The biological roots of language

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1. Introduction

Humans communicate by means of innate signals (Hinde 1972) supplemented with culturally determined, and thus acquired, codes. The latter abide by the same rules as innate signals. The combination of the two systems creates a very wide range of means of expression (Nelissen 2000). Language is the most important evolutionary development in our species. It dominates our social lives. Consequently, the question arises: Where did language and speech originate? And, equally intriguing, why did these abilities develop exclusively in humans? We shall take an interdisciplinary approach to answering these questions whereby psychology, ethology, primatology, neuroanatomy and evolutionary biology will all play a part.

2. Why do humans have a large brain?

Comparison between different species within the groups of primates, bats or carnivores has shown there to be a correlation between the size of the neocortex and group size (Aiello and Dunbar 1993). Group size is often influenced by ecological variables. This was also the case among ancestral humans: larger groups meant better protection against attackers and predators. However, this increase in group size also created new problems with respect to the processing of information required for maintaining group cohesion. The resolution of these problems ultimately led to a larger neocortex.

3. Neocortex size and social skills

Species with a larger neocortex are able to maintain a greater number of complex and sophisticated social relationships. Within a group of highly developed organisms, group life implies the continuous observation and assessment of fellow group members in order to identify individuals as potential coalition or reproduction partners, as potentially dangerous, etc. Keeping accounts of such social interactions and social skills requires a large neocortex (Dunbar 1992).

THEORY OF MIND or ToM (Premack and Woodruff 1978) means understanding another individual's mental state. This ability begins with a second-order intentionality (i.e. understanding that the other understands). According to developmental psychologists, the ability to realize that another person's set of beliefs may differ from your own is essential to ToM.

In daily life, humans use a fourth-order intentionality, but this is hard to ascertain in other species. Apes certainly have second-order intentionality, perhaps even third-order. Other primates have second-order intentionality at the most (Byrne 1995). An indication of this is found in acts of TACTICAL DECEPTION (Whiten and Byrne 1988), i.e. deception by providing false information. Byrne (1995) discovered that there is a correlation between neocortex size and the frequency with which tactical deception is exhibited. A larger neocortex allows more tactical deception.

ToM has been demonstrated very clearly in chimpanzees. Tests for measuring ToM in children (who develop ToM at the age of 4, Astington 1995) and autists (who do not develop ToM, Leslie 1987) have shown that chimpanzees, which have second-order intentionality, score higher than autists and the same as four-year-olds (O'Connell 1996).

All the above research shows that keeping together and co-ordinating large groups presupposes the development of cognitive skills such as ToM; this evolution towards ToM in humans coincided with the development of enormous brain capacity.

For various species and primate groups, the correlation between neocortex size and group size can be calculated. By introducing the human neocortex size into this correlation equation, it is possible to determine human group sizes at the time our current brain was being shaped by the evolutionary process (Dunbar 1992). The calculation yields a group size of 148. A figure in the region of 150 corresponds to (1) the number of people that one knows well, (2) the number of persons from whom one can ask a favor and (3) the size of communities (tribes, villages...) in many societies (Dunbar 1993). Among other primates, the largest groups consist of only 50 to 55 individuals.

Primates maintain contacts with one another by means of tactile communication, in particular through social grooming. The larger the number of individuals involved in the grooming interactions, the stronger the bond between them. If humans were to use the same mechanism to maintain contacts with all group members, however, there would – certainly in the "environment of evolutionary adaptedness" in which our behavior was shaped (Barkow et al. 1993) – be insufficient time for other biological functions (e.g. foraging, parental care, defense...). Calculations have shown that if primates lived in groups consisting of 150 members, they would spend 40% of their time on social grooming. This would be untenable: the upper limit for time spent on grooming interactions is around 20% (Dunbar 1991).

In order to be able to maintain sufficient social contacts, man switched from tactile to acoustic communication (Dunbar 1997). This created a number of opportunities: (1) sounds can be aimed at many individuals simultaneously, while grooming is a dyadic activity, (2) acoustic signals are more varied than tactile signals and therefore carry more information; this allows a broader dissemination of information, and experiences can be passed on to others who can use this information to adjust their cognitive social maps, (3) acoustic information is a quicker, more effective means of presenting oneself to potential partners; it is no longer necessary to rely on acts to advertise one's traits.

Research has shown that different species of primates use acoustic signals with specific information: vervet monkeys produce different alarm calls for an approaching leopard, snake and martial eagle (Cheney and Seyfarth 1990). It is therefore very likely that ancestral humans also attributed information content to different sounds, creating the right conditions for the development of language.

