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Pavlov: Vivisectionist of the Mind

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ABSTRACT

Ivan Pavlov (1849-1936) experimentally demonstrated a conditioned reflex mediated in the brain, conditioned in the sense that it was learned and unconscious. This discovery was the unintended result of his medical research program directed at gastric functions. The discovery of the reflex, and the associated experimental methods, constitute a paradigm that had a major influence of experimental psychology during the 20th century. The history of Pavlov's discoveries takes place at a complex intersection of scientific progress, at the confluence of biological science and the unintended consequences that some discoveries had on traditional cultural beliefs. The role that physiology plays in Pavlov's story points to the age old and on going problem of the relationship between the mind and body. Pavlov's discovery unintentionally threatened the traditional understanding of the mind-body relationship, specifically the beliefs about free will and unconscious motivation. Pavlov's discovery fostered continuous research for over one hundred years to date. In the 21st century Pavlov's methods may again prove useful for the emerging science of neurogastroenterology.

Pavlov: viviseccionista de la mente

Palabras clave
Pavlov,
reflejo condicionado,
localización cerebral,
relación mente cuerpo,
neurogastroenterología

RESUMEN

Ivan Pavlov (1849-1936) demostró experimentalmente un reflejo condicionado mediado en el cerebro, condicionado en el sentido de que fue aprendido e inconsciente. Este descubrimiento fue el resultado no deseado de su programa de investigación médica dirigido a las funciones gástricas. El descubrimiento del reflejo, y los métodos experimentales asociados, constituyen un paradigma que tuvo una gran influencia en la psicología experimental durante el siglo XX. La historia de los descubrimientos de Pavlov tiene lugar en una intersección compleja del progreso científico, en la confluencia de la ciencia biológica y las consecuencias no deseadas que tuvieron algunos descubrimientos en las creencias culturales tradicionales. El papel que juega la fisiología en la historia de Pavlov apunta al antiguo y continuo problema de la relación entre la mente y el cuerpo. El descubrimiento de Pavlov amenazó involuntariamente la comprensión tradicional de la relación mente-cuerpo, específicamente las creencias sobre el libre albedrío y la motivación inconsciente. El descubrimiento de Pavlov fomentó la investigación continua durante más de cien años hasta la fecha. En el siglo XXI, los métodos de Pavlov pueden volver a resultar útiles para la ciencia emergente de la neurogastroenterología.

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Introduction

After years of investigating the physiology of digestion, Ivan Pavlov (1849-1936) discovered a way to research cerebral brain functions. He announced his discovery in April 1903 at the 14th International Congress of Physiologists in Madrid. The importance of Pavlov's discovery cannot be overstated: By providing a method for experimenting on a normal functioning brain, Pavlov made mind an observable object suitable for experimentation. This accomplishment was a major advance over then current methods of cerebral research, which were by and large based on inferences derived from a variety of disciplines, of these disciplines, physiology held a privileged position.

Pavlov himself was trained as a physiologist, as were other pioneering psychologists; namely, William James and Wilhelm Wundt. This connection between physiology and psychology suggests the two aspects of the age-old and on-going problem of mind-body relationship.

In Edwin Boring's (1886-1968) account of psychology's origins, Germany was the first among the European nations to recognize physiology as a science. He attributed this to German scientific phenomenalism, which he defined as the approach to science that emphasized description, classification, and inductive methods (Boring, 1957, p. 18). In 1850 the German physicist Hermann Von Helmholtz (1821-1894) calculated the speed of the human nervous impulse. Boring believed that this did more to demonstrate that the mind could be an experimental subject than any previous research. Pavlov's discovery of the conditioned reflex continues in this on-going process of making the mind an experimental subject.

The discovery of the conditioned reflex takes place in the emerging biological sciences, specifically in the physiology of the neurology of vital organs. Neurology was a prime example scientific progress: Where progress depends upon previous discoveries, and where diverse fields of research areas cross-over and influence each other. It is an example of where "The fundamental concepts which make up the particular Zeitgeist… change under the pressure of new discovery…" (Boring, 1957, p. 41-44). In these historical dynamics, Pavlov's discovery of the conditioned reflex takes place at an astonishingly complex intersection at the confluence of biological science and mental processes.

Reflex, as used in physiology, dates from 1736. Reflex was a metaphor, it came from the common experience of a mirror's reflection. In physiology reflex denoted the neural function that meditates between sensations received from the environment and the corresponding movements in muscles and in the vital organs. Understanding this function is critical to understanding the control and organization of vital processes necessary for an organism's survival. In 1751 Robert Whytt demonstrated experimentally that stimulation was mediated in the spinal cord of a decapitated frog. This had the unintended consequences of implications for current beliefs about human nature in terms of the mind-body problem. The reflexive movement in the frogs obviously resulted from unconscious material causes. As discoveries by physiologists began to contradict the traditional belief that coordinated purposeful activity was the result of consciousness, a revolution in the understanding of human nature followed. Pavlov played an important role in this history. Pavlov's biographer, Daniel Todes (1952 - present), believed that Pavlov unknowingly followed his experiments in the nervous control of digestion into psychology (Todes, 2002, p. 222), and through his biographies of Pavlov, he presented convincing evidence to support this.

