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Study 2:

BATS

Bats really stand out in the animal world. They are the only mammals that can fly, and they live much of their lives hanging upside down. Most species are active only from dusk until dawn, spending their days in dark caves. Many bats have developed adaptations that let them find their way (and their prey) in complete darkness. Bats have survived as a group for more than 50 million years, longer than most other modern animals. All bat species are part of an order called *Chiroptera*, which comes from the Greek words *cheir* ("hand") and *pteron* ("wing"). There are more than 1,000 bat species in the world, making them one of the most prevalent orders of mammals.

Traditionally, bat species are divided into two suborders: *Megachiroptera* (megabats) and *Microchiroptera* (microbats). Most megabat species are frugivores (fruit eaters) or nectavores (nectar drinkers) and look a lot like other mammals, with large eyes, small ears, and extended snouts. In contrast, most microbat species are insectivores and have a unique facial appearance, with large ears and peculiarly shaped, stubby snouts. One microbat that is an exception to this is the vampire bat, which feeds not on insects, but on mammals' blood. It can consume half its body weight in blood in one feed.

While megabats have good eyesight, microbats use echolocation for navigation and finding prey. Also, the two suborders differ in terms of where they live: megabats are found only in Africa, Asia, and Australia, whereas microbats live all over the world. Although most scientists agree that the division of bat species into two suborders is a

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useful heuristic, the phylogenetic relationship among the different groups of bats has been the subject of much debate.

Although bats and birds both fly, a bat wing actually has more in common with a human arm than a bird wing. A bird's wing has fairly rigid bone structure, and the main flying muscles move the bones at the point where the wing connects to the body. In contrast, a bat has a much more flexible wing structure. It is similar to a human arm and hand, except it has a thin membrane of skin (called the *patagium*) extending between the "hand" and the body, and between each finger bone. Bats can use the wing like a hand, essentially moving through the air like a swimmer moves through water. The rigid bird wing is more efficient at providing lift, but the flexible bat wing allows for greater maneuverability.

To help them navigate and find their prey in the dark, microbat species have developed a remarkable system called echolocation. By emitting high-pitched sound waves and listening to the echoes, bats can determine with great precision the location of an object, how big it is, and the direction in which it is moving. Bats calculate the distance of the object by the amount of time it takes for the sound wave to return and the exact position of the object by comparing when the sound reaches its right ear to when the sound reaches its left ear. Similarly, a bat can tell how big an insect is based on the intensity of the echo: a smaller object will reflect less of the sound wave, and so will produce a less intense echo.

Although they hunt all night, bats will pass the daylight hours hanging upside down from a secluded spot, such as a cave or a hollowed-out tree. There are a couple of different reasons why bats roost this way. First of all, hanging upside down puts them in position for takeoff, which is important because bats cannot launch themselves into the air from the ground. It is also a great way to hide from danger. During the hours when most predators are active, bats congregate where few animals look and most cannot reach. Although snakes, possums, and raccoons sometimes hunt bats, birds of prey are the main predator of bats. Most bat species roost in the same location every day, clustering with other bats for warmth and security.

Bats have a special physiological adaptation that enables them to hang upside down. A bat's talons work like human fingers, except that humans must contract muscles to grasp an object, whereas bats must do the opposite – relax their muscles. When humans grasp an object, they contract several arm muscles, which in turn pull tendons connected to their fingers, which pull the fingers closed. To hang upside down, a bat opens its talons to grab hold of the surface, and then simply lets its body relax. The weight of the upper body pulls down on the tendons connected to the talons, causing them to clench. Since it is gravity that keeps the talons closed, instead of a contracted muscle, the bat doesn't have to exert any energy to hang upside down.

Like all mammals, bats maintain their body temperature internally. However, unlike most mammals, bats allow their body temperature to sink to the ambient temperature whenever they are not active. As their temperature drops, they enter a torpor state, in which their metabolism slows down considerably. By reducing their biological activity and not maintaining a warm body temperature, bats conserve energy. This ability is important because flying all night is hard work. When the temperature is cold for long periods during the winter months, some bats enter a deeper torpor state called hibernation. Other bat species follow a yearly migration pattern, traveling to cooler

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climates in the warm months and warmer climates in the cool months. This is why some regions experience “bat seasons” every year.

