Review

Unveiling the Function and Evolutionary Significance of Carnotaurus Horns: A Morphological and Behavioral Study

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Review

Unveiling the Function and Evolutionary Significance of Carnotaurus Horns: A Comparative Morphological and Behavioral Study

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Abstract: This literature review investigates the morphological and behavioral significance of the horns of *Carnotaurus sastrei*, a theropod dinosaur from the Late Cretaceous period. Through a comprehensive analysis of fossil specimens, comparative anatomy, and biomechanical modeling, this review explores the evolutionary adaptations and potential functions of these distinctive cranial structures. The horns of *Carnotaurus* are hypothesized to serve multiple roles, including species recognition, thermoregulation, and intraspecific combat. Our findings suggest that its cranial horns likely served a primary role in species recognition, intimidating rivals and signaling mating readiness. It also could have been used occasionally in head-butting contests, potentially as a display of dominance, but likely did not play a role in thermoregulation. Additionally, we examine the ecological context in which *Carnotaurus* lived, assessing how environmental factors could have influenced the development of such features. The implications of this study extend to broader discussions on the functional morphology and adaptive strategies of theropod dinosaurs, highlighting the complex relationship between form and function in the evolutionary history of predatory dinosaurs like *Carnotaurus sastrei*.

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Carnotaurus sastrei was a medium-sized carnivorous theropod from the Late Cretaceous Period of the Mesozoic Era. Standing at approximately 3 m tall, having a length of 7.5-8.0 m from head to tail, and weighing 1.3-2.1 metric tons, *Carnotaurus* was relatively lighter and smaller than other larger carnivorous theropods, such as *Tyrannosaurus rex* and *Giganotosaurus carolinii*. Their presence spanned most of what is now Argentina, South America. *Carnotaurus* tended to prefer the warm temperature and humidity provided by regions such as lakes, coastal plains, and tidal flats.

Though *Carnotaurus* had disproportionately short arms, it wielded two powerful hind legs that have been hypothesized to create efficient bipedal locomotion, allowing for higher speeds but simultaneously reducing its ability to make quick turns. Another distinct characteristic of *Carnotaurus* was its pair of horns that protrude from its skull from both sides, superior to the eye socket. These cranial protrusions were part of the frontal bone and measured approximately 15 cm in length. Many hypotheses have arisen from the discovery of this feature, and the most discussed ones are species recognition, thermoregulation, and intraspecific combat.

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In this literature review, I will investigate the function and evolutionary significance of the cranial horns observed in *Carnotaurus sastrei*. I will analyze each of the three hypotheses of species recognition, thermoregulation, and intraspecific combat, and determine their accuracy. Then, I will examine the environmental factors and conditions that could have led to the development of *Carnotaurus sastrei's* horns. Finally, I will end with a conclusion regarding the horns' various purposes and implications for the evolutionary mechanism acting on theropods like *Carnotaurus*.

Species Recognition of *Carnotaurus sastrei*'s Horns

Carnotaurus sastrei may have used its horns for interspecies recognition. Functions like this can be validated using comparative analysis with other theropods employing their cranial protrusions. As properties and visual appearances of cranial horns might vary between individuals, they might have been used for identification and characterizing different *Carnotaurus* individuals.

We must first explore the cranial anatomy of *Carnotaurus* and examine the implications of its cranial ornamentation for species recognition. It is likely that the horns may have functioned in sexual selection, with more prominent horns and elaborate cranial ornamentation being favorable in terms of mating success. Additionally, the horns might also have served as a visual display to other *Carnotaurus*, asserting dominance and strength while also intimidating potential rivals. The variation of horns across different individuals could have allowed for mate identification during courtship displays. This would be especially important considering the densely vegetated habitat *Carnotaurus* occupied, where there was heavy undergrowth and an increased necessity for identification.

Carnotaurus sastrei's cranial protrusions may have also played a crucial role in establishing social hierarchies within *Carnotaurus* populations. More prominent horns would likely have signified a healthier, stronger individual. Through their placement on the cranium, the *Carnotaurus* horns would be easily visible and thus assert dominance, creating a social hierarchy in which *Carnotaurus* individuals with smaller, less ornamented horns would avoid confrontation with those wielding larger, more ornamented horns.

Further analysis can be made using the comparative analysis with other theropods. For *Dilophosaurus wetherilli*, its paired crests that emerge from the nasal bone likely had distinctive characteristics and sizes among different individuals, allowing for species-specific interactions and playing a major role in visual communication. Similar conclusions can be made for *Monopholosaurus jiangi* and *Majungasaurus*, which wielded a pair of cranial crests and horns, respectively. In all of these dinosaurs from different theropod lineages, cranial protrusions were noted to enable visual communication and identification of certain individuals, creating a social hierarchy among their respective populations. This suggests that convergent evolution favored these cranial features among various species of theropods.

Through comparative analysis of other theropods with cranial protrusions, *Carnotaurus sastrei*'s cranial horns likely served a crucial role in visual display, allowing for species-specific interactions and identification. This would have been especially important for *Carnotaurus*, as some of its environment consisted of dense vegetation, where identification of certain individuals would have been difficult. More prominent, ornamented cranial horns would probably have been favorable over less prominent, simple horns. They could have asserted dominance, represented mating readiness, and intimidated potential rivals. This would also have established a social hierarchy among *Carnotaurus* populations, preventing confrontations between individuals of different social classes.

Thermoregulation of *Carnotaurus sastrei*'s Horns

The thermoregulation hypothesis suggests that the horns of *Carnotaurus* could have been well-vascularized, allowing blood to flow through them. This increased blood flow could facilitate heat exchange, helping to cool the animal. In hot environments, blood would be directed to the horns, releasing heat to the surrounding air, thus cooling the body. This would have been of great use for *Carnotaurus*, as it lived in a semi-arid environment where temperatures could fluctuate significantly. Thermoregulatory adaptations would be advantageous in such climates, helping *Carnotaurus*

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maintain optimal body temperatures for metabolic and physical performance, suggested by Farlow & Pianka (2002).

The presence of numerous prominent vascular canals within the cranial bones of *Carnotaurus* suggests an extensive network that may have facilitated blood flow. These observations were present externally and internally in the endocranial cavity upon fossil evidence. If present, significant blood flow would have served as a mechanism of heat dissipation and thermoregulation.

There exist few studies that discuss and determine the validity of the thermoregulation hypothesis of *Carnotaurus sastrei*. The most extensive conclusion we can currently arrive at is that *Carnotaurus* had densely vascularized horns, allowing for dissipation of heat and engaging in thermoregulation. However, since few studies confirm this, as well as the sole presence of indirect evidence, we cannot currently conclude that thermoregulation was a function of *Carnotaurus*'s cranial horns. If so, it was likely to be a supplemental feature, not a major one.

Intraspecific Combat of *Carnotaurus sastrei*'s Horns

The third major hypothesis behind the function of *Carnotaurus*'s horns is intraspecific combat. This may have included displays of dominance and mating rituals. To understand if *Carnotaurus*'s horns served this purpose, we must first determine if its skull morphology was capable of withstanding high stresses. Then, we will be able to analyze the validity of the intraspecific combat hypothesis.

A key insight into the stability and strength of *Carnotaurus*'s cranial horns is given by Bonaparte et al. (1990), in which the scientists suggested that the position of the horns were adept for head-butting and similar combat behavior. In addition, the robust and lightweight characteristics of these cranial protrusions could have been used to deliver and withstand large impacts. This would also suggest that the behavior of *Carnotaurus* was aggressive and combative, often fighting amongst themselves for aspects such as dominance and mating success. This behavior would be a reasonable cause for *Carnotaurus* to develop strong skulls and combative mechanisms.

However, there is also evidence that contradicts this claim. One such study by Mazzetta et al. (2009) involved applying three-dimensional finite element analysis (FEA) to a model of a *Carnotaurus* skull in certain scenarios. It was discovered that *Carnotaurus*'s cranium could have endured high-velocity impacts through its teeth in a hatchet-like biting technique. On the other hand, intense frontal head-butting was found to induce excessive stress on its skull, meaning that actions similar to this scenario could cause damage, perhaps even long-term damage, on *Carnotaurus*'s cranium.

Furthermore, another study conducted by Méndez (2012) explored the cervical vertebrae of *Carnotaurus*. It was discovered that the cervical vertebrae of *Carnotaurus* were relatively robust and rigid compared to those of other theropods. This rigidity suggests that the neck of *Carnotaurus* was not as flexible, which could limit its range of motion. Such rigidity would constrain *Carnotaurus*'s ability to perform dynamic, flexible movements typically associated with combat and head-butting.

A study conducted by Mazzetta et al. (1999) provides us with a reasonable compromise between the use of *Carnotaurus*'s cranial horns. Using comparative analysis, they determined that other dinosaurs like *Ceratosaurus* had much more extreme, prominent horns. Though the horns of *Carnotaurus* were not as notable, the scientists believe that they still played a role in daily life, especially in occasional combative bouts, also determined by Cerroni et al. (2020). It is likely that *Carnotaurus* engaged in head-butting, but not to the extent that Bonaparte et al. (1990) proposed since excessive combat would lead to cranial damage.

Therefore, it is likely that *Carnotaurus* would have been able to engage in intraspecific combat using its horns, fighting over mates, and for dominance. However, the rigidity of the cervical vertebrae and the specific cranial anatomy indicate that while the horns might have been involved in combat, head-butting may not have been a primary or highly effective behavior for *Carnotaurus*.

Conclusion

Limitations on Existing Research

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Though many existing studies were able to help us in our review of the function of *Carnotaurus sastrei*'s cranial horns, there is still much more research to be done to fully understand their primary use, whether for display, thermoregulation, or intraspecific combat. Key issues include the reliance on incomplete fossil specimens, which can skew interpretations due to preservation biases, and the limited sample sizes that constrain functional reconstructions. Additionally, functional interpretations are often based on indirect evidence and comparisons with modern analogs or other dinosaur species, which may not fully capture the unique ecological and behavioral context of *Carnotaurus*.

Takeaway

The primary function of *Carnotaurus sastrei*'s cranial horns was likely as a display mechanism. Evidence suggests that the horns likely played a significant role in species recognition and social signaling, aiding in visual communication and dominance displays, which would be crucial in the dense vegetation of its habitat. The thermoregulation hypothesis, while supported by indications of vascularization in the cranial bones, remains less substantiated due to limited direct evidence. Finally, while the horns may have been used in combat, the rigidity of the cervical vertebrae and the mechanical constraints observed suggest that intense head-butting was less likely to be a primary behavior. Overall, the horns of *Carnotaurus sastrei* were likely multifunctional, with a strong emphasis on social and display roles, rather than being solely adapted for combat or thermoregulation.

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