Pavlov's Experiments

The discovery of the conditioned reflex is a story of experiments. For this brief account, the relevant experiments span approximately 1888 to 1901. The story begins when Pavlov was 40 years old, experiencing pathological symptoms of depression, and desperately hoping to find a job as a professor of physiology while suffering employment as a poorly paid supervisor for Phd dissertations in a small obsolete under-equipped laboratory at the Military Medical Surgical Academy in St. Petersburg, Russia (Todes, 2014, p. 103-105). This history of the conditioned reflex begins with an article on digestion found in the *Textbook of Physiology* (1883). In his article, a leading European authority on digestion, Rudolf Heidenhain (1834-1897), claimed that the central nervous system had no effect on gastric secretion. In his experiments, Heidenhain cut the nerves that connected the stomach to the brain, and he found that the stomach secreted gastric acids when it contained food, and the secretion appeared only after food reached the stomach. Heidenhain denied the central nervous system control of gastric secretion, but he acknowledged anecdotal reports that secretion occurred upon the mere sight of food, and he said that, if confirmed, then his opinion would have to be revised (Todes, 2014, p. 154). Contrary to Heidenhain's authority and current consensus, Pavlov was convinced that vital gastric functions were controlled by the central nervous system (Todes, 2014, p. 106-107; 2000, p. 39).

The stomach seems like an unlikely beginning to Pavlov's discovery. The explanation lies in the context of the 1890s imperial Europe and in Pavlov's role as a physiologist at a medical school in St. Petersburg. Consider that Pavlov's research program began before refrigeration, before modern hygiene, before modern sanitation practices, and before regulated food supplies and modern supplements. Writing about nineteenth century British medicine, Miller said that the rapid urbanization due to industrialization came with economic depression and widespread poverty. Under these circumstances, a gastric epidemic affected all levels of society, and stomach diseases formed a staple of the doctor's practice. At the same time, with new technologies came research possibilities; for example, after the discovery of anesthesia and antiseptics surgeons could safely open the abdominal cavity (Miller, 2018). St. Petersburg was known as Europe's deadliest city. Social reforms in Russia brought peasants to cities, and the resulting urbanization was accompanied with dysentery, tuberculosis, and typhus. Under these desperate circumstances, Russia was forced to modernize its medical institutions (Todes, 2014, p. 22).

Today Pavlov's approach to gastric research is called neurogastroenterology. Briefly, digestion occurs along a series of organs from mouth to anus forming a tube approximately 900 centimeters long. Digestion results from complex interactions between organs that are precisely controlled by nerves. In Pavlov's day, little was known about the process of digestion. Robert Whytt (1714-1766)

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observed that the gut had a large number of nerve endings (Miller, 2018, p. 3). In the 1860s, Leopold Auerbach (1828-1897) discovered a network of nerve cells between the layers of muscles that encircled the gut. Today this network is known as the enteric nervous system, or the second brain (Gershone, 1999).

In 1889 and 1890 Pavlov published two experiments coauthored with E. O. Shumova-Simanovskaia (1852-1905): "The Secretory Nerve of the Gastric Glands of the Dog" (1889) and "The Innervation of the Gastric Glands of the Dog" (1890), (Todes, 2002, p. 57). They are important because they are arguably Pavlov's first steps towards the experiment that would define the conditioned reflex (Todes, 2014, p. 107). The experiments Pavlov used to discover the conditioned reflex, he invented, and the history of experiments is a substantive part of Pavlov's story.

The essay, "The Nature and History of Experimental Control" (Boring, 1963) is relevant for explaining the discovery of the conditioned reflex. In this short history, experimental control had three meanings: (1) keeping conditions constant, (2) varying the independent variable in a specified way, and most importantly (3) experimental control was comparison, because comparison demonstrated difference. The *New English Dictionary* of 1893 defined experimental control as, "…a standard of comparison used to check the inferences deduced from an experiment by application of the Method of Difference" (Boring, 1963, p.111-112).

The method of difference was John Stuart Mill's (1806-1873) idea. Proof of cause was justified by the method of difference, where event A was followed by B, while at the same time a comparison demonstrated that not-A was followed by not-B. Similar to the method of difference for providing an experimental comparison was the method of concomitant variations, when in a sequence of events one event provided a comparison for the next.

