SCHOLAR RESEARCH REPORT

The Evolution of Sequence Cognition in Primates

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Abstract

The success of humans as a species can, in many ways, be attributed to the development of language, tool use and large-scale social organisation through culture. All of these are predicated upon an ability to understand, learn and remember sequences. It has been proposed that humans are better than other animals at doing so. The research described below is focused specifically on primates, investigating in a broader scope, compared to previous research, how well monkeys, apes and humans can understand the order of performed actions. The study conducted by me, and another Laidlaw scholar was adapted for children and its goal was to see how the ability to perceive sequences develops and changes in humans during their formative years. While the results of this study cannot yet be conclusively discussed due to a lack of sufficient data, interesting conclusions can be drawn from the preliminary findings and observations of the decision-making of children during the phase of data collection. The work was conducted by St Andrews and Durham universities, the data collected largely in Edinburgh Zoo. The research on sequence cognition in primates that our child study was embedded in was developed and overseen by our academic supervisor.

LAIDLAW SCHOLARS

Durham University

Background

“The reliance of Homo sapiens on culture and cooperation has resulted in what can best be described as ‘‘a spectacular evolutionary anomaly.’’ The extra-somatic adaptations, technological dominance, and success of our species in colonizing every terrestrial habitat have no parallel” (Hill et al., 2009: 187-200).

Modern humans have regarded themselves as intellectually superior to other animals since their emergence as a species, yet this view of human distinction from other animals has been put under a lot of scrutiny and the reasons for their cognitive uniqueness remain under debate. Characteristics that have often distinctly been associated with human dominance include language and mass cooperation, as well as technical intelligence. However, when examining the question of uniqueness, it can be argued that other animals possess similar features. Bees, for example, have adapted to the environmental pressures of resource transportation by developing a complex social structure (Teodorovic and Dell’Orco, 2005: 60). Fireflies evolved a communication system based on light to cope with selection pressures (Carlson and Copeland, 1985: 415-436). Caledonian crows have been demonstrated to be able to learn how to use tools (Von Bayern et al., 2009: 1965-1968). Hence, non-primate animals individually possess traits that have been described as distinctively human. Yet, what makes primates, specifically the Great Apes, different is the ability to do all of them (Laland and Seed, 2021: 689-716; Tomasello and Herrmann, 2010: 3-8). Underpinning everything is a more advanced aptitude for learning and remembering sequences, the debate to which this research aims to contribute to. The link between the distribution of toolmaking and language have been shown to be closely linked by observing trends in symbolism and the development of tools in the earliest hominins, both also predicated on more sophisticated sequence recognition (Morgan et al 2015: 6029).

There are three main proposals for the emergence of primate intellect: socialisation (Dunbar, 1992: 469-493; 2007: 1344-1347), fruit locating (Milton, 1981: 534-548) and tool use (Parker, 2015:1-12). Dunbar (1992, 2007) argues that the cause for larger brains in primates can principally be attributed to the theory that they are a necessary adaptation to the pressure of living in groups, indicating that the volume of the neocortex, responsible for cognition and consciousness, is correlated with group size (see Figure 1), while it is not as correlated with other ecological variables. This is supported by the find that Great Apes can learn new hand action routines by ascertaining the order of the sequence constituents, indicating that sequences and sociality are connected, and there perhaps is not so much division between social and physical reasoning (Byrne, 2016; Byrne and Bates, 2010). However, evidence has emerged to suggest that perhaps the volume of the neocortex is not the most reliable measure of indicating primate insight or ability to understand sequences due to the previously overlooked role of the cerebellum (Molinari et al., 2008: 611-615), that regulates motor movement in the body, as well as apes possessing brains too large for their conservative group sizes.

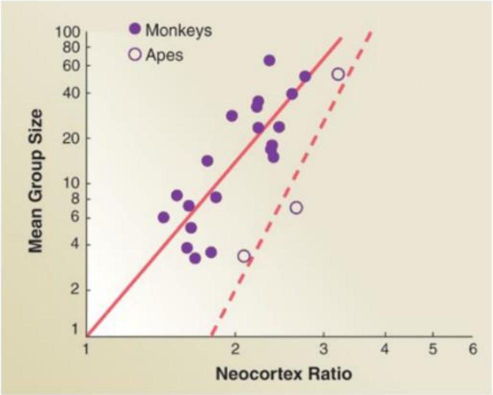

Figure 1: The correlation between the size of the neocortex and group size in primates, however the size of the neocortex is shown to be too big for the size of the typical ape troupe (Dunbar, 1992: 469-493)