Many people have a negative reaction to bats, and it's easy to see why. Bats have also long been tied with vampires. While Bram Stoker was the first to have Dracula transform into a bat, a popular story titled Varney the Vampire published in 1845 is actually the earliest evidence we have of popular bat-vampire connection. Also, just by virtue of their appearance and behavior, bats play into a number of human fears.

However, insectivorous bats are the best bug killers on the planet, For example, a famous colony of more than 20 million Mexican free-tail bats that lives in Bracken Cave, Texas will eat up to 200 tons of insects in a night. Nectavoric bats are also prolific plant pollinators. Many species feed on plant nectar, gathering pollen on their bodies as they feed and helping the plant to disperse its seed when they visit other plants.

VACCINES

A vaccine is a biological preparation that establishes or improves immunity to a particular disease. Most vaccines are prophylactic, which means that they prevent or ameliorate the effects of a future infection by any natural pathogen. The flu vaccine is an example of a prophylactic vaccine that is given annually to protect against the influenza virus. However, vaccines have also been used for therapeutic purposes, such as for alleviating the suffering of people who are already afflicted with a disease. An example of such a therapeutic use is the vaccines currently being developed for the treatment of various types of cancer. Until recently, most vaccines have been aimed at children, but the development of therapeutic vaccines has increased the number of treatments targeted at adults.

The early vaccines were inspired by the concept of variolation, which originated in Asia. Variolation is a technique in which a person is deliberately infected with a weak form of a disease. Some historians claim that the earliest record of variolation can be found in an 8th century text from India called the *Nidana*. However, the first unequivocal reference to variolation comes from a Chinese text by Wan Quan called the *Douzhen Xinfa* written in 1549. The *Douzhen Xinfa* describes how dried smallpox scabs were blown into the nose of an individual who then contracted a mild form of the disease. Upon recovery, the individual was immune to smallpox. A small proportion of the people who were variolated died, but nowhere near the proportion that died when they contracted the disease naturally.

By 18th century, the practice of variolation had spread to Africa, India and the Ottoman Empire. In 1717, the wife of the British ambassador to the Ottoman Empire, Lady Mary Montagu, learned about variolation in Constantinople (which is known as Istanbul today) and advocated for the practice when she returned to England. At her behest, royal physicians conducted an experiment in which a number of prisoners and abandoned children were variolated. When the children and prisoners were deliberately exposed to smallpox several months later and none contracted the disease, the procedure was deemed safe. Neverthless, variolation carried a large degree of risk. Not only could the patient die from the procedure, but also the mild form of the disease could spread, causing an epidemic.

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Over the following centuries, medical researchers like Edward Jenner and Louis Pasteur transformed the ancient technique of variolation into the modern day practice of inoculation with vaccines. Jenner immunized people against smallpox by inoculating them with cowpox, a related, but relatively mild, disease. The cowpox virus he used to prove the effectiveness of this technique came from a cow named Blossom, whose hide is now hanging in the St. George's Medical School Library.

Inoculation represented a major breakthrough because it reduced the risk of vaccination, while maintaining its effectiveness. Inoculation is the practice of deliberate infection through a skin wound. This new technique produces a smaller, more localized infection relative to earlier variolation in which inhaled viral particles in droplets spread the infection more widely. The smaller infection works better because it is adequate to stimulate immunity to the virus, but it also keeps the virus from replicating enough to reach levels of infection likely to kill a patient.

Vaccines work because they prepare the immune system to deal with pathogens that it may encounter in the future. When a vaccine is given, the immune system recognizes the vaccine agents as foreign, destroys them, and then "remembers" them. When the real virulent version of an agent comes along, the body recognizes the protein coat on the virus and responds by destroying the infected cells before they can multiply. Of course, vaccines do not guarantee complete protection against developing the disease. Sometimes a person's immune system does not respond because of a lack of B-cells capable of generating antibodies to that antigen or a lowered immunity in general. Still, even when a vaccinated individual does develop the disease vaccinated against, the disease is likely to be milder than without vaccination.

