other forms of communication; the other does not. Those who argue for a discontinuity have noted that the main function of language is thinking and that thinking is primarily a manifestation of our superior problem-solving intelligence. Adherents of this view also claim that language differs so radically from other forms of communication that its basic features could not have evolved by natural selection (Chomsky 1965).

Like Darwin, those who hold the continuous point of view argue that, when the gap between two species seems too large, one must find the numberless gradations that intervene. But since language leaves no fossils, many students of language concluded that the problem was insoluble because it would prove impossible to find those gradations (Gould and Lewontin 1979; Pinker 1994). Glaringly absent from either position is the importance of particular social skills and how they co-evolved with language. Most linguists agree that the main function of language is social. Until recently, however, the social functions of language have been largely ignored. As I will maintain throughout this chapter, social skills that evolved with language are a necessary condition for the evolution of language.

The social skills in question evolved as a consequence of decidedly unsocial events. They were an indirect product of the evolution of bipedalism, which occurred approximately 6 million years ago (mya). Bipedalism resulted in a smaller pelvis and a concomitant reduction in the size of the birth canal. Approximately 1.5 mya, the increased volume of the brain created a mismatch between brain size and the size of the birth canal. This impasse was resolved by limiting the growth of the human brain in the womb to insure that the head could pass through the birth canal. However, once the new infant emerged, she was more helpless than any other non-human primate at birth. To survive, human infants required approximately 10 months of daily care from their mothers, the longest such period of any non-human primate. I will argue that the intense social interaction that took place during that 10-month period was the foundation for the evolution of language.

1 Theories of the Evolution of Language

Before elaborating that view, it would be helpful to review earlier attempts to formulate theories of the evolution of language. In response to the publication of *The Origin of Species* (Darwin 1859), various members of the European intelligentsia

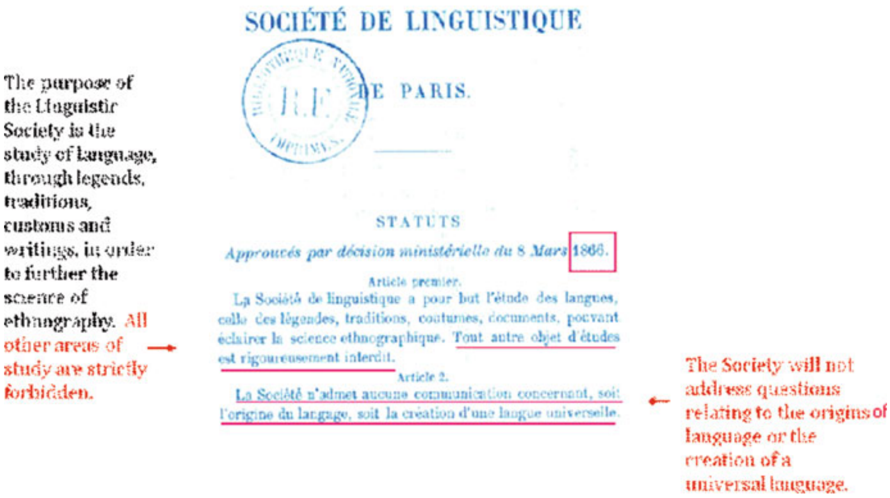

Fig. 1 Edict issued by the Linguistic Society of Paris banning further discussion of the evolution of language

proposed what have come to be known as onomatopoetic theories of the evolution of language. These theories, which were given appropriate names, like the bow-wow, the pooh-pooh, and the yo-he-ho (Kenneally 2007) theories, assumed that the first words a human uttered were imitations of natural sounds; for example, words like, *moo*, *bark*, *hiss*, *meow*, and *quack-quack* referred, respectively, to cows, dogs, snakes, cats and ducks. The obvious and fatal problem for all onomatopoetic theories was that, even if true, they could only account for a miniscule portion of the words of a basic vocabulary. They could not, for example, account for such common words as *same*, *beauty*, *truth*, *male*, *fish*, *tree*, *flower*, etc.

In response to the onslaught of these and other uncritical theories of the evolution of language, the Linguistic Society of Paris issued an edict in 1866 that banned all further discussions of that topic. An English translation of the Society's ban appears in Fig. 1. With minor exceptions, it was very effective. Indeed, more than a hundred years elapsed before psychologists, biologists, linguists, philosophers, neuroscientists and anthropologists showed an interest in that topic. What changed? As it turned out, quite a bit. The major developments were behaviorism, its demise, the cognitive revolution and ape language projects.