4. Language as a means of bonding

If language originated as a means of bonding, one may expect (1) human conversational groups to be larger than non-human primate grooming groups, and (2) informal conversations to contain a lot of social information (about oneself or others). Research into these predictions supports the hypothesis that language originated primarily for social reasons. Analyzing the content of conversations in refectories, at receptions, etc., Dunbar et al. (1995 & 1997) found that:

(1) generally speaking, conversational groups are limited to four individuals, with one speaker and three listeners. While during grooming contact is maintained with only one partner, a typical conversation involves three persons. Likewise, the calculated human group size of around 150 is approximately three times larger than chimpanzee group size (53). If the purpose of language is to increase the number of participants in an interaction, then its degree of efficiency in realizing this goal is exactly what one would expect.

(2) the content of informal conversations is distributed as follows:

social topics	67.01%
recreational activities	12.46%
work	10.83%
culture	3.88%
technical topics	2.96%
politics	2.86%

Social topics (personal relationships, experiences, activities of the speaker, the listeners or an absent party) make up the majority of conversational substance. Non-social topics, relating to society at a more general level (culture and politics, including religion, morality, ethics...), account for only a small part of conversational time.

These findings are strongly supportive of the hypothesis that language developed in the course of evolution as a means of bonding between humans. Once this function was developed, other functions arose, so that language could also be used for different purposes, like (1) deception and (2) advertising one's qualities, for example when searching for a partner. It is conceivable that deception might be used on a large scale by freeriders, who exploit the cooperative nature of groups while failing to repay the debt (Enquist and Leimar 1993, Dunbar 1997). Gossiping behavior, i.e. exchange of information about individuals' social failings and practicing deceit, may have developed as a means to prevent this from happening. The freeriders only emerged after large groups had formed and stabilized, in contrast to the second language function that could arise, sexual advertising, which is independent of the existence of large groups. Both deception and sexual advertising clearly involve additional mechanisms that originated in language, but that are not its primary causality. The idea that sexual advertising may be one of the language functions, is in conformity with Miller's (2000) suggestion that the human brain including language evolved as a sexual signaling device. Darwin (1871) made the same argument when he suggested that human language and music evolved, like bird song, for courtship.

5. Endorphins as reinforcers

When monkeys and apes groom, rather large quantities of endogenous opiates are released into their bloodstream: the pinching and squeezing of the skin results in constant low-level pain, which induces the release of endorphins (Keverne et al. 1989). Consequently, being groomed is perceived as a pleasant experience, reinforcing further grooming activity. With the emergence of language, this direct reinforcer of social contact disappeared. So how was language as a means of bonding able to take over this proximal function?

Dunbar (1997) formulated a speculative, yet interesting and explanatory hypothesis. He postulates that language imitates grooming by also inducing opiate production. This would mean that language too is a reinforcer of social interaction. Language's imitation of grooming is made possible by the incorporation of smiles and laughter in conversations. There are indeed strong indications that these forms of behavior cause the release of endorphins into the bloodstream. This explains why people feel physical wellbeing, a 'high' even, after a bout of laughter. Conversations involving much laughter also make people feel good. Informal conversations are often aimed at inducing smiles and laughter. Dunbar therefore believes laughter to be a substitute for the physical contact achieved during grooming and to have the same proximal effect, as if it were 'grooming at a distance'.

We may conclude that language was originally a means of human bonding aimed at ensuring cohesion of larger groups than among non-human primates. Language enabled group members to exchange information much more effectively. Other functions evolved from there, as processes and mechanisms often assume new functions in the course of evolution. While this hypothesis still needs to be substantiated scientifically, it provides a good alternative to the older hypothesis that language needed to develop as a tool for co-ordinating hunting activities.

6. A neuroanatomical approach

The neuroanatomy of language reflects both its complexity and its recent evolution. This knowledge is primarily based on (1) the study of symptoms in patients with brain damage (tumor, stroke...) resulting in aphasia (= a speech impediment caused exclusively by brain deficiency), and (2) PET analyses (Positron Emission Tomography).

The ANTERIOR SPEECH AREA or BROCA'S AREA (Nelissen 1997) was first described by Paul Broca in the mid-19th century. This area is usually situated in the left frontal lobe (in 3% of the population this language area is located in the right hemisphere, Springer and Deutsch 1997). A few years later, Carl Wernicke described the POSTERIOR SPEECH AREA or WERNICKE'S AREA, also situated in the left hemisphere, but in the temporal lobe (Nelissen 1997). This area is located between the PRIMARY AUDITORY CORTEX (where auditory signals are analyzed) and the ANGULAR GYRUS. The latter – adjacent to the visual cortex – allows co-operation between the visual and the auditory brain cortex. Wernicke's area is connected to Broca's area by a bundle of nerve fibers, known as the ARCUATE FASCICULUS.