Some vaccines are made from dead or inactivated virulent organisms that have been killed with chemicals or heat. Examples are vaccines against influenza, cholera, and hepatitis. Other vaccines contain live, attenuated virus organisms that are cultivated under conditions that disable their virulent properties. Examples include yellow fever, measles, rubella, and mumps. Aluminum-based adjuvants, such as squalene, are typically added to boost immune response. Vaccines can be monovalent or polyvalent. A monovalent vaccine is designed to immunize against a single antigen or single microorganism. A polyvalent vaccine is designed to immunize against two or more strains of the same organism, or against two or more organisms.

One challenge in vaccine development is economic: many of the diseases that could be eradicated with a vaccine, such as malaria, exist principally in poor countries. Although many vaccines have been highly cost effective and beneficial for public health, pharmaceutical firms and biotechnology companies have little incentive to develop vaccines for these diseases because there is little revenue potential. Even in more affluent countries, financial returns are usually minimal while the costs are great. The number of vaccines administered has actually risen dramatically in recent decades, but this rise is due to government mandates and support, rather than economic incentive. Thus, most vaccine development relies on "push" funding that is supplied by government, universities, and non-profit organizations.

Overall, the invention of vaccines has led to a marked decrease in the prevalence of certain diseases. For example, vaccines have contributed to the eradication of smallpox, one of the most contagious and deadly diseases known to man. Other diseases, such as polio, measles, and typhoid, are nowhere near as common as they were a hundred

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years ago. As long as the vast majority of people are vaccinated, it is much more difficult for an outbreak of disease to occur and spread, an effect called herd immunity. Yet, critics have campaigned in opposition to vaccination for centuries. Disputes have arisen over the morality, effectiveness, ethics, and safety of vaccination. Still, the mainstream medical opinion is that the benefits of preventing suffering and death from serious infectious diseases greatly outweigh the risks of rare adverse effects following immunization.

BREAD

Bread is prepared by baking dough made from two main ingredients: flour and water. Bakers call the inner, soft part of bread the crumb, which is not to be confused with small bits of bread that often fall off, called crumbs. The outer hard portion of bread is called the crust. Bread can either be leavened or unleavened. Leavening is the process of adding gas to the dough before or during baking to produce lighter, more chewable bread. Most of the bread consumed in contemporary cultures is leavened. However, unleavened bread has symbolic importance in many religions and, thus, nowadays it is primarily consumed in the context of religious rites and ceremonies. For example, Jews consume unleavened bread called *matza* during Passover.

Flour provides the primary structure to bread because it contains proteins – it is the quantity of these proteins that determines the quality of the finished bread. Wheat flour contains two non-water soluble protein groups (glutenin and gliadin), which form the structure of the dough. When worked by kneading, the glutenin forms long strands of chainlike molecules while the shorter gliadin forms bridges between the strands of glutenin, resulting in a network of strands called gluten. The network of strands, or gluten, is responsible for the softness of the bread because it traps tiny air bubbles as the dough is baked. If the network of strands is more cohesive or tightly linked, the bread will be softer. Gluten development improves if the dough is allowed to rest between mixing and kneading.

The amount of flour is the most significant measurement in a bread recipe. Professional bakers use a system known as Bakers' Percentage in their recipe formulations. They measure ingredients by weight rather than by volume because it is more accurate and consistent, especially for dry ingredients. Flour is always stated as 100%, and the rest of the ingredients are a percent of that amount by weight. For example, common table bread in the U.S. uses approximately 50% water, whereas most artisan bread formulas contain anywhere from 60 to 75% water. The water (or sometimes another liquid like milk or juice) is used to form the flour into a paste or dough.

Yeast is used in baking as a leavening agent. A single-cell microorganism (most commonly *Saccharomyces cerevisiae*), yeast help bread to rise because they convert the fermentable sugars present in the dough into carbon dioxide gas and alcohol. The alcohol, which burns off during baking, contributes to the bread's flavor. The carbon dioxide gas created by yeast causes the dough to expand or rise as the carbon dioxide forms bubbles. The stretchy, balloon-like consistency of the gluten in the bread dough traps the bubbles and keeps the carbon dioxide from escaping. When the dough is baked it "sets" and the bubbles remain, giving the baked product a soft and spongy texture. Most bakers in the

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U.S. leaven their dough with commercially produced baker's yeast, which yields uniform, quick, and reliable results because it is obtained from a pure culture.

