

An Investigation in to Tyrannosaurid Evolutionary Supremacy as a Product of Advantages in Increased Brain Capacity

Isaac William Chan

Research Scholars Program, Harvard Student Agencies, In collaboration with Learn with Leaders

ABSTRACT

The idea that dinosaurs, particularly members of the theropod clade, are animals far more dynamic and sensorily/cognitively acute than the dumb, brutish movie monsters and giant lizards they were once depicted as is not new to today's scientific community. However, the specific potential of dinosaurian brain capacity, beyond simple functions and sensory input, remains hotly debated. Not only are claims of extremely advanced, 'intelligent' sauropsid behaviors inherently dubious – the fossil record, a primary source for paleontological study, preserves evidence pertinent to these claims with far less clarity than it does morphological or physical characteristics, rendering many conclusions speculative. 'Tyrannosaurid-centric' research, popular within paleontology, is among the most critical mediums of pioneering investigation into dinosaur neurology, its degree of advancement, and its evolutionary contribution. Tyrannosaurids are well-described due to the wealth of resources invested in and uncovered by North American paleontology and the species *T. rex*'s great popularity in the world of science as well as pop culture. It is well-recognized that the peaks of the tyrannosaur evolutionary lineage reflect a unique magnitude of evolutionary dominance and ecological supremacy, having produced not just the most physically massive and powerful predators to walk the earth, but a family of species possessing honed senses and theorized brain capacity exceptional for, and likely unparalleled by, any theropod branch. Ascertaining the most significant driving impetus behind tyrannosaur evolution can provide deeper and more revised insight into archosaurian and avian biological organization while informing our assessments of pattern indelibility in the continuity of the natural world.

Keywords: *Paleontology, tyrannosaurid, Tyrannosaurus rex, dinosaur, theropod, evolution.*

Subject: Paleobiology

INTRODUCTION

The Cretaceous period marked a transition between the predatory dominance of Jurassic allosaurids, Early Cretaceous carcharodontosaurids, and their relatives (i.e., carnosaurs) and that of the tyrannosaurids, a branch of coelurosaurs which, by around 100 million years ago, reigned uncontested within the Northern Hemisphere. Though apex theropods are naturally highlighted by paleontological research, the causality of such a transition has yet to be entirely explicable. Surprisingly, few studies have delved into this context concerning the exact comparative advantages of the tyrannosaurids lineage.

The potential variables in tyrannosaurid evolution are numerous – these include the cause of their skewed global distribution (absence in the Southern hemisphere), the enigmatic sparsity of the medium-sized predator niche in areas where large tyrannosaurids were dominant, and differing prey-based specializations and environmental responses between tyrannosaurids and more sauropod-dependent theropod predators. These variables and the apparent physical/morphological advantages of (primarily) Late Cretaceous tyrannosaurids may seemingly controvert or otherwise complicate the secure presence of non-negligible neurological advantages within the clade.

However, a more comprehensive analysis incorporating such facets, comprised of inferences upon fossil evidence, existing authorities/sources of academic literature in paleontology, and a unique combination of perspectives on

Mesozoic ecology, makes it clear that the primary advantages of *T. rex* and its progenitors/relatives in outcompeting other theropod groups were their distinctly high brain capacity, sensory/cognitive acuity, and subsequent organized social behavior.

MATERIALS, METHODS & RESULTS

The primary sources utilized in this paper can be summarized as data combining neurological simulation and the fossil record. Specifically, several assertions in Herculano-Houzel's recent paper, *Theropod dinosaurs had primate-like numbers of telencephalic neurons*, are doubtful and possibly exaggerated – e.g., the claims pertaining to primate-level social organization among tyrannosaurs that have garnered high publicity in the scientific and general community. The source, while professional, does not originate with a specialist in paleontology, nor are its generalizations on animal intelligence a product of scientific consensus – hence, it is compromised in reliability.

However, the data extracted from said research – comparisons of neurological potential between various dinosaur species - is incorporated with moderation and cross-referencing with paleontological and scientific knowns and is thus presented largely without said margins of error. Overall, primary source data in this paper is used selectively to support distinct and specific claims.

The secondary sources incorporated are diverse in focus and uncorrelated in aim, enforcing their validity in objective support of the thesis even though their usage involves the assimilation of processed data and analytical content cited as extrinsic or nonoriginal to this study. Many advanced counterarguments to the thesis are targeted, and independent sub-theses/connections derived using such comprehensive secondary research. Furthermore, these secondary sources comprise highly current scientific knowledge and journalistic peer review processing (circa 2010-2022). Some, such as Hurum et al.'s *Giant theropod dinosaurs from Asia and North America: Skulls of Tarbosaurus bataar and Tyrannosaurus rex compared*, provide data quantifiably substantiated (through fossil measurements and anatomical study) and in alignment with well-recognized paleontological conclusions. Other more dated material (the late 1990s at the latest to early 2000s) either covers basic, verifiable conclusions closely tied to fossil descriptions and discoveries or involves the opinions of highly renowned experts such as Robert T. Baker or Phillip Currie.

In conclusion, this study's diverse research material and thorough methodology provide strong support for brain capacity as the central driving impetus of tyrannosaurid evolutionary dominance.

Tables and Data

	Brain mass (g)	Percent (% ± .5)	Telencephalic neuron count (millions)			
			A	Percent (% ± .5)	B	Percent (% ± .5)
<i>Tyrannosaurus rex</i>	343	180	311.3	143	3,289	155
<i>Acrocanthosaurus atokensis</i>	191	100	445.5		2,116	
<i>Alioramus altai</i>	73.2	38	173.2	49	1,028	56

Percents are all in relation to either the mass or telencephalic neuron counts of *A. atokensis*. A = ectothermic (reptilian) estimates, B = exothermic (avian) estimates. (Herculano-Houzel, 2022)

Figure 1 (see above) compares the exceptional brain capacity of tyrannosaurids and other theropod neurologies.

DISCUSSION & CONCLUSION

Neurologist Suzana Herculano-Houzel's recently published study (*Theropod dinosaurs had primate-like numbers of telencephalic neurons*) utilizes data processed from various scientific literature and journalistic sources to establish a baseline detailing and referencing the brain capacity of various dinosaurs (Herculano-Houzel, 2022). Herculano-Houzel applies the relationships between encephalization quotient and telencephalic mass characteristic of exothermic avian and ectothermic reptiles, respectively, to produce two sets of comparative neuron counts between various genera (based on Houzel's secondary research of fossil cranial cavity scans) (Herculano-Houzel, 2022). In both cases, *Tyrannosaurus rex* exhibited the highest cognitive and neurosensory potency among all medium-to-large sized non-avian theropods: according to estimates from the most up-to-date and genus/specimen-specific sources, around half as great as *Acrocanthosaurus atokensis*, a large, several-ton carcharodontosaurid from Early Cretaceous North America (see

Figure 1) (Herculano-Houzel, 2022). *Alioramusaltai*, a small tyrannosaur, displayed half the number of neurons and nearly 40% of the brain mass of *A. atokensis* despite weighing only 350 kg (see Figure 1) (Herculano-Houzel, 2022; Wong, 2009). Thus, as is generally recognized in the paleontological community, tyrannosaurids possess a brain capacity separating them from most dinosaur species and, as is particularly crucial to the focus of this paper, other non-avian theropods.

Herculano-Houzel further suggests, through regression line plots encompassing the aforementioned calculations, that non-avian theropods adhere to the same relationships of brain, body, and telencephalic mass as the avians that existed prior to the pre-Cretaceous-Paleocene extinction event (Herculano-Houzel, 2022). The implication presented in the study is that certain theropods exhibit the same neurology as today's long-lived (highly developed), intelligent, tool-using, and community-building avians and even mammals; *T. rex*, in particular, is noted as a peak example of these metrics and possible traits (Herculano-Houzel, 2022). However, peer review has brought under intense question the methodological extrapolations of the paper, in particular the assumption of similarly allocated neurological organizations in non-avian theropods, Cretaceous birds, and modern birds, which, along with the relationship between body mass and brain mass/composition, is not discernible from telencephalic neuron data alone. This claim, accounted for as possessing notable margins of error, nevertheless presents significant implications for tyrannosaurid brain capacity as reflective not just of sensory acuity (which is known) but of intelligence. Basic quantitative reasoning can be procured in corroboration of this; *T. rex*'s comparatively greater olfactory (max bulb to max cranial diameter) ratio—scalable to roughly a 23% increase in olfactory bulb diameter compared to *A. atokensis* (per the work of Zelenitsky et al.)—fails, even in combination with rough body size disparities, to account for a brain mass estimated to be roughly twice that of the carcharodontosaur (Herculano-Houzel, 2022; Zelenitsky et al., 2009).

Counterarguments against the role of brain capacity as central in Tyrannosaur evolution may instead attribute their dominance to physical advantages such as large size, robust skeletal structure, and specialized predatory ecology. This line of thought may point to the sparse population distribution of tyrannosaurs in the southern hemisphere as well as emphasize the similarities shared by *T. rex* and its kin with abelisaurids such as *Carnotaurusastrei* or *Majungasaurus crenatissimus*, which dominated their southern ecosystems concurrently with the peak of tyrannosaur evolution in the north. Abelisaurids also possessed relatively square, laterally robust skulls (compared to carnosaurs, for instance) and minuscule arms, which would imply to some the same correlation with hunting strategy as in tyrannosaurs and suggest that the tyrannosaurid predatory advantages were more physical rather than sensory, neurological, or cognitive.

However, such theories are rendered moot when considering that abelisaurid skull characteristics such as lesser tooth and snout length, a bone-reinforced occiput, and a forward-compressed temporal fenestra indicate the same or similar use of the upper jaw in generating downwards force, corresponding flexion at the base of the neck, and wide gape as carnosaurs (e.g., *Allosaurus fragilis* of the Late Cretaceous), ideal for damaging disproportionately large prey (in contrast to the grappling, tearing, and crushing of tyrannosaurs) (Bakker, 1970). In conjunction with their dependence on sauropod-heavy ecologies, such evidence disproves notions that abelisaurid predatory behavior was uniform to that of tyrannosaurs.

Another natural argument would subsequently highlight the tyrannosaurid absence in the southern atmosphere as a product of their inability to hunt in regions where carcharodontosaurids were highly frequent, and sauropods were, in correlation, the available prey (in comparison to Cretaceous North America, where sauropods were not environmentally supported and carnivores such as *T. rex* typically hunted prey such as ceratopsians). However, there is an absence of scientific evidence sufficient in magnitude to substantiate this thesis. Fossil records of tyrannosaurs in the southern hemisphere are not simply sparse under the criteria of large, *T. rex*-proportionate size - they are nearly entirely nonexistent, even with regard to the smaller-size tyrannosaurs that, with demonstrably higher agility, less robust physical structure, and starkly differentiable predatory strategy when compared to their adult morphs, would have been fully capable of finding sustainable sources of prey and surviving under the shadow of larger predators.

Further research is required to ascertain the reasons behind this absence; currently, geographical barriers are an as-likely or as-supported cause of the tyrannosaurid regional constraint as predatory specialization. In further controversion of the latter theory, direct competition between tyrannosaurs and carnosaurs, rather than a purely environmentally-driven niche transformation, is corroborated by evidence such as the sudden disappearance of predators (the North American *A. atokensis* and European *Neovenatoralerii*) that did not possess the consumption needs of peak carcharodontosaurid gigantism and possessed ornithischian (iguanodontian) prey options, and the discovery of coexistent tyrannosaur-carnosaur pairs such as *Guanlong/Sinraptor* (Late Jurassic Asia), *Timurlengia/Ulughbegsaurus* (Late Cretaceous Europe), and *Moros/Siats* (Late Cretaceous North America) (Tanaka et al., 2021). Additionally, tyrannosaurids are strongly implied to have been capable of exploiting the availability of

sauropod prey by a) the widespread distribution of *T. rex* specimens even in regions inhabited by titanosaurs (*Alamosaurus*) and b) the gracile form of *Tarbosaurus bataar's* skull (Sampson et al., 2005; Hurum et al., 2003). With the almost Allosaurid structure and implied stress distribution of said skulls, laterally and uniformly thin when compared to the much more abrupt post-lacrimal widening of *T. rex's* back jaws, it is clear that large, apex tyrannosaurs were successful in multiple predatory niches, being physically adaptable to preying on non-ceratopsian species (which were less frequent in *T. bataar's* habitat) and likely including Asiatic sauropods (e.g., *Nemegtosaurus*) (Hurum et al., 2003).

Perhaps the most substantial evidence for the tyrannosaurid cognitive advantage comes in three linked forms: the research of early, transitional, or near-basal genera in understanding the roots of tyrannosaurid evolution, the niche assimilation hypothesis, and the consistent discovery of several tyrannosaurid "mass gravesites" – bonebeds laden with multiple species individuals of various ages – implying 'gregarious' behavior.

In accordance with the work of Brusatte et al. (2016) and McKeown et al. (2020), large brain size is the first distinct landmark to have arisen at the root of tyrannosaurid evolution. This conclusion stems from the descriptions made available by advances in proto-tyrannosaurid research, specifically those of *Timurlengiaeuotica* and *Bistahieversorsealey*.

Both tyrannosaur ancestors, via specimens with highly preserved brain cases, elucidate an area of evolutionary understanding with depth previously unseen and exhibit traits such as relatively enlarged brains and exceptionally elongated and linearly structured cochlear ducts (Brusatte et al., 2016; McKeown et al., 2020). The former intrinsically implies comprehensively superior cognition, and while much of a tyrannosaur's neurological resources are ostensibly allocated to its senses (enlarged midbrain) rather than more complex functions, heightened sensory input and environmental perception are arguably the first steps towards not only economized physical predation but more flexible and socially potent cognitive processes in animals. For instance, the latter characteristic – a deep cochlear duct – enables the detection of extremely low frequencies. This is highly atypical of most theropods and has been suggested by Brusatte et al. (2016) to indicate the use of an augmented range, subtlety, and detail of noises and vocalizations, enabling a high level of communication (Brusatte et al., 2016). The development of disproportionately large olfactory bulbs as absent until the evolution of more derived coelurosaurs, as illustrated by the differences between *T. euotica* and the later, more cladistically recent *B. sealey*, demonstrates that communicative hearing, or at least overall cognition and senses aside from acute smell, were even more deep-rooted catalysts of tyrannosaurid evolution than olfactory reception (Brusatte et al., 2016; McKeown et al., 2020). With *B. sealey* being among the first tyrannosauroids to attain large size, Brusatte et al. (2016) and McKeown et al. (2020) have theorized that increased overall brain capacity preceded any other development towards the state of giant size and apex predation.

By extension, the 'niche assimilation hypothesis' – terminology used in research such as that of Holtz – notes the comparatively scant presence of medium-sized predators in the tyrannosaur-ruled ecologies of Late Cretaceous Asia and North America and suggests the importance of smaller tyrannosaurids to the overall dominance of the clade. Holtz highlights the role of juvenile and subadult species, physically agile, more gracile, and subsequently distinct from their adult form in specialization, in dominating the consumption of prey shared with other middle-sized dinosaurs; such prey statistically analyzed to be no less diverse and copious in number during the time of large, apex tyrannosaurs (Holtz, 2021). However, these dynamics can also be applied to smaller tyrannosaurids preceding *T. rex*, such as *Gorgosauruslibratus*, *Daspletosaurus*, and *Albertosaurus sarcophagus*. While powerful, dominant predators, albertosaurines may have been functionally similar to *Tyrannosaurus* juveniles. These albertosaurines (e.g., *Albertosaurus*, *Teratophoneus*) and their later relatives (i.e., *Daspletosaurus*) have (with far greater consistency than the South American carcharodontosaurid *Mapusaurusroseae*, for instance) been discovered in groups at times without traces of herbivores and thus indications of predator-traps or simple mob feeding (Currie, 1998; Titus et al., 2021). Such implied pack behavior would explain how mid-sized tyrannosaurids and juvenile tyrannosaurs attained such significant advantages over their former niche co-inhabitants.

Combined with previously analyzed information, this evidence provides solid foundations for describing tyrannosaurids as uniquely social theropods. Pack hunting is not limited to the big cats in their hunt for large African mammals or to komodo dragons, crocodiles, and other uncooperative mobs (likely akin to carcharodontosaurids – less cognitively developed and less evident to be social animals – as they fed upon titanosaurs); wolves hunt bison or musk ox in packs as well, this being a more similar dynamic to tyrannosaurs and their prey. Pack hunting capitalizes on existing predatory capabilities in maximizing efficiency and output while reducing injury risk or increasing survival probability. Tyrannosaurid social groups may not have had social mechanisms or divisions of labor as intricate or codependent as some modern animals, with the starkly distinct prey of their young and adult growth stages. However, with different

stages of tyrannosaur development, size increase, and hence ecological niche so drastically tied to food source availability, it is highly conceivable that the uniquely cognizant and socially cooperative capacity of earlier tyrannosaurids, with neurological potential inherited by their post-basal progenitors, passed down the juveniles of later, apex tyrannosaurs, were responsible for a rapid evolutionary ascension and definitive, forceful replacement of carnosaurs, allosaurids, carcharodontosaurids, and any other theropod competitor (Woodward et al., 2020). This advantage would have garnered the level of consumption necessary to sustain the most enormous, powerful, and majestic of the tyrant lizards.

REFERENCES & FOOTNOTES

- [1]. Bakker, R. (1970, January 1). Brontosaurus Killers: Late Jurassic Allosaurids as Sabretooth Cat Analogues. Semantic Scholar. Retrieved March 18, 2023, from <https://www.semanticscholar.org/paper/BRONTOSAUR-KILLERS-%3A-LATE-JURASSIC-ALLOSAURIDS-AS-Bakker/800caeb4db967eae70df2d37b607bf8f5990c8bd>
- [2]. Brusatte, S., Averianov, A., Sues, H.-D., Muir, A., Butler, I. (2016). *New tyrannosaur from the mid-Cretaceous of Uzbekistan clarifies evolution of giant body sizes and advanced senses in tyrant dinosaurs*. PNAS. The Proceedings of the National Academy of Sciences. Retrieved February 26, 2023, from <https://www.pnas.org/doi/pdf/10.1073/pnas.1600140113>
- [3]. Currie, P. J. (1998, January 1). Possible evidence of gregarious behavior in Tyrannosaurids. ERA. Retrieved March 18, 2023, from <https://era.library.ualberta.ca/items/19b93ddc-a4b9-4807-9d19-90d21648dfff>
- [4]. Herculano-Houzel, S. (2022). *Theropod dinosaurs had primate-like numbers of telencephalic neurons*. Journal of Comparative Neurology, 00, 1– 13. <https://doi.org/10.1002/cne.25453>
- [5]. Holtz, T. (2021, June 17). *Theropod guild structure and the tyrannosaurid niche assimilation hypothesis: Implications for predatory dinosaur macroecology and ontogeny in later late cretaceous asiamerica*. Canadian Journal of Earth Sciences. Retrieved February 25, 2023, from <https://cdnsiencepub.com/doi/10.1139/cjes-2020-0174>
- [6]. Hurum, J., Sabath, K. (2003). *Giant theropod dinosaurs from Asia and North America: Skulls of Tarbosaurus bataar and Tyrannosaurus rex compared*. Acta Palaentologica Polonica. Retrieved March 19, 2023, from <https://webaccess.app.pan.pl/archive/published/app48/app48-161.pdf>
- [7]. McKeown, M., Brusatte, S. L., Williamson, T. E., Schwab, J. A., Carr, T. D., Butler, I. B., Muir, A., Schroeder, K., Espy, M. A., Hunter, J. F., Losko, A. S., Nelson, R. O., Gautier, D. C., & Vogel, S. C. (2020). *Neurosensory and Sinus Evolution as Tyrannosauroid Dinosaurs Developed Giant Size: Insight from the Endocranial Anatomy of Bistahieversorsealeyi*. Anatomical record (Hoboken, N.J.: 2007), 303(4), 1043–1059. <https://doi.org/10.1002/ar.24374>
- [8]. Sampson, S. D., & Mark A. Loewen. (2005). Tyrannosaurus rex from the Upper Cretaceous (Maastrichtian) North Horn Formation of Utah: Biogeographic and Paleoecologic Implications. Journal of Vertebrate Paleontology, 25(2), 469–472. <http://www.jstor.org/stable/4524461>
- [9]. Tanaka Kohei, Anvarov Otabek Ulugbek Ogli, Zelenitsky Darla K., Ahmedshaev Akhmadjon Shayakubovich and Kobayashi Yoshitsugu. (2021) *A new carcharodontosaurian theropod dinosaur occupies apex predator niche in the early Late Cretaceous of Uzbekistan*. R. Soc. open sci. 8: 210923. <http://doi.org/10.1098/rsos.210923>
- [10]. Titus, A., Knoll, K., Sertich, J., Yamamura, D., Roberts, E., Lukacic, A., Ginouves, J., Glasspool, I., Suarez, C. (2021, April 19). *Geology and taphonomy of a unique tyrannosaurid bonebed from the upper Campanian Kaiparowits Formation of southern Utah: implications for tyrannosaurid gregariousness*. PeerJ. Retrieved February 25, 2023, from <https://peerj.com/articles/11013/>
- [11]. Wong, K. (2009, December 1). *Tiny tyrannosaurs rewrite evolutionary rules*. Scientific American. Retrieved March 4, 2023, from <https://www.scientificamerican.com/article/tinier-tyrannosaurs/>
- [12]. Woodward, H. N., Tremaine, K., Williams, S. A., Zanno, L. E., Horner, J. R., & Myhrvold, N. (2020). Growing up Tyrannosaurus rex: Osteohistology refutes the pygmy "Nanotyrannus" and supports ontogenetic niche partitioning in juvenile Tyrannosaurus. Science advances, 6(1), eaax6250. <https://doi.org/10.1126/sciadv.aax6250>
- [13]. Zelenitsky, D. K., Therrien, F., & Kobayashi, Y. (2009). Olfactory acuity in theropods: palaeobiological and evolutionary implications. Proceedings. Biological sciences, 276(1657), 667–673. <https://doi.org/10.1098/rspb.2008.1075>