On the basis of research on aphasia patients a model that can explain the production of language in the brain has been developed. A conscious language output (the utterance of a word for example) originates in Wernicke's area. From there, signals are carried via the arcuate fasciculus to Broca's area. Here, a detailed and co-ordinated program for vocalization is compiled. This program is then sent to the nearest facial zone of the motor cortex, from where mouth, lip, tongue and larynx muscles are controlled.

This basic scheme becomes more interesting if one considers it in the broader context of cortical processing. Indeed, Wernicke's area does not proceed automatically with the formulation of a word, but will merely react to other processes. Moreover, Wernicke's area plays a significant role in the conscious understanding of spoken words, both by the speaker and the listener. The captured auditory information travels from the ear to the auditory cortex, where it is processed and conveyed to Wernicke's area. Here, the signal is consciously recognized as a word with a specific meaning that lies stored in the memory. This signal can follow the basic scheme described above. If a word has to be read, written or spelled, however, the auditory input will not suffice. Therefore, the signals are sent as an auditory pattern from Wernicke's area to the angular gyrus, where – in co-operation with the visual cortex – a visual pattern of the word is formed. The visual representation allows the word to be split up into separate letters. This information can then flow through Wernicke's area to Broca's area and the motor cortex. If a word has to be put down in writing, the information will travel from Broca's area to that part of the motor cortex which co-ordinates hand and finger movements.

An interesting phenomenon is the conversion of an auditory word pattern into a visual pattern and vice versa. This transformation is realized by the angular gyrus, which is in contact with the auditory as well as the visual system. Without this transformation, reading and writing would be impossible. Heard language is phylogenetically much older: man has been speaking for well over a hundred thousand years (see infra), but only started writing a few thousand years ago. One can imagine that the angular gyrus evolved in the course of human development as a substrate of symbolic thinking and that it was used by our brain to create a visual language.

The functioning of the different language areas is illustrated by the various forms of aphasia. A distinction is made between MOTOR or EXPRESSIVE APHASIA (when a word that is understood cannot be conveyed to the motor system) and SENSORY or RECEPTIVE APHASIA (when words cannot be understood) (Nelissen 1997).

Broca's aphasia is a motor deficiency resulting in impaired speech and difficulty in understanding the language of others. The production of words is hampered. This form of aphasia is caused by damage to Broca's area. Wernicke's aphasia, on the other hand, is a sensory deficiency. Phonetically and grammatically there are no problems: Wernicke's aphasics speak fluently. But their words are distorted, omitted or used incorrectly, rendering sentences incomprehensible. In case of CONDUCTIVE APHASIA, the arcuate fasciculus is interrupted. As both Broca's area and Wernicke's area remain intact, patients are able to speak fluently, and to recognize and understand every word, but the content of their speech has no meaning, for the correct information cannot be transferred to Broca's area. They are able to understand words or sentences that they hear or read, but they are unable to repeat them. In the case of ALEXIA (word blindness) or AGRAPHIA (the patient cannot write due to brain damage), the angular gyrus is damaged, causing a separation of the auditory and visual areas.

The fact that the various language functions are located in different cortex areas (motor system and grammar in Broca's area, semantics in Wernicke's area, 'visual' language via the gyrus angularis, etc.) can be explained by the separate development of these functions. An interesting perspective on this issue is offered by S. H. Ambrose.

7. The link between the evolution of language and the manufacturing of tools

Ambrose (2000) argues that the development of grammatical structure and the evolution in the fabrication of complex tools – tools consisting of different components – coincide. By combining components in different ways, one can create tools with different functions (the combination of a long handle with a sharp stone is a spear, a short handle with a long sharp stone is a knife, etc). This is analogous to language, where the same words can be arranged in different ways to create different meanings. A similar hierarchical sequence can be discerned in the composition of tools (the production of a handle, a sharp stone, a connection… and the combination of these items) and in the composition of a language expression.

According to Ambrose (2000, 2001), the intricacy of tool fabrication requires the same complex neural structure as language. He believes this evolution started 300,000 years ago. The frontal brain lobe, in which Broca's area is situated, supplies the neural substrate for these functions.

We should keep in mind that during evolution biological and psychological mechanisms are constantly taken over for new purposes. This applies as much to the vocal behavior of our primate ancestors that was transformed into human speech as to language itself, which turned from a bonding device to an information transferring system. Much work needs to be done to validate this hypothesis, but it offers opportunities to test a lot of predictions in the field of evolutionary psychology.

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