Hence, the role of ecological factors and extractive foraging have come to the forefront of understanding the reasons behind primate brain evolution. For example, the spatial distribution of plant nutritional resources is hypothesised to play a major part – remembering where a food item is located, during what time of the year it can be found and how to attain it while avoiding predators and wasting as little energy as possible, as well doing so navigating through complex group relations, demands more brain power (Milton, 1981: 534-548). A closer correlation between brain size and extractive foraging has also been found (Barton, 2012: 2097-2107), evidence of high response sensitivity to the environment demonstrating specialisation leading to increased neural plasticity (Buzsaki et al., 2014: 41-50; Sherwood and Gómez-Robles, 2017: 399-419), and extractive foraging, requiring technical intelligence, has also been found to be connected to the cerebellum in particular, especially in apes (Powell et al., 2017). This is supported by the hypothesis that mental faculties evolved independently, supported by the notion that there is a direct connection between the neo-cortex and cerebellum in primates, but not in insectivores and that there is no association between brain size and neo-cortical grey matter (see Figure 2), further undermining the importance of the neocortex in the evolution of primate intelligence (Barton and Harvey, 2000: 1055-1058).

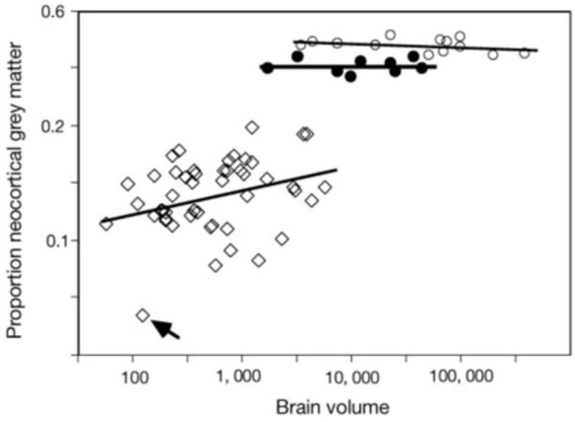

Figure 2: Dark circles - strepsirrhine primates; light circles - haplorhine primates; light diamonds – insectivores. While the volume of the neocortex is directly proportional to brain size, the proportion of neocortical grey matter is not. This indicates an independent or mosaic evolution of the brain, meaning each species developed specialisations for their various environmental pressures, suggesting varying mental abilities (Barton and Harvey, 2000: 1055-1058).

When looking at the relation of brain structure to processing sequences, it has been found that domain-general capacities underlie sequence functions in humans, the frontal cortex playing a crucial role in processing conserved sequences, specifically corresponding to the operation of language, which is especially developed and expanded in humans (Wilson et al., 2017: 72-82). Meanwhile, the cerebellum, which contains four times the number of neurons that the celebrated neocortex, has expanded more dramatically throughout ape evolution. This places a greater emphasis on the importance of technical intelligence than the commonly accepted social kind in humans and other apes – including an ability to understand sequences better, supporting technological advancement, cumulative culture and language (Barton and Venditti, 2014: 2440-2444; Dehaene et al., 2015: 2-19; DeCasien et al., 2022: 432-445). This supports the notion that sophisticated sequence cognition allowed humans to become adaptive intellectual all-rounders (DeCasien et al., 2022: 432-445; Laland and Seed, 2021: 689-716).

Furthermore, another study also highlights humans' unique cognitive abilities compared to other primates. Shared intentionality for navigating the complexities of living collaboratively with other group members sets humans apart from other apes (Tomasello and Herrmann, 2010: 3-8). Even though Great Apes understand the physical and social world in largely the same way as humans, and cognitively operate similarly, humans possess brains three times larger than our closest relatives, the chimps, at 1300cc versus 400cc (ibid). Based on other child and primate studies, it has been concluded that humans' social-cognitive skills operate at a much higher capacity than other apes even with pre-literate and pre-numerate toddlers (ibid). Curiously, a link has also been found between vision processing and brain size, the size of the visual pathways congruent with visual activities and tasks, suggesting that greater acuity photic vision is indicative of greater mental functions, and humans generally have better vision that other primates (Barton, 2006: 224-236).

Another study illustrates the difference between humans and other primates in how information, particularly sequential information, is perceived and recalled, results concluding that bonobos failed to solve the sequence discrimination even after over 2000 trials, while humans learned the difference between the order of two stimuli with barely any delay, which supports the notion that non-human animals are devoid of a working memory for stimulus sequences (Lind et al., 2023). Moreover, another study exposed that the capability to understand and represent the hierarchical structure of sequences is a lot less ample in non-human primates, meaning there is an insurmountable bottleneck for an ability to have language (Conway and Christiansen, 2001: 539-546). Thus, the goal of this research was to test the evidence that non-human primates have less of a capacity to learn and remember sequences than humans. The child study aims to demonstrate how this progresses specifically throughout humans' developmental postnatal years.