2 Behaviorism

In his *Principles of Psychology*, Herbert Spencer argued that, just as the theory of evolution was used to explain anatomical changes in different species over time, it applied with equal force to changes in animal behavior (Spencer 1886). That idea fostered an interest in comparative psychology, a new discipline that studied differences and similarities in the behavior of various species. After a brief flirtation with anthropomorphic and cognitive interpretations of behavior (Romanes 1884), most comparative psychologists adopted behaviorism as their guiding philosophy.

Behaviorists believed that a science of psychology should be based entirely on observable independent and dependent variables. Their goal was to mold psychology into a hard science like physics and chemistry (Hull 1943). What the behaviorists failed to notice, however, was the importance of unobservable events in the very sciences they tried to emulate. Imagine, for example, how physics would fare without the concepts of gravity or atomic particles.

During the first half of the twentieth century, behaviorists practiced what they preached by restricting themselves to theories of learning that relied entirely on two similar models of conditioning. The first was based on Pavlov's discovery that a dog would salivate in response to an arbitrary stimulus, such as a bell, that signaled the appearance of food [classical conditioning (S→S) (Pavlov 1927)]. The second was based on experiments in which Skinner trained rats to make an arbitrary response, such as pressing a bar, to obtain food [instrumental conditioning (R→S) (Skinner 1935)]. A common feature of virtually all conditioning theories of that era was the assumption that all learned behavior, in both animals and humans, including language, could be reduced to S→S or R→S associations.

Consider, for example, how a behaviorist would explain the way you find your hotel in a strange town. By trial and error, you learn which way to turn at seven choice points: left at the post office, right at the bank, right at the gas station, left after crossing a bridge, left at the playground, right at the library, and right after the high school. Your memory of which way to turn at each physically distinct choice point is all you need to return to your hotel. In that sense, learning a sequence of turns requires nothing more than the skills that a rat needs to navigate a seven-choice point maze.

As shown in Fig. 2a, responding correctly at the first choice point ensures that you will next encounter the second choice point, and only that choice point; responding correctly at the second choice point, ensures that you will next encounter the third choice point, and only that choice point, and so on, until you get to your hotel. What you learn can be characterized as a sequence of S–R associations, $\mathbf{S_1{:}R_1} \rightarrow \mathbf{S_2{:}R_2} \rightarrow \mathbf{S_3{:}R_3} \rightarrow \mathbf{S_4{:}R_4} \rightarrow \mathbf{S_5{:}R_5} \rightarrow \mathbf{S_6{:}R_6} \rightarrow \mathbf{S_7{:}R_7} \rightarrow \mathbf{S^R}$ (Skinner 1938), where $\mathbf{S_n}$ is a symbol for a particular choice point and $\mathbf{R_n}$ is a symbol for the correct response at that choice point. It is important to note that, with the exceptions of $\mathbf{S_1}$ and $\mathbf{S^R}$, each choice point functions as a reward for the prior response and as a discriminative stimulus for the next response.

Remarkably, Skinner's theory of grammatical sentences, which appeared in *Verbal Behavior* (1957), followed the same logic as that used by a rat to learn a maze. The first word of a sentence provided a cue for the second, which in turn provided a cue for the third, etc. Although, in hindsight, Skinner's theory of sentence construction seems simplistic, it should be viewed in the context of an extraordinary string of successful experiments that demonstrated the ease with which the principles of instrumental conditioning could be applied to just about