The three fold principle of experimental control with its emphasis on the need for comparison is important for understanding Pavlov's discovery, but it is also important to acknowledge that it applies to ideal circumstances. Physiologists imitated physicists, and physics was a reductive approach to nature. It reduced a phenomenon into its components, elements, and then investigated the elements for cause and effect relationships. Physiology tried to explain complex biological systems likewise, but vital functions are ephemeral, and gastric research involved astoundingly complex organ processes. For Pavlov and his contemporaries, controlling for the intervening and confounding factors often presented intractable problems. As Todes noted, given the state of biological science in the 1890s it was not surprising that Pavlov's experiments often ended with ambiguous results that suggested multiple interpretations (Todes, 2000, p. 56-58).

Pavlov's Development as a Physiologist

Pavlov's approach to experimental physiology can be attributed to identifiable influences. In 1870 Pavlov entered the University of St. Petersburg, where Ilya Fadeevich Tsion (1842-1912) mentored Pavlov in physiology. Tsion instructed Pavlov for two years (Todes, 2002, p. 28). As for Tsion's qualifications: In France, Tsion worked with the famous Claude Bernard (1813-1878), and in Germany, with the equally famous Carl Ludwig (1816-1895). With Bernard, Tsion investigated the nervous regulation of vital functions. With Ludwig, Tsion contributed to the discovery of the vasomotor depressor nerve, for which he received an award from French Academy of Sciences. Tsion also contributed to the development of Ludwig's isolated heart. As described by Pavlov's biographer, Tsion was the "very model of a modern experimental physiologist" (Todes, 2000, p. 28-29; 2002 p. 50).

Beginning in 1872, Pavlov attended Tsion's lectures during the day and spent his evenings in Tsion's laboratory at the Military Medical-Surgical Academy (Todes, 2000, p. 31). Tsion's instruction emphasized the organs that performed vital functions: circulation, digestion, emotions, and thinking. By this time, vivisection had changed from a means for observation, and Pavlov learned vivisection as a method for experimentation (Todes, 2002, p. 51).

In January of 1873, Tsion delivered a commencement speech that provides insight into Pavlov's theoretical approach to physiology (Todes, 2014, p. 53). In his "The Heart and the Brain" speech, Tsion highlighted the recent discoveries of physiology and responded to fears that these discoveries were threatening society by contributing to an immoral mechanistic philosophy of human nature (Todes, 2014, p. 54).

The underlying meaning of Tsion's speech is important for understanding Pavlov's influence on 20th century cultural-political history. Tsion forced his audience to consider revolutionary implications attributed to physiological discoveries. At that time, the consensus of human nature was predominately Cartesian. Descartes was compelled by religious considerations to keep soul and body separate. The body could safely be subjected to scientific analysis while the mind was safe from materialistic science. In several European languages, the word for mind was synonymous with the soul, which was immortal and belonged to religious authorities. In the 19th century, discoveries in physiology forced a reconsidering of the mind-body relationship as interactive and inter-dependent. While the authorities found it necessary to encourage the development of medical science, they discouraged the materialist interpretations of human nature. In tsarist's Russia, people were tied by God to the Russian church and the moral social order (Todes, 2014, p. 22).

In his speech, Tsion said that physiology confirmed the poet's view that there was a relationship between the heart and the emotions. He said that the heart was an organ of emotions because it was influenced by love, jealousy, fear, grief, joy, and anger. Each emotion produced a distinctive heartbeat that could be graphed by the sphygmograph or cardiograph (Todes, 2014, p. 54). With reference to organs, emotional states, and involuntary processes, Tsion spoke to the complex relationship between mind and body. At the same time, Tsion equivocated when he reassured his audience of the remote possibility of their fears that physiology was a threat to the social order by introducing material science into matters of the immortal soul, "Perhaps in the distant future physiologists might discover the mechanics of cerebral processes" (Todes, IP 2014, p. 55). In fact, that day was closer than Tsion imagined, it came in 1901 with the discovery of the conditioned reflex. Was Pavlov in the audience?

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Medical School

In 1874 and 1875 Pavlov presented his student research on the nervous regulation of the heart and the pancreatic gland (Todes 2002, p. 53), and in 1875 Pavlov received the undergraduate degree of Candidate of Natural Sciences. To pursue physiology, Pavlov needed a degree in medicine, and he enrolled in the Academy of Medical Surgery in St. Petersburg. As a student, Pavlov became a fellow of the academy and the acting director of Botkin's (1832-1889) physiological laboratory. In 1883, Pavlov completed his dissertation, "The Afferent Nerves of the Heart," in which he demonstrated the reflex regulation of the circulatory organs. MLA style: Ivan Pavlov – Biographical. NobelPrize.org. Nobel Prize Outreach AB 2021. Wed. 3 Nov 2021. https://www.nobelprize.org/prizes/medicine/1904/pavlov/biographical/

Pavlov left Russia for post graduate work. From June of 1884 to May of 1885 Pavlov was in Breslau at Rudolf Heidenhain's (1834-1897) laboratory, and from May 1885 to May of 1886 he was in Leipzig at Karl Ludwig's laboratory. