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BIOMECHANICS OF CHEETAH WITH APPLICATIONS IN ROBOTICS AND ATHLETICS

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Abstract

The primary emphasis of this article is on cheetahs as fast-moving terrestrial animals whose biomechanics are investigated. An investigation into the biomechanics of this animal provides light on its specialized adaptations that enable to attain extraordinary velocities, thereby shedding light on its evolutionary past and interspecies interactions. Cheetahs have undergone significant physiological, anatomical, and behavioral modifications to accommodate its exceptional speed. The research thoroughly examines the adaptations of the cheetah, encompassing its musculature, talons, and limb structure. Additionally, the respiratory and cardiovascular adaptations that cheetahs possess to facilitate sprinting are discussed in the article. This article also discusses how robot designers and athletes can utilize the strategies used by cheetahs to achieve extremely high speeds through adaptation.

Keywords: Cheetah, Biomechanics, Sportsmanship, Robot, Speed

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INTRODUCTION

Biomechanical studies contribute to the understanding of the specialized adaptations that fast-moving animals have developed to achieve their high speeds. Researchers can understand about both the evolutionary history and relationships between species by studying the biomechanics of fast moving animals [1, 2]. Fast running animal biomechanics is a multidisciplinary studies that investigates how these species acquire their amazing speed [3-5]. Biomechanics research in fast moving animals has applications in sport science, assisting athletes in optimizing techniques to improve performance and reduce injury risk. This research may also be used to develop robots and produce efficient kinematics. This is why researchers have long been attempted to understand the biomechanics of fast moving land animals [1-5].

The extraordinary quickness, speed, and style of the fast moving land animals have caused interest, investigation, and appreciation of the researchers [6-9]. Land animals that run at high speeds have acquired extraordinary adaptations to excel at fast locomotion [5]. This paper will take us on an investigation to discover the secrets of the quick mobility of Cheetahs. We'll go over the features that cheetah has and discuss its adaptations, highlighting the main parts of its anatomy, muscles, and physiology that make it runners. The scientific classification of cheetah is given in Table 1.

Table 1: The scientific classification of Cheetahs.

Scientific Classification	**Cheetahs**
Domain	Eukaryota
Kingdom	Animalia
Phylum	Chordata
Class	Mammalia
Order	Carnivora
Family	Felidae
Subfamily	Felinae
Genus	*Acinonyx*
Species	*jubatus*

Reaching running speeds of 65 to 75 miles per hour, the cheetah is the planet's fastest terrestrial animals [10-12]. Elevated body weights for male and female adult cheetahs are 65 kg and 55 kg, respectively [13]. A cheetah's long, thin legs, strong footpads, and flexible spine, which allows for a long stride, are all anatomical traits that have been specifically evolved to support their extraordinary running ability [14]. Due to its keen eyesight, cheetahs can find food during the day. Because of the way its spotted coat blends in with the tall, dry grass of its natural habitat, cheetahs are very good at staying hidden [15].

The goal of this paper is to apply a multidisciplinary approach to the understanding of the biomechanics of the fast-moving terrestrial animal cheetah. Energy efficiency, force, momentum, friction, and energy transfer have all been used to explain how it can reach great speeds. To further comprehend the biology and evolutionary processes of this creature, the concept of zoology has been applied.

METHODS

A multidisciplinary approach is useful to understand the biomechanics of swiftly moving land animals. We use physical and anatomical analysis, and observational study to determine their running speeds and physical adaptations. Observational studies are required to comprehend how animals move and act in their natural habitats [16]. Field researchers and wildlife biologists use high-speed cameras to take pictures of swiftly moving animals [17, 18]. Determining the maximum speed, acceleration, and running method of each species is made easier with the use of this information. Anatomical investigations entail the dissection of deceased specimens in order to get accurate information on the neurological and musculoskeletal systems that underpin the mobility of a subject [19]. These research' findings emphasize the distinctive characteristics of swiftly moving animals, such as their long limb bones, well-developed muscles, and the presence of certain adaptations like semi-retractable claws that provide them momentum during fast sprints. Physical measures are required to assess the physiology and biomechanics of these species. We conducted a comprehensive assessment of the literature on skeletal measures, muscle fiber analysis, respiratory and cardiovascular evaluations, and biomechanical modeling. These studies can be used for the analysis that follows.

The investigation of muscle fiber structure to evaluate how force and speed are produced is known as muscle fiber analysis [20]. Skeleton measurements involves a method which is

necessary to determine the involvement of joints, spinal structures, and limb bones in movement [21]. Respiratory and cardiovascular assessments enables us to evaluate the respiratory and cardiovascular systems to find out how much oxygen is used and how well the circulatory system is working at a high speed [22]. The creation of mathematical representations that mimic the motion of these animals while accounting for force application, energy transfer, and motion mechanics is known as biomechanical modeling [23, 24]. By integrating these methods, we can create a thorough understanding of the biomechanics of swiftly moving land mammals.

RESULTS AND DISCUSSION

With a focus on cheetahs in particular, the biomechanics of swiftly moving terrestrial animal has been studied. An remarkable range of physiological characteristics and adaptations have emerged, allowing cheetahs to attain such amazing speeds. Figure 1 displays the posters of cheetahs at different times throughout their rapid movement. These illustrations show the position and shape of the spine, tail, and hind legs during acceleration.

Muscles are made up of collections of muscle fibers that contract to produce movement and force. Approximately fifty percent of the cheetah's body mass is composed of musculature [25]. More than eighty percent of the cheetah's musculature in the thigh or upper rear limb consists of these rapid twitch muscle fibers [25]. That constitutes an extremely large percentage of that muscle type, which is the source of their amazing high speed. Cheetahs have exceptionally massive psoas muscles, which extend out the hip and then draw it back, allowing them to push off very hard with their rear leg and create a lot of power. During sprinting, the cheetah stretches its back legs and pulls back quickly and strongly with its spine flexed [26] (figure 1). Due to the physical relationship between the skeleton muscles and bones in cheetah, excellent posture stability and limb motion modulation are made possible.

The high speed of cheetah can be explained using mathematical analysis as follows.

The power that cheetah can developed can be expressed as

$$E = P.\ t \qquad (1)$$

where P= developed by the muscles of cheetah

E= kinetic energy that cheetah can generate with power P

t= time required to developed the power P

Now, the useful energy which can be used to gain high speed v is given by

E_{useful} = C. E. (2)

where C= where C is the coefficient of energy transformation, which depends on muscle efficiency, stride length, and biomechanical consideration.

Here, E_{useful} = ½ mv^2 (3)

where m is the mass of the cheetah and v is the velocity gained by cheetah.

Using Equations (1), (2) and (3) we get

$v = \sqrt{(2. C. P. t / m)}$ (4)

Equation (4) can be used to estimate the speed of cheetah. This equation describes the general method of calculating speed. However, various complex factors that govern cheetah speed may occur, necessitating more extensive study.

Understanding and replicating the cheetah's technique can help athletes, particularly sprinters, enhance their performance [27]. The tremendous push-off from the rear leg, which is analogous to having a turbo boost, allows for faster acceleration and high speeds. Athletes may train utilizing comparable biomechanics to optimize their own power generation. Bio-inspiration is becoming the primary technique employed by robot designers. Robots that must navigate rough terrain quickly might take inspiration from the cheetah's characteristic walk [28]. Consider a robot with a similar system that can swiftly extend and retract its limbs. This might be particularly useful in situations requiring rapidity and dexterity, such as search and rescue operations or environmental investigation.

Cheetahs have a strongly muscled back, which allows the spine to expand and bend, allowing them to stretch out when running and taking long steps [26, 29] (figure 1). Due to the fact that cheetah has spinal columns, or spines [30] a vast range of physiological motions are made possible by the vertebral column, which also supports and shields the spinal cord. Cheetah has skeletal component set consisting of the humerus, radius, ulna, femur, tibia, and fibula [31, 32]. The skeletal components provide mobility while preserving the structural integrity of the appendages. In order to safeguard important organs like the

heart and lungs, pronghorn and cheetahs have ribcages. The ribcage expands and contracts during breathing to aid with ventilation. Cheetah has a pelvic girdle made up of the pubis, ischium, and ilium that supports the posterior extremities and facilitates movement.

The process in which the cheetah's spinal column enables flexion and extension while sprinting may impart greater efficacy to training programs for athletes, specifically those engaged in dynamic sports such as gymnastics or martial arts [33]. Physical activity that strengthens and stretches the vertebrae may improve overall performance, agility, and injury prevention. Presently, the architecture of robots with enhanced locomotion is inspired by the spine of a cheetah in the domain of robotics [34]. Consider a robotic system that possesses an extensible backbone, which grants it the ability to extend its extremities and traverse significant distances while efficiently adapting to diverse topographies. In scenarios requiring robots to navigate complex environments—such as disorderly outdoor spaces or areas impacted by disasters—this form of design exhibits considerable potential.

Claws are present on the limbs of cheetahs with the nails always extended [35]. There are four toes touching the ground, out of which middle two toes are the most weight bearing [36]. When a cheetah runs in a zigzag motion after its prey, it gets very close to the ground. Its claws and nails provide a lot of grip and stability in this posture of cheetah. During sprints, cheetahs can retain a more firm grip because to its semi-retractable claws. Because cheetah walk on its toes rather than its entire foot, cheetah is example of animal with digitigrade limbs [37]. This modification enables a longer stride and greater speed by reducing friction and ground contact. Using the mechanical advantage that comes from the limb bones acting as springs and using more energy, this adaptation also improves running performance. Further, long, slender legs that are well suited for running is seen in cheetah. Speed is increased by longer strides, which are made possible by longer legs [38].

Athletes can learn a valuable lesson from the cheetah's zigzag movement, particularly those who play sports that require sudden direction changes [39]. Athletes may decide to change their training regimens or footwear for better traction if they comprehend how the claws provide stability and grip during these quick motions. For optimal grip, think about having digitigrade limbs integrated into your body! This could significantly change how robots move in the robotics domain. One method of improving robot agility and speed is to design them to walk like cheetahs—that is, on their toes instead of their entire foot [34]. Longer strides and faster movements are made possible by this adaptation, which lowers

friction and ground contact. A robot with these limbs might be able to navigate complicated environments quickly and accurately.

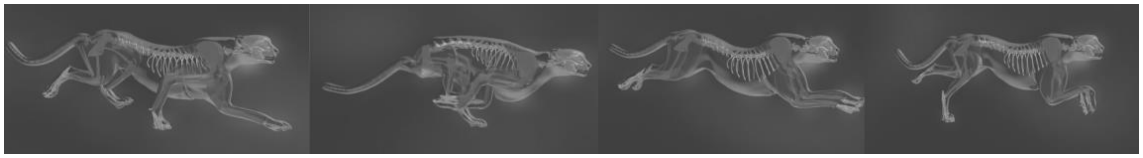


Figure 1: Different position of cheetah during fast motion(Source: https://www.youtube.com/watch?v=V8vejjVgIHg).

The cheetah tail is around half the length of the rest of the structure [35], (figure 1). Its tail is unusually long in comparison to the rest of the animal, and it serves as a rudder. As a result, it aids in steering around steep turns while zigzagging and pursuing after their prey. The tail is also quite muscular, and it aids in counter-balancing or counter-weighting so that they do not lose balance while running or turning rapidly.

Understanding how the cheetah's tail functions as a rudder and counterbalance can help athletes, particularly those who play sports that need for fast direction changes, adjust their training methods [40]. Exercises that mimic the function of the cheetah's tail to strengthen and stabilize the core could help with agility and precision during quick movements. To negotiate tight turns without losing balance, it's like having an integrated stabilizer. The cheetah's tail is now used as a model in robotics to create robots that must move quickly and maneuver through challenging environments [41]. Robots could be able to balance and maneuver in difficult terrain by using a tail-like appendage as a dynamic stabilizer. Imagine a robot that can maneuver through crowded areas or around sharp turns without falling over gracefully thanks to a mechanism modeled after a tail.

Anatomical components of the heart, cardiovascular muscles are present in cheetahs [42]. The heart muscles contract on a regular basis which helps blood flow throughout the body. The internal organs of cheetah, such as the digestive system and blood vessels, have smooth muscles which are responsible for both voluntary and involuntary motions. The underlying mechanism of muscular contraction that cheetahs share is connected to the concept of sliding filaments. This hypothesis states that myosin and actin filaments interact inside muscle fibers to produce force and permit movement.

Cheetah can both exchange oxygen and carbon dioxide during breathing because to its lung. Cheetahs have variable respiration rates that change according on exercise level. When cheetah sprints, its respiration rate reaches up to 150 breath per minute. Gas exchange is facilitated by the lung architecture's alveoli and bronchial passages [42]. The diaphragm, a muscle that facilitates breathing, is present in cheetah. Lung volume changes by the diaphragm's contraction and relaxation, which aids in breathing and exhaling [43]. Cheetah's breastbones are loosely linked to the rest of the musculature [44], and the chest cavity allows for a significantly bigger expansion of space where the lungs may expand. This feature allows cheetahs to be very flexible in the front and to spread out their strides (fig2). Cheetahs have tracheas, which are the anatomical tubes that connect the larynx to the bronchial airways in the lungs. The respiratory system's trachea is responsible for supplying and withdrawing oxygen. Tiny air sacs called alveoli are found in the lungs and aid in the exchange of carbon dioxide and oxygen. Diffusion of gases is facilitated by the capillaries around the alveoli. Hemoglobin is necessary circulatory systems to carry oxygen from the respiratory organs to numerous tissues and organs throughout the body. Following their combination with oxygen molecules in the pulmonary system, hemoglobin molecules are released at different locations throughout the body. Alterations in perforation facilitate enhanced ventilation and, concerning cheetahs, assist in thermoregulation during swift pursuits.

During rapid sprinting, the cheetah's body temperature rises quickly. Cheetahs distribute heat in a variety of ways. Cheetahs may expel heat from their mouths and feet. The black spots on its body help in heat dispersal [45]. Cheetah have streamlined body that minimize drag and air resistance when sprinting. So cheetah better able to move through the air in this shape.

Knowing how cheetahs disperse heat during fast movement can provide athletes—especially those participating in intense sprints—with new ideas for improving cooling mechanisms. Consider breathable, high-performance sportswear or creative cooling methods inspired by the cheetah's ability to remove heat from its feet and mouth. Optimizing performance requires controlling body temperature, and the cheetah is a great source of inspiration. Nowadays, the cheetah's streamlined body serves as a model for robotics designers creating airborne robots that must maneuver with efficiency. By emulating the cheetah's form, one can minimize air resistance and drag, allowing for quicker and more energy-efficient movement. Imagine a robot with an aesthetically

pleasing and aerodynamic design that can move through difficult environments with little difficulty.

CONCLUSION

In conclusion, the comprehensive biomechanical study of cheetahs reveals a suite of specialized adaptations, from musculature to respiratory and cardiovascular systems, enabling their exceptional speed and agility. Employing a multidisciplinary approach and mathematical modeling, this research not only enhances our understanding of cheetah biomechanics but also offers valuable insights for applications in sports science and robotics. Athletes can optimize their performance by emulating cheetah strategies, such as the powerful push-off and limb structure, while robot designers can draw inspiration for more efficient and agile robotic systems. The study showcases the interdisciplinary impact of investigating fast-moving terrestrial animals, with cheetahs serving as nature's blueprint for biomechanical efficiency, influencing advancements in various fields.

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