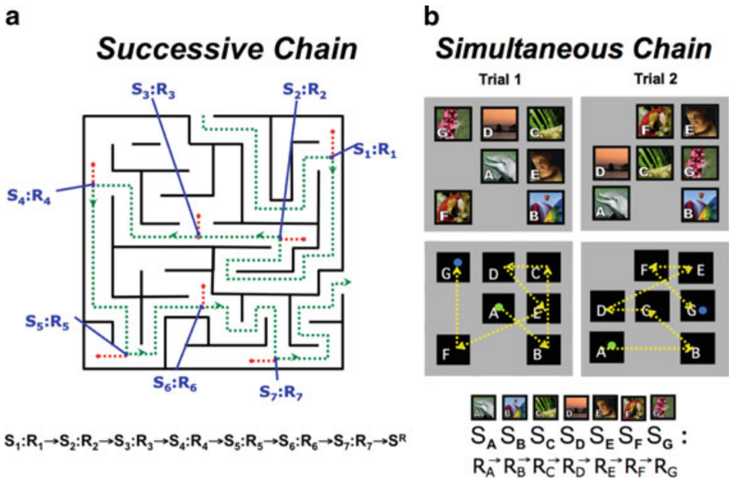

Fig. 2 (**a**) Basic plan of a traditional maze. Each choice point is separated, both spatially and temporally, from the others. A run through the maze is characterized as a *successive chain* that is composed of a series of S–R associations. (**b**) Simultaneous chaining paradigm. Each panel depicts a trial during training on a simultaneous chain. The configuration of the items, typically photographs, varies randomly from trial to trial. The photographs at the *bottom* of the figure show, for the benefit of the reader, the correct order in which a subject must respond to obtain a reward. The *bottom portion* of each panel depicts the route that a subject must follow (*yellow arrows*) with respect to the items shown in the *top panel* to receive a reward. Barring a 1 in 5,040 guess, a simultaneous chain must be learned by trial and error. A reward is presented only after the subject has responded to each item in the correct order. An error at any point of the sequence ends the trial. See text for additional details

any behavior in such disparate areas as behavior therapy (Masters and Rimm 1987), instruction by teaching machines (Skinner 1959), testing the effectiveness of particular drugs (Spiegel 2003) and teaching pigeons to guide missiles (Belzung and Le Pape 1994; Spiegel 2003), to name but a few. The success of this approach, in particular Skinner's imaginative applications of the principles of instrumental conditioning (Skinner 1953), fostered a climate in which it seemed possible to teach an animal to master any skill, including language. It was therefore not surprising that many of Skinner's students began programs whose goals were to obtain empirical evidence to support his theory of language.

3 Chomsky's Critique of Verbal Behavior and Behaviorism

Chomsky, arguably the most important linguist of the twentieth century, was not impressed by Skinner's achievements using instrumental conditioning. In a highly influential review of *Verbal Behavior* (Chomsky 1959), Chomsky exposed some fatal flaws in Skinner's model of sentence construction.[1] For example, a 5-year-old child has no problem understanding the sentence – *A father told his son that Ted Williams, who spent a lot of time fishing with custom made fishing rods and who was also a famous pilot during World War II, had the highest seasonal batting average of all* – despite a gap of 22 words that intervened between the noun, Williams, and its predicate, had. Chaining theory is unable to explain this example of an embedded sentence because it can only move from one item to the next and because it cannot explain knowledge of relationships between non-adjacent words. Chomsky also provided examples in which chaining theory could not even account for the meaning of adjacent words, for example, in ambiguous sentences and phrases such as *they are visiting firemen* or *the shooting of hunters*, or in a nonsensical sentence such as *green ideas sleep furiously*, which is grammatically correct, but nonsensical.

In his critique of *Verbal Behavior*, Chomsky explored other grammars, of greater complexity that could account for the meaning of sentences that were beyond the grasp of chaining theory and that could also account for the effortless manner in which speakers of all languages transform simple declarative sentences into other tenses; for example, changing *John throws the ball to Bill*, to its negative, interrogative, passive and passive negative forms, respectively: *John is not throwing the ball to Bill*, *Does John throw the ball to Bill? John had thrown the ball to Bill*, and *John hadn't thrown the ball to Bill*. We will not pursue more recent models of grammar that Chomsky and his students have proposed and, indeed are still proposing, because they are applicable to grammars that appeared long after language evolved. More relevant are Chomsky's arguments that grammar is the distinguishing feature of language and that an innate Language Acquisition Device (LAD) does the heavy lifting in the evolution of language.

The LAD is an example of what cognitive psychologists refer to as a module; a functional portion of the brain that is dedicated to the control of a particular cognitive ability, e.g., perception, language, memory, etc. (Fodor 1983; Cosmides and Tooby 1992). The LAD has many functions that helped to compensate for what Chomsky referred to as the impoverished stimulus. The problem is that the verbal stimuli that a child experiences seem too meager to explain a child's linguistic knowledge. Most words are learned after a single exposure to its referent. Indeed, a mere 2 years after a child utters her first word, her vocabulary increases dramatically to thousands of words, reaching a rate that has been estimated to be as high as one new word/hour. More impressive is a child's mastery of grammatical rules without any formal instruction. For Chomsky, these facts can only be explained by the LAD, an innate module of the brain that contains the abstract rules of a universal grammar.

[1] Lashley (1951) made a similar argument and also suggested a hierarchical, as opposed to a linear, structure of learned responses in which particular nodes controlled the spacing of particular subordinate responses. These and related ideas have been described in detail by others and will not be elaborated in this chapter (Anderson and Bower 1974). [Gardner]

Chomsky and other linguists have asked, quite reasonably, how could so major a mechanism as an LAD have evolved by natural selection during the approximately 6 million years that have elapsed since humans and chimpanzees split from a common ancestor? To be sure, the point of Chomsky's question is not whether language evolved but how natural selection could account for the sudden appearance (as measured in evolutionary time) of the most complex form of natural communication known to man (Chomsky 1986). Anything less than a single mutation wouldn't do because, just as a quarter or a half a wing would not be of any help to flying birds that evolved from flightless birds, a quarter or a half of a grammar would not be of any use to our ancestors when attempting to communicate with language. If there were such stages, Chomsky asks, what kind of grammars would they be?

Given the complexity of the LAD, Chomsky argued that it could not have evolved in what was the equivalent of an eye blink in evolutionary time. Instead, he argued that the LAD took over a part of the brain that was used by some other function, such as navigation, by a process known as exaptation (Hauser et al. 2002). In this view, the LAD did not owe its existence to natural selection because it was already in place when the need to generate and comprehend grammatical utterances arose. A number of biologists, citing Darwin's concept of pre-adaptation (Williams 1966; Gould 1977; Gould and Vrba 1982), have argued that many structures first appeared as exaptations. Wings, for example, are considered to be exaptations of structures whose original functions were predation and/or thermoregulation. It is important to recognize, however, that exapted structures are just as susceptible to natural selection as any other structures. Primitive wings, for example, which could propel birds in flight for only very short distances, could be modified by natural selection for long-distance flying. Similarly, natural selection could have modified an exapted LAD to accommodate various environmental pressures. But that explanation begs the question: what were those pressures?

4 Ape Language Projects

One of the surprising developments during the last half of the twentieth century was the appearance of a large number of projects that questioned the view that language, and grammar in particular, was uniquely human. Why the sudden appearance of these projects? One obvious reason was Chomsky's controversial conclusion that only humans can use language to communicate. That view provoked students of animal behavior to find evidence that he was wrong. Indeed, Skinner's influence on psychology was at a peak at the time and, as mentioned earlier, Skinner's achievements created an expectation that any type of behavior could be trained. Another factor was the observation that the human and chimpanzee vocal apparati differed significantly (Lieberman 1968, 1975) and that a chimpanzee's inability to articulate human phones might explained various failures to teach home-reared infant chimpanzees to speak either English or Russian (Hayes 1951; Kellogg and Kellogg 1933; Ladyna-Kots 1935).

In each case, the idea was to reverse those failures by shifting from a vocal to a visual medium of communication. The species that participated in these studies varied widely: parrots (Pepperberg 1991), dolphins (Herman et al. 1984), orangutans (Miles 1983), gorillas (Patterson 1978) and chimpanzees, both *Pan troglodytes* (Gardner and Gardner 1969; Premack 1971; Rumbaugh et al. 1973; Terrace et al. 1979) and *Pan paniscus* (Savage-Rumbaugh 1994). Most of these studies presented evidence that non-human animals can communicate by using language. If true, such claims would obviously complicate theories of the evolution of language. A review of these claims, with which I disagree, will clarify why language remains a thorn in the side of the theory of evolution. In the interest of brevity, I will focus on experiments that studied chimpanzees, the most popular subject of these projects. My conclusions, however, apply equally to other species.

The Gardners sought to reverse earlier failures by teaching a chimpanzee a spoken language by using American Sign Language (ASL), a natural language used by thousands of deaf Americans. ASL was the main medium of communication between Washoe (an infant female chimpanzee) and her caretakers and between the caretakers themselves while in Washoe's presence. Premack, who started an independent project at roughly the same time that the Gardners began theirs, taught the principal subject of his study (a juvenile female chimpanzee named Sarah) to use an artificial visual language consisting of plastic chips of different colors and shapes. Rather than waiting for language to emerge spontaneously, as one might with a child, Premack devised specific training procedures for teaching Sarah various atomic components of language.

