LIONS AND GAZELLES
(KINEMATICS OF PREDATOR/PREY INTERACTIONS)

Overview

Predator-prey interactions often depend on the comparative kinematic abilities of the participants, and there is a wide range of strategies for both hunters and hunted. In many cases, prey can ultimately run faster, but predators have greater acceleration so can catch prey if they both start at the same time.

Complementary resources:

lecture/ppt slides	*clicker questions*	*homework/exam questions*
6 (some missing images)	1 (separate document)	Several (mix of biological and everyday experience situations)

Physics concepts

Key quantities are <u>velocity</u> and <u>acceleration</u> – and the distinction between them.
The time it takes to achieve a certain velocity is often of critical biological importance – frequently more important than the final velocity itself

- Acceleration ability, whether for getting up to speed at the start of a chase, or for rapidly changing speed and direction during pursuit, is an extremely important feature in predator-prey interactions, whether on land or in water
- Acceleration ability can depend on size in some interesting ways:
    - leg length, available muscle power, mass and inertia
    - connection to biological scaling: see paper by Domenici, 2000
- Interesting to consider what may aid or limit acceleration
    - in different environments or media, e.g. air vs. water
    - with different locomotor strategies, e.g. fish swimming vs. squid jetting
    - when main issue is achieving high velocity (outrunning or outswimming), vs. rapidly changing direction (evasion, maneuverability)

Good place to start looking at <u>plots</u> with axes of v, t, distance, and shapes of curves
Estimating v, distance covered, acceleration from different types of plots, what information can be read or inferred, based on what is shown.
Issues of estimation, precision, accuracy in relation to real data (e.g. estimates of acceleration from video recordings, footprints)

As with many locomotion-related topics, this is an opportunity to connect to paleontology and look at how fundamental physics help us fill in, or at least estimate, missing data, e.g.

behavior in extinct organisms that left bones and trackways. The fact that the laws of physics have not changed since the dinosaurs means that physics is useful in interpreting even very old data. More information about the Glen Rose Trackway in Paluxy, TX is available at the American Museum of Natural History web site.

Biological background

Some hunters chase down their prey; others accelerate quickly from an ambush, and rely on surprise to capture prey that are in fact faster than they are themselves. Some potential prey can simply outrun their predators; others use evasive maneuvers (such as rapid, unpredictable changes of direction), or behavioral strategies such as schooling that limit a predator's ability to focus on and capture a single individual.

The differences in kinematics between predators and prey have important behavioral and ecological implications: predators (such as lions) that can out-accelerate but not out-run their prey (such as gazelles) should not waste time continuing a chase if they don't succeed in the first few seconds. The physics distinction between velocity and acceleration explains this observed behavior, as well as (more fundamentally) how lions can catch gazelles at all (even though gazelles can run about twice as fast).

There are many descriptions of predator-prey interactions in the biological literature, which offer varying degrees of physical explanation and/or data.

References

Primary:

Elliott, P., Cowan, I.M., and Holling, C.S. 1977. Prey capture by the African lion. *Canadian Journal of Zoology* 55(11):1811-1828. doi:10.1139/CJZ-55-11-1811

Level: Main emphasis is on behaviors and conditions that correlate with hunting success, including detailed mathematical modeling. This is primary biological literature. Not suitable for students; potentially useful source of primary data for instructors developing quantitative examples or problems. Most of the mathematical analysis is probably not immediately relevant to physics, though some elements might be.

Notes: (from abstract) "The attack involves a matching of the sprinting abilities of predator and prey. To analyze this aspect in detail, the velocity curves [velocity *versus* position] of running are defined for the lion and four prey species." A "numeric definition of the velocity curve for each species" is developed in mathematical terms, starting from Newton's 2nd law of motion, relating accelerating force to velocity. The numbers put into the equations come from extensive field observations of animal behavior.

There are some useful data for quantitative problems: Table 10 (p. 1821) lists rate constants and maximum velocities for lions, wildebeest, zebra, and gazelle, and velocity curves are shown graphically in Fig. 5 (y axis in ft/s, x axis in seconds) (p. 1822). The third graph (gazelle and lion) is the basis for Fig. 1.1 in Alexander, 2003 (cited below), which we have found very useful.

