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NEUROANTHROPOLOGICAL UNDERSTANDING OF COMPLEX COGNITION – NUMEROSITY AND ARITHMETICS

Zarja Muršič*

Faculty of Education – University of Ljubljana
Ljubljana, Slovenia

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ABSTRACT

Humankind has a long evolutionary history. When we are trying to understand human complex cognition, it is as well important to look back to entire evolution. I will present the thesis that our biological predispositions and culture, together with natural and social environment, are tightly connected. During ontogenetically development we are shaped by various factors, and they enabled humans to develop some aspects of complex cognition, such as mathematics.

In the beginning of the article I present the importance of natural and cultural evolution in other animals. In the following part, I briefly examine the field of mathematics – numerosity and arithmetic. Presentation of comparative animal studies, mainly made on primates, provides some interesting examples in animals' abilities to separate between different quantities. From abilities for numerosity in animals I continue to neuroscientific studies of humans and our ability to solve simple arithmetic tasks. I also mention cross-cultural studies of arithmetic skills. In the final part of the text I present the field neuroanthropology as a possible new pillar of cognitive science. Finally, it is important to connect human evolution and development with animal cognition studies, but as well with cross-cultural studies in shaping of human ability for numerosity and arithmetic.

KEY WORDS

evolution, cognition, mathematics, numerosity, arithmetic

CLASSIFICATION

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*Corresponding author, η: zarja.mursic@gmail.com; +386 40 454631;
Faculty of Education, Kardeljeva ploščad 16, 1000 Ljubljana, Slovenia

INTRODUCTION

Throughout the history of anthropology, the question of humanity and what shapes human beings remains its essential challenge. Some researchers argued that human biology can be analytically separated from culture and that it is meaningful to study only human biological evolution [1]. Nevertheless, scholars [1-5] stress the importance of culture and human history for emergence and development of humanity as a species.

If we separate human biology from environment and culture, it can lead us to deterministic view of human beings. This deterministic assumption implies that we could explain everything with understanding the very beginnings of the species *Homo sapiens*, as well as its other preceding species.

However, is it really possible to understand animals with explanation of their basic behavioural operations? Studies done in natural environment prove the complexity of animal behaviour. The complexity observed in animals is not necessarily internal to the biological frame of the animals' organisms. Behaviour often emerges from the interaction between the animal and the surrounding complex environment [6].

Population-specificity can be observed in humans as well as in populations of, e.g., chimpanzees (*Pan troglodytes*). Let us take for example the use of tools in different populations of chimpanzees. Boesch and Tomassello [7] wrote about their specific behaviours, like ant dipping and leaf clipping, which differ in form and function among many different populations of chimpanzees. Sapolsky and Share [8] reported the emergence of a unique culture in a troop of olive baboons (*Papio anubis*), related to the overall structure and social atmosphere of the troop. This example shows, how can change within the group interaction pattern initiate biological change in its members [9]. Social interactions among animals can thus have profound effects on biology. The latter example shows us the importance of studies in animal cognition and their observations in natural environment, where we can observe how living creatures adapt their behaviour. It is clear that at least social animals do not act just as it is determined by innate fixed rules.

COMPLEXITIES IN BEHAVIOUR – BRAIN EVOLUTION

Examples from animal cognition show clear complexities in behaviour [10]. Behaviour shows higher levels of action in the environment. Growing number of evidence support the thesis that human actions are wired in our brains [3; p.23]. One of the reasons that this is possible is the prematurity of human children. Somewhere in human evolution, there has been a significant extension of the period of dependency, affected by slowing down the rate of maturity. Long period of dependency on parents in humans enabled young to learn to communicate, to adapt to their surroundings, and to participate successfully in a social group [5; p.171]. Therefore, the important questions arise – what are innate properties of brain enabling these processes, and how can we relate brain wiring during the lifespan of a subject to her/his environment and culture.

The humans are well known for the development of a specific social-cognitive niche [1]. According to Whiten and Erdal [11] the main components of the latter are cooperation, egalitarianism, mindreading (theory of mind), language and cultural transmission. The important parts of humankind are also collaboration, teaching and imitation [2, 13, 13]. However, all listed components primarily enabled human to become unique and highly competitive predatory organisms. It is important to note that almost all forms of niche creation are unintentional.

Humans are hyper-social and have access to complex cognitive skills. One of them is also our capability to compute and use of mathematics. Our brain did not develop just to solve mathematical mysteries. We solely developed complex nervous system to survive and reproduce within a given environment. Our basic capabilities, such as spatial orientation and innate computation, which help us finding our way in the surrounding environment, are as important for us as for any other animal species.

Computers are obviously much better in computing than we are. However, the machines are not able to recognize objects, obstacles and they cannot find a way around the world as easy as we do. The important distinction is that humanity developed from other ancestral beings through millions of years of evolution to do these tasks successfully.

One of the main reasons for our success lies in our well-developed and complex nervous system. The first nervous system was developed in animals that had to move and change environment where they lived. The reason why we have the nervous system is the interaction of living creatures with the surroundings and perception of the environment.

On the other hand, we have some abilities that no other animal possesses. The main objective of this paper is actually to argue that complex cognitive skills, such as mathematical reasoning, i.e. numerosity and arithmetic, are an addition achieved as a side-product of the development of specific human culture.

All specific ways of acting, perceiving and knowing, we are accustomed to call cultural, are incorporated, in the course of ontogenetic development, into the neurology, musculature and anatomy of the human organism; thus they are equally facts of biology and culture [3; p.40, 4]. Ingold [4; p.16] suggests that "development thinking allows us to recognize that we are not dealing with separate but parallel systems, respectively biological or cultural, but rather that the biological process of development, of the living human organism in its environment, is precisely the process by which cultural knowledge and skills are inculcated and embodied."

NUMEROSITY AND ARITHMETICS

From the perspective of human evolution, it is thus obvious that the development of mathematical skills was important part of the prospect of our species. In searching for the roots of cognitive grounds for the development of quantification, I will begin with presentation of some animals' capacities to recognize quantity up to number four.

The ability to make consistent rough estimates of the number of objects in a group is called numerosity [14; p.51]. Many animals (pigeons, parrots, raccoons, rats, chimpanzees) have innate capacity for numerosity. Deheane [15] writes about a part of the brain specialized for a sense of quantity. This is inferior parietal cortex, especially angular cortex [14; p.24]. Following Tobias Danzig, Deheane [15; p.xviii] refers to it as number sense. Region active in number processing in humans is the intraparietal sulcus [15; p.239].

Recognizing the quantity leads to very basic arithmetic. Arithmetic uses following capabilities: subitizing, perception of simple arithmetic relationships, the ability to estimate numerosity with close approximation and the ability to calculate and memorize short tables [14; p.26]. Most basic literal aspects of arithmetic are subitizing, instantly recognizing small numbers of items, and a capacity for the simplest forms of adding and subtracting small numbers [14; p.51]. Addition, subtraction, multiplication and division are basic arithmetic operations. More sophisticated mathematics is a lot more than solely arithmetic. Mathematics extends the use of numbers to many other ideas: the numerical study of angle (trigonometry), the numerical study of change (calculus), the numerical study of geometrical forms (analytic geometry) and so on [14; p.47].

STUDIES IN ANIMAL QUANTIFICATION ABILITIES

Researchers in the field of animal cognition stress the importance of mental continuity [16]. Continuity led to the development of humankind. We developed in parallel with other animal species. We share some of the main universal characteristics with other animals. However, unique traits developed in different animal species. For researching the universal traits among different animals we use comparative animal studies.

Comparative studies show that animals are able to count. Experiments with raccoons, canaries, some monkeys and other animals showed that some form of the sense for numbers is widely shared [15]. Studies with rhesus macaques (*Macaca mulatta*) showed that they can distinguish between small numbers (smaller than 4); but when numbers are larger, the ability to distinguish precisely between amounts becomes more difficult [17].

Research done with chimpanzees showed also an ability of abstract addition. The researchers [18] designed two experiments. In the first experiment chimpanzees (*Pan troglodytes*) had to select between two objects (three-quarters of an apple and half an apple), physically more similar to a third one (half-filled glass). The second experiment showed that chimpanzees could mentally combine two fractions. For example, sample stimulus was made of one-quarter apple and half-full glass, and the choice was full disc or three-quarters disc. Chimpanzees chose the latter more often than chance alone would predict. This proved that chimpanzees are able to base theirs responses on conceptual similarity and that they have an intuitive grasp of how these proportions should combine [15; p.14].

It seems that chimpanzees can even do simple addition quite successfully. In an experiment, chimpanzees (*Pan troglodytes*) were introduced with two trays of chocolate chips [19]. The first tray contained two piles. On the first pile there were four chocolate chips, the second pile contained three chocolate chips; altogether that made seven chocolates. The second tray also had two piles. First pile had five chocolate chips and the second pile had one chocolate chip; altogether six. Chimpanzees were successfully selecting the tray with more chocolate chips on it even without training. To achieve the result, they had to preform two additions and the final comparison between sums [15; p.15].