Researchers studying ape language accepted as a given the prevailing working assumption of psycholinguistics that human language makes use of two levels of structure: the word and the sentence. In contrast to the fixed character of various forms of animal communication (e.g., bird songs that assert the presence of food or a readiness to mate and bee dances that specify the location of a food source with respect to the hive), the meaning of a word is arbitrary. One must keep in mind, however, that even though apes can learn substantial vocabularies of arbitrary symbols, there is no a priori reason to regard such accomplishments as evidence of human linguistic competence. Dogs, rats, horses, and other animals can also learn to produce arbitrary words to obtain specific rewards.

A second level of structure, one that assumes the word (Chomsky 1965), is generally regarded as the essential feature of human language. Sentences characteristically express propositions through words and phrases, each bearing particular grammatical relations to one another (actor, agent, object, and so on). Psychologists, psycholinguists, and linguists are in general agreement that a human language requires knowledge of a grammar. How else can we account for a child's ability to create an indefinitely large number of meaningful sentences from a finite number of words?

In an early diary report, the Gardners noted that Washoe used her signs in two or more… in 29 different two-sign combinations and four different combinations of three signs (Brown 1970). That report prompted Brown to comment, It was rather as if a seismometer left on the moon had started to tap out 'S-O-S' (p. 211). Indeed, Brown, who was the most eminent psycholinguist of his time, compared Washoe's sequences of signs to the early sentences of a child and noted similarities in the structural meanings of Washoe and children's utterances (agent-action, agent-object, action-object, and so on).

Other projects reported similar combinations of two or more symbols. Sarah produced strings of plastic chips such as *Mary give Sarah apple* (Premack 1976). Lana, a juvenile female chimpanzee, was trained to use an artificial visual language of lexigrams. Each lexigram, which is a combination of a specific geometric configuration and a specific colored background, was presented on the keys of a computer console or on a large visual display. After learning to use individual lexigrams, Lana learned to produce sequences of lexigrams such as *Please machine give M & M* (Rumbaugh et al. 1973). Because variations of these sequences occurred on the first occasion in which it was appropriate to use other signs or lexigrams, it was concluded that such sequences were actual sentences.

In an early diary report, Roger Fouts, one of Washoe's main trainers, described what is arguably the most famous sequence of signs generated by a chimpanzee (Fouts 1975). Washoe reportedly signed *water bird* after Fouts, asked her – *what's that?* – in the presence of a swan. What made this observation even more remarkable was the fact that Washoe did not have signs for specific water birds such as swans and ducks. It therefore seemed to Fouts that Washoe invented a way of conveying what she saw by a combination of signs.

Before we accept Fouts' rich interpretation of Washoe's sequence, it is necessary to rule out four simpler interpretations of *water bird*: (1) Washoe may have been prompted by Fouts to sign *water bird*; (2) Washoe may have signed *bird water*, but Fouts may have recorded Washoe's utterance in the order in which English-speaking people combine adjectives and nouns; (3) Washoe may have signed *water* and *bird* as two separate utterances; and (4) Fouts had previously trained Washoe to make the signs *water* and *bird* for food reward before the swan appeared. Washoe may have therefore signed *water bird* for a food reward without any specific understanding of what those signs referred to.

To eliminate such killjoy interpretations of this and other sentences that chimps were purported to have produced, I decided to start my own project centered around an infant chimpanzee I named Nim Chimpsky (Terrace 1979). Nim was a young male chimpanzee that, like Washoe, had been reared by human surrogate parents in an environment in which ASL was the major medium of communication. The goal of Project Nim was to obtain non-anecdotal evidence of the grammatical structure of sequences of signs produced by a chimpanzee. His trainers accomplished that goal by dictating the signs they observed, as well as their contexts, into miniature tape recorders and then transcribing the tapes after their session with Nim ended.

Over the course of 4 years, Nim's teachers recorded more than 20,000 combinations of two or more signs. Superficially, many of Nim's combinations appeared to be generated by simple finite-state grammatical rules (e.g., more + x; transitive verb + me or Nim). Indeed, many of Nim's multi-sign utterances