Gas-producing chemicals can also be used as a leavening agent. Whereas yeast takes two to three hours to produce its leavening action, a dry chemical leavening agent like baking powder is instantaneous. Many commercial bakeries use chemical additives to speed up mixing time and reduce necessary fermentation time, so that a batch of bread may be mixed and baked in less than 3 hours. "Quick bread" is the name that commercial bakers use for dough that does not require fermentation because of chemical additives. Often these chemicals are added to dough in the form of a prepackaged base, which also contains most or all of the dough's non-flour ingredients. Commercial bakeries also commonly add calcium propionate to retard the growth of molds.

The first commercial sliced bread was sold in 1928, and was marketed as Kleen Maid Sliced Bread. While today, we say "the greatest thing since sliced bread," the sales pitch for the first sliced loaf was "the greatest forward step since bread was wrapped."

While wrapping and slicing may seem like simple advances, the simplicity of bread is indicative of its history – it is one of the oldest prepared foods, dating back to the Neolithic era. The first breads produced were probably cooked versions of a grain-paste, made from ground cereal grains and water by hunter-gather tribes. The discovery of the first bread either occurred through accidental cooking or deliberate experimentation with water and grain flour. Descendants of these early breads are still commonly made from various grains worldwide, including the Middle Eastern *pita*, the Mexican *tortilla*, and the Indian *roti*. The basic flatbreads of this type also formed a staple in the diet of many early civilizations, including the Sumerians who ate a type of barley flat cake and the Egyptians who ate flat bread called *ta* in 12th century BC.

The development of leavened bread can probably be traced to prehistoric times as well. Yeast spores occur everywhere, so any dough left to rest will become naturally leavened. For example, an uncooked dough exposed to air for some time before cooking would probably contain airborne yeasts as well as yeasts that grow on the surface of cereal grains. Thus, the most common source of leavening was early bakers retaining a piece of dough from the previous day to utilize as a form of dough starter. Although leavening is likely of prehistoric origin, the earliest archaeological evidence comes from ancient Egypt. Scientific analysis using electron microscopy has detected yeast cells in some ancient Egyptian loaves.

Bread has been of great historical and contemporary importance in Western and Middle Eastern cultures, and it is commonly used in these cultures as a symbol of basic necessities, such as food and shelter. For example, the word bread is now commonly used in English speaking countries as a synonym for money (as is the case with the word "dough"). The political significance of bread is also considerable. In 19th century Britain, the inflated price of bread due to the Corn Laws caused major political and social divisions, prompting riots. The Assize of Bread and Ale, a 13th century law, showed the importance of bread in medieval times by setting heavy punishments for bakers who short-changed their customers. This led to a common practice of baking thirteen items when a dozen was ordered, so as to avoid being accused of short-changing; this is why, even now, thirteen items is known as a "baker's dozen." Today, bread remains a popular food in many societies, and the variety of breads enjoyed across these societies continues to expand.

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RESPIRATION

Humans breathe in and out anywhere from 15 to 25 times per minute. The main function of the respiratory system is gas exchange between the external environment and the circulatory system. A gas that the body needs to get rid of, carbon dioxide, is exchanged for a gas that the body can use, oxygen. Located within the chest cavity and protected by the rib cage, the lungs are the most critical component of the respiratory system. The lungs are responsible for the oxygenation of the blood and the concomitant removal of carbon dioxide from the circulatory system. The other major function of the lungs is to manage the concentration of hydrogen ions in the blood, an important factor in regulating the acidity of blood (pH), which must be kept in a narrow range. If too much carbon dioxide is retained, the blood's pH becomes too acidic; if too much is being released, the blood's pH becomes too alkaline.

When a person inhales, the diaphragm and intercostal muscles (the muscles between the ribs) contract and expand the chest cavity. This expansion lowers the pressure in the lungs below the outside air pressure. Air then flows in through the airways (from high pressure to low pressure) and inflates the lungs. The lungs are made of spongy, elastic tissue that stretches and constricts during breathing. When a person exhales, the diaphragm and intercostal muscles relax and the chest cavity gets smaller. The decrease in volume of the cavity increases the pressure in the lungs above the outside air pressure. Air from the lungs (high pressure) then flows out of the airways to the outside air (low pressure). The cycle then repeats with each breath.