However, animals also make mistakes in comparison of quantity and computations. They are prone to distance effect and magnitude effect [15; p.16]. When comparing two numbers that are closer together, the error rate is higher. This is the distance effect. Magnitude effect happens when compared numbers have equal distances, but compared numbers are larger. Recognizing this fallacies, distance and magnitude effect, demonstrates that animals do not posses a discrete representation of numbers [15; p.16].

Research on animals show we have to take the sense of number [15, 20] as something that exists prior and external to language. Then perhaps, basic arithmetic may also exist without language.

NUMEROSITY AND ARITHMETIC IN HUMANS

The latter example can be observed in studies of patients with damaged language centres of the brain, but can still solve simple arithmetic tasks. Varley and colleagues [21] studied patients with large left-hemisphere perisylvian lesions that led to severe grammatical impairment and some difficulties in processing phonological and orthographic number words. The patients did not have any problem with solving mathematical problems, involving recursiveness and structure-dependent operations. The results demonstrate the independence of mathematical calculations from language grammar in the mature cognitive system [21].

Moreover, the way in which we are solving simple mathematical tasks does not depend on our language per se [21]. The way of solving simple mathematical operations depends on the environment and other cultural factors, such as mathematics' learning strategies and education systems.

Studies connecting experimental and natural conditions in numerical processing shed a light on the parts of the brain connected with numerosity. Research [22] on three subjects used electrocorticography. The controlled part of the experiment used simple arithmetic task, where subjects had to judge the accuracy of complete arithmetic equations (one single digit added to double-digit number) and non-arithmetic memory statements (memory statements without any numerical content). Natural condition was subject normal interaction with environment. They labelled natural events from simultaneous video and intracranial EEG (electroencephalography). Reviewers of the videos had to evaluate the behavioural content of the video; especially whether it had or had not a numerical content; this included numerals, ordinals and quantifiers ('some', 'all' and 'every') when they were combined with quantities and numbers ('some sleep'). Study showed activity in intraparietal sulcus (IPS) in both conditions. This shows towards the importance of connecting numerosity to arithmetic.

Electrophysiological studies with patients show where in brain lays the ability for numerosity and arithmetic. Behavioural studies across different cultures present us with differences in arithmetic.

Comparison across cultures in cognitive arithmetic [23] presented different performance success between students with different origin. Canadian university students – Chinese origin (CC), non-Asian origin (NAC) and Chinese university students educated in Asia (AC) – solved simple arithmetic problems with four basic operations. ACs outperformed CCs and NACs in complex arithmetic task. In simple arithmetic task ACs and CCs were equal, both groups performed better than NACs. Results imply that differences in formal education together with extracurricular culture-specific factors and social environment have an affect on solving arithmetic tasks.

Tang and colleagues [24] did a study with native Chinese and native English speakers. Using functional MRI, they demonstrated different cortical representations of numbers between Chinese and English speakers. Native Chinese speakers engage a visuo-premotor association network for simple task in addition. In comparison, native English speakers largely employ a language process and rely on left perisylvian cortices for the same tasks. Additional observations were done. There was a functional distinction among the brain networks involved in the task for numerical quantity comparison between Chinese and English groups. The interpretation of the difference between Asian and Western performance of addition lies in the neurodynamic differences during mental arithmetic as resulting from habitual use of abacus in primary school, which results in ability of Asians to use visual-spatial simulation for mental calculations. On the other hand, Western subjects used only verbal processing systems [3; p.48].

The latter example represents the important skill-like dimension of culture. The Asians learn or train to use visual-spatial domain of cognition to calculate more efficiently. The presented differences prove that culture and environments, where the humans developed, played much more important role in specific human abilities and manners in task solving. The presented study as well supports Ingold's idea that biological process of development is the process by which cultural knowledge and skills are inculcated and embodied [4].

NEUROANTHROPOLOGY

In the final part of the paper, I present the idea that neuroanthropology represents a very good approach to combine all previously presented examples. We have to understand that mathematics in humans does not develop because of natural evolution, but is a product of cultural evolution. When we understand it in that kind of manner, we can understand also the biological properties of our ontogenetically developed mind that enable us to compute and solve complex mathematical tasks.

Firstly, we can gain important views on human cognitive abilities from patients and their experiences; as for example does Oliver Sacks who actually called himself a neuroanthropologist [3; p.27]. A study of patients with damaged language centres shows the important fact that mathematical reasoning does not depend only on language. It is, basically, an additional and independent part of our cognition. Furthermore, with cross-cultural studies of mathematics, the so-called ethno-mathematics [25], we gain the knowledge about how our development in specific environment shapes our cognition. For further investigation it would be interesting also to study patients with same lesions raised in different environment. Presented research and views on human mind and cognition also provide new views on education. Further findings in the presented field might also change our educational systems and bring some novel ideas into it.

Neuroanthropology does not focus on broad-based concepts, like habitus and cognitive structure; instead, it focuses on how social and cultural phenomena actually achieve the impact they have on people in material terms [3; p.31]. It is important to take into consideration structural inequalities and differences between people from various places and cultural background. The paper presented such difference between the Asians and the Westerns, which became apparent because of their exposure to different social and cultural environments. Neuroanthropology, with taking such differences in consideration and with linking neuroscience and anthropology, should provide another important pillar of cognitive science [3; p.31].

CONCLUSIONS

When trying to explain some characteristics of human complex cognition – numerosity and arithmetics – we need to take into account our evolution. Firstly, we have to start with simple animals and understand whether it is important for them to know the quantity of predators and conspecifics. This may not necessarily be the knowledge of separate organisms, it may actually be a property of the interactions with and within the ecosystem. From this we can base our understanding of higher animals – mammals and specifically primates. As presented above, we can learn from primate studies that they posess some kind of sense for quantity, and they can even combine the quantities [18-20]. This is from where basic arithmetic is most likely derived.

For now we only know that humans posses more complex understanding of mathematics. We do not know how it developed. The important aspect of human cognition is cumulative culture [2]. In my opinion, one of the most important predispositions for the emergance of accumulation of knowledge and practices in humans is prolonged period of ontogenetical development (childhood period). During this period we are particularly susceptible to the environment, natural and social, and to outside stimulus. Since we can communicate our ideas, imitate and learn [5, 12, 13], our brain shape in the way that we do things; similarly as others in our natural and social environment. These processes also lead from simple quality recognition towards concept of numbers and arithmetics.

Presented examples and studies show possible ways in development of more complex mathematics, which is important skill that shaped humankind. Therefore, it is important to study and combine studies from neuroscience, case studies of patients with damages of certain brain areas and cross-cultural studies. They have a great potential to lead to more general understanding of the rise of complex human cognition. They also contribute to better understanding of human mind. It may not lead us to universal understanding; however, it will provide solid foundations to the importance of the environment – natural and social – for the wiring of the brain and also our behaviour.

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NEUROANTROPOLOŠKO RAZUMIJEVANJE KOMPLEKSNE KOGNICIJE – BROJNOST I ARITMETIKA

Z. Muršič

Pedagoški fakultet – Sveučilište u Ljubljani
Ljubljana, Slovenija

SAŽETAK

Ljudska vrsta ima dugotrajnu evolucijsku prošlost. U nastojanjima za razumijevanje kompleksne kognicije ljudi važno je imati u vidu cjelokupnu evoluciju. Izložit ću tezu da su naše biološke predispozicije i kultura čvrsto vezane s našom prirodnom i društvenom okolinom. Tijekom ontogenetskoga razvoja oblikovani smo različitim faktorima. Ti faktori omogućili su ljudima razviti neke vidove kompleksne kognicije, poput matematike.

Na početku rada izlažem važnost prirodne i kulturne evolucije kod drugih životinja. U sljedećem dijelu ukratko izlažem područja matematike – brojnost i aritmetiku. Predstavljanja komparativnih studija životinja, prvenstveno provedenih na primatima, pruža zanimljive primjere o sposobnostima životinja da razluče različite iznose. Od sposobnosti za uočavanje brojnosti kod životinja nastavljam do neuroznanstvenim studija ljudi i naših sposobnosti za rješavanje jednostavnih aritmetičkih zadataka. Također navodim interkulturalna proučavanja aritmetičkih vještina. U zadnjem dijelu rada predstavljam područje neuroantropologije kao mogući novi stub kognitivne znanosti. Na kraju, važno je povezati ljudsku evoluciju i razvoj sa studijama kognicije kod životinja, ali također i s interkulturalnim studijama oblikovanja ljudskih sposobnosti vezanih uz brojnost i aritmetiku.

KLJUČNE RIJEČI

evolucija, kognicija, matematika, brojnost, aritmetika