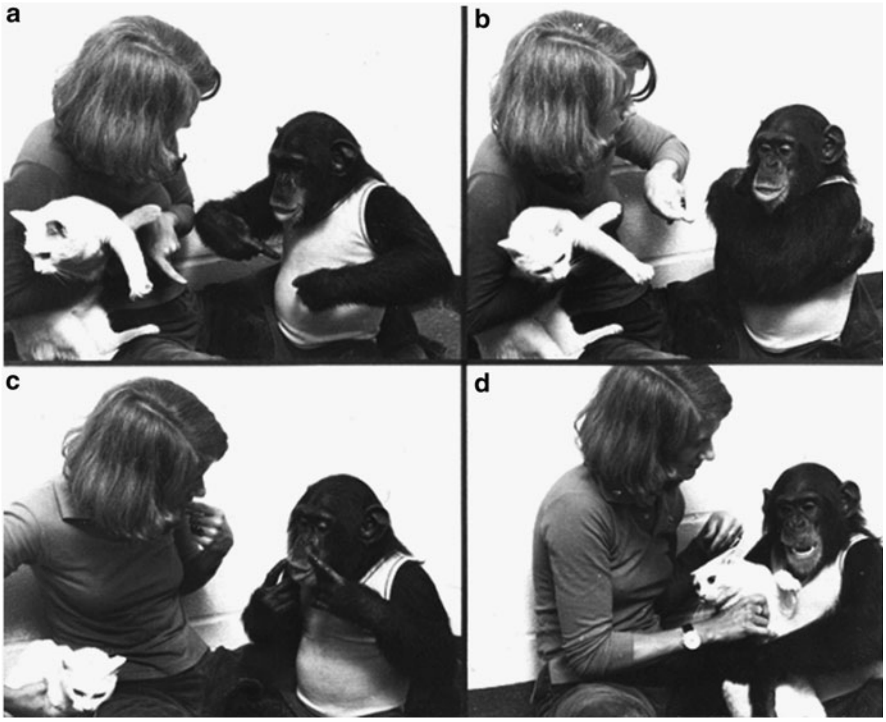

Fig. 3 Nim signing the linear combination *me hug cat* to his teacher (Susan Quinby). From Terrace et al. (1979b). Photo by H. S. Terrace

resembled a child's initial multiword utterances (Braine 1976; Bretherton and Bates 1979; Nelson 1981). All told, the corpus of Nim's utterances provided the strongest evidence to date of an ape's ability to create sentences.

As clear as that combinatorial evidence seemed, closer inspection showed otherwise. A frame-by-frame analysis of videotapes of Nim's signing revealed that his signs were nothing more than elaborate requests for rewards that he could not otherwise obtain and that there was no basis for interpreting the various sequences he produced as sentences (Terrace et al. 1979; Terrace 1979). The vast majority of Nim's signs, both in his single- and multi-sign utterances, occurred when his teachers withheld rewards until he signed. That insured that Nim would sign many multi-sign sequences. Nim's combinations were also full or partial imitations of signs that his teachers used as prompts. Virtually none of Nim's sequences were spontaneous. When, for example, Nim wanted to play with a cat his teacher was holding, he might sign *Nim cat, me cat, hug cat, Nim hug cat* before his teacher handed him the cat. Even then, videotape analyses showed that the teacher prompted Nim continuously as he was signing *who that?* or, *Nim want cat?* See, for example, Fig. 3, which shows what appears to be a three-item sequence, *me hug cat*. Each of those signs was triggered by a teacher's sign

Fig. 4 Nim being prompted to sign cat by his teacher (Susan Quinby). From Terrace et al. (1979b). Photo by H. S. Terrace

(lower left hand corner of the upper right and the two bottom panels). Figure 4 shows Nim's trainer drilling Nim on the sign *cat* before the cat was released from her box.

In hindsight, the meanings of Nim's signs were projections of his teachers, who directed all of their attention to his signing in the interest of obtaining objective records of each sign. So focused were they on Nim's signs that they were unaware of their nonspontaneous and imitative nature. It is, of course, true that young children imitate many of their parents' utterances. But, as shown in Fig. 5, the relative frequency of a child's imitated utterances is substantially lower than that of a chimpanzee. Further, although the imitative phase in children is transitory, Nim never moved beyond that phase (Terrace et al. 1979). As shown in Fig. 6, Nim's signing remained predominantly nonspontaneous and imitative, unlike the highly accelerated growth of a child's vocabulary at the end of Stage I of language acquisition (cf. Bloom et al. 1976; Brown 1973). Analyses of available films of other signing apes revealed similar patterns of nonspontaneous and imitative discourse [e.g., Washoe signing with the Gardners (Gardner and Gardner 1973) and her other teachers, and Koko signing with Patterson (Schroeder 1977)]. Miles (1983) performed a discourse analysis of videotapes of the orangutan Chantek's signing with his teachers and reported, there is no evidence ... that Chantek's multi-sign combinations ... are sentences (p. 53).