Hopcraft, J.G., Sinclair, A.R.E., and Packer, C. 2005. Planning for success: Serengeti lions seek prey accessibility rather than abundance. *Journal of Animal Ecology* 74:559-566.

Level: The main emphasis is ecology, not physics or explicit integration of physics, so this is more of an instructor resource/ground-truthing paper than something useful to assign to students.

Notes: "We used long-term radio-telemetry data to investigate how Serengeti lions (Panthera leo) distribute themselves with respect to hunting opportunities….lions fed in areas with high prey 'catchability' rather than high prey density." Evidence supporting the idea that lions understand physics – or at least that the distinction between acceleration (which they do better than their prey) and velocity (at which prey excel) has plausibly been a factor in the evolution of their hunting strategies.

Alexander, R.M. 2003. Principles of Animal Locomotion. Princeton University Press, Princeton NJ. 371 pages. [ISBN 0-691-08678-8]

Level: Accessible to undergraduates, but presumably one would choose sections rather than assign the entire book.

Notes: A classic book, and for good reason. Covers flight, swimming, and terrestrial locomotion, along with the basic physical principles involved. Very useful reference for instructors, for background, literature references, and summary diagrams for various locomotion-related topics. Emphasizes morphology and behavior more than energetics.

Specifically on speed and acceleration: pp. 2-3, Fig. 1.1 shows speed against time for lion and gazelle; original source is Fig. 5, p. 1822 of Elliott et al. 1977 (see above).

Additional:

Domenici, P. 2001. The scaling of locomotor performance in predator-prey encounters: from fish to killer whales. *Comparative Biochemistry and Physiology* Part A 131 (2001): 169-182

Level: Review article from the biological literature; fairly dense and long, so not appropriate to as required reading for all students (though could be useful for students working on a related project or topic). Graphs illustrate relationships between size and speed, size and acceleration, size and turning radius, as well as physical parameters/abilities and behavioral strategies. Physics is simple and clearly explained.

Notes: Besides relevance to predator-prey issue, also a nice illustration of how and why scaling – absolute and relative physical size – is important in biology.

Webb, P.W. 1988. Simple physical principles and vertebrate aquatic locomotion.

***American Zoologist* 28:709-725**

Level: A classic and comprehensive review; a great resource/reference for instructors, but would be very challenging for most undergraduates (though the article is clear, and motivated students should be able to follow it with some effort). Extensive bibliography cites original studies.

Notes: Organized around physics issues, starting with basic principles (momentum transfer, forces acting on swimming animals, etc.). Very useful and clear diagrams relate physical principles and mechanisms to variations in animal morphology. Reynolds number is explained, and its consequences enumerated; a scale showing Re is integrated into Fig. 3, which represents the relative importance of force components across a wide range of vertebrate taxa, sizes, and shapes. The physical considerations are clearly linked to biological phenomena (behavior and morphology). The conclusion includes a brief discussion of the relationship between biological and physical approaches: "…[A] feedback loop links hydrodynamicist with biological tests of reality (Table 1) and such interaction remains essential to advance in the area." (p. 722)

Alexander, R.M. 2002. Stability and manoeuvrability of terrestrial vertebrates. *Integrative and Comparative Biology* 42(1):158-164

Level: Review; not too technical, though perhaps a bit much for students. Excellent brief bibliography.

Format: pdf available from JSTOR. http://www.jstor.org/stable/3884589

Notes: Not specifically focused on predator-prey, but the locomotion topics covered are relevant. Per the title, an overview of these issues in terrestrial vertebrates, with particular emphasis on the role of frictional forces, problems related to turning, and connections between body posture and acceleration (e.g. "Humans and other bipeds must lean forward while accelerating and backward while decelerating"). Lots of nice examples mentioned, with some numbers in the text and sources cited for many (e.g. photographs of barrel racing "show horses leaning at about 45° to the vertical as they round the barrels, suggesting that their transverse accelerations must be approximately equal to the gravitational acceleration, and that the coefficient of friction with the ground must be at least 1.0"). Examples include humans on foot, bicyclists, horses, and others.

Good material here on **forces** and **friction**