Methodology

THE PAPER TOWEL TASK

For the sake of continuity, the same experiment, called “the paper towel task”, was performed across all species. Two containers were presented (see figure): a green one and a grey one with a tube inserted at the top. The green box always contained a low-value reward. But the grey box was either empty or contained a high-value reward depending on what actions were carried out beforehand.

Figure 3: The green container with the “cop-out” sticker to the left, and the grey chimney-like box where the sequence was demonstrated on the right. The figure shows the “causal logic” version of the paper towel task with a smaller container absent in front of the grey box.

Only two actions could have been executed in relation to the tube of the grey box:

A – a paper towel was inserted into the tube

B – a high value reward was inserted into the tube.

As such, these two actions were completed in a sequence:

AA – two paper towels inserted, no reward

BB – two rewards inserted, both fall through the tube into the box where they cannot be retrieved

BA – the reward, then the paper towel are inserted, the reward falls through again

AB – the only “correct” answer, where the paper towel is inserted first, followed by the reward that doesn’t fall into the box because of the paper tower.

After showing the sequence, the subject would choose one of the boxes.

There were two versions of this task that had causal cues or didn’t to demonstrate if it made the task easier. In the causal logic version, the researcher would remove the tube every time the grey box was picked and tip it over, where the reward would either fall out or would be shown to be devoid of it. In the non-causal version, the tube wasn’t removed, but there was a little box in front of the grey container that would contain a reward whenever the AB sequence was performed.

The monkeys and chimpanzees had food rewards, but since this study was adapted for children between the ages of 3-11, the rewards were low-value star stickers and high-value stickers that they could collect for a provided sticker scene they chose beforehand, and the task would take around 15 minutes to complete per child. These choices were recorded on a coding sheet.

DATA COLLECTION

The project commenced in the middle of July. It began with an induction into interning at the zoo and a decision of where to set up the stand to conduct research. After preparing poster ads with the purpose of attracting research subjects, the apparatus, the rewards, and practicing conducting testing, we were ready to begin data collection.

The stand and apparatus were set up in a corridor at Budongo Trail - the chimpanzee enclosure - before the zoo opened (see Figure). After seeing the ad, children and parents interested in participating approached our stand. After briefly explaining the study and methodology and gaining consent from the parents, the children were tested, and they left with their sticker scenes. This was repeated into the late afternoon, usually with a break for lunch, at which point we were ready to pack up for the day. Over the course of 6 weeks, data from 222 subjects was collected.

The data furthermore needed to be recorded. The coding sheets and consent forms were scanned and stored. The videos of the testing were also compressed, organised and put into storage. The collected data was furthermore entered into a spreadsheet for further analysis and review.

Figure 4: The corridor at Budongo Trail where the research was conducted. (Urban Realm. (2022). *Budongo Trail : Public : Scotland's New Buildings : Architecture in profile the building environment in Scotland - Urban Realm*. [online])

Preliminary Findings

As the stage of data collection has not yet been completed, and the existing data related to the child study is insufficient to reach any definitive conclusions, the discussion of outcomes can be only based on limited information and insights gained during the period of gathering information.

Out of the general observations made over the course of data collection, it appeared that, indeed, younger children had a much harder time gauging how to consistently win the most stickers. It appeared that the younger the child was, the more likely they were to just choose a side and stick to it regardless of actions performed in relation to the apparatus. The youngest often had difficulty maintaining attention for the duration of 15 minutes, often spurred on by their parents, sometimes not quite understanding what was asked of them. One three-year-old consistently pointed at the green jar because it was prettier and shinier than the neighbouring container. Others just liked collecting the little star stickers that found their way onto their clothes, hands and faces.

As the children got older though, between the ages of around five and eight, many began to guess there was a pattern or a sequence to it. Many of them assumed the distribution of stickers was related to an alternating pattern. Others realised there was a high chance of attaining the high-value reward if a token was inserted into the non-cop-out box. Some of them correctly understood they would win a sticker for their sticker-scene in the last stage of testing only after the AB sequence was demonstrated. Others were auditory learners and assumed there would be a high-value reward whenever they heard the box being clicked shut on one side behind the cardboard sheet. Children older than that would usually find the experiment so easy that a few of them even began to needlessly complicate it, simulating there may be some trick or "catch". Testing without the causal cue proved to be a lot more difficult for children to understand.

Acknowledgements

This experience also provided an enormously valuable insight into how the research process works, giving me first-hand experience, which no doubt will be useful and applicable to any forthcoming academic activity. Furthermore, this allowed additional in-depth understanding into the sphere of human evolution. I want to express particular gratitude towards my academic supervisor for the support and guidance shown over the research period, my colleague and the Laidlaw programme for giving an opportunity to develop my research skills. Thank you also to Edinburgh Zoo for permitting research at their facilities and Living Links for enabling the study of human evolution. Also to St Andrews Baby and Child Lab for use of their facilities.

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