The respiratory system has many components. Air enters the body through the nose or mouth and goes past the epiglottis into the trachea, a rigid tube that connects the mouth with the bronchi. The epiglottis is a flap of tissue that closes over the trachea when a person swallows so that food and liquid do not enter the airway. The air continues down the trachea until it reaches the bronchi. From the bronchi, air passes into each lung and spreads out by following narrower and narrower bronchioles. The bronchioles are the numerous small tubes that branch from each bronchus into the lungs and get progressively smaller until they each end in an alveolus. Alveoli are tiny, thin-walled air sacs at the end of the bronchiole branches where gas exchange occurs. The total surface area of the alveoli in one set of lungs is approximately the size of a tennis court.

Within the alveoli, gas exchange occurs through diffusion. Diffusion is the movement of particles from a region of high concentration to a region of low concentration. The oxygen concentration is high in the alveoli, so oxygen diffuses across the alveolar membrane into the pulmonary capillaries, which are small blood vessels that surround each alveolus. The hemoglobin in the red blood cells passing through the pulmonary capillaries has carbon dioxide bound to it and very little oxygen. The oxygen binds to hemoglobin and the carbon dioxide is released. Since the concentration of carbon dioxide is high in the pulmonary capillaries relative to the alveolus, carbon dioxide diffuses across the alveolar membrane in the opposite direction. The exchange of gases across the alveolar membrane occurs rapidly – usually in fractions of a second.

Humans do not have to think about breathing because the body's autonomic nervous system controls it. The respiratory centers that control the rate of breathing are located in the pons and medulla oblongata, which are both part of the brainstem. The

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neurons that live within these centers automatically send signals to the diaphragm and intercostal muscles to contract and relax at regular intervals. Neurons in the cerebral cortex can also voluntarily influence the activity of the respiratory centers. A region within the cerebral cortex, called motor cortex, controls all voluntary motor functions, including telling the respiratory center to speed up, slow down, or even stop. However, the influence of the nerve centers that control voluntary movements can be overridden by the autonomic nervous system.

Several factors can trigger such an override by the autonomic nervous system. One of these factors is the concentration of oxygen in the blood. Specialized nerve cells within the aorta and carotid arteries called peripheral chemoreceptors monitor the oxygen concentration of the blood. If the oxygen concentration decreases, the chemoreceptors signal to the respiratory centers in the brain to increase the rate and depth of breathing. These peripheral chemoreceptors also monitor the carbon dioxide concentration in the blood. Another factor is chemical irritants. Nerve cells in the airways can sense the presence of unwanted substances like pollen, dust, water, or cigarette smoke. If chemical irritants are detected, these cells signal the respiratory centers to contract the respiratory muscles, and the coughing that results expels the irritant from the lungs.

Disorders of the respiratory system fall mainly into two classes. Some disorders make breathing harder, while other disorders damage the lungs' ability to exchange carbon dioxide for oxygen. Asthma is an example of a disease that influences the mechanics of breathing. During an asthma attack, the bronchioles constrict, narrowing the airways. This reduces the flow of air and makes the respiratory muscles work harder. In contrast, pulmonary edema is an example of a disease that minimizes or prevents gas exchange. Pulmonary edema occurs when fluid builds up in the area between the alveolus and pulmonary capillary, increasing the distance over which gases must exchange and slowing down the exchange. Various medical interventions are used treat disorders of the respiratory system, but coughing is the body’s main method of defense.

The respiratory systems of other animals differ from that of humans in varying degrees. Most other mammals have a similar respiratory system, but often have subtle differences. For example, horses do not have the option of breathing through their mouths and must take in air through their nose. The respiratory system of birds, which contains unique anatomical features such as air sacs, differs significantly from that found in mammals. Reptiles have a much simpler lung structure than mammals as they lack the extensive airway tree structure found in mammalian lungs. In amphibians, the skin is an important respiratory organ – it is highly vascularized and secretes mucus from specialized cells to facilitate rapid gas exchange. Overall, respiratory systems differ substantially across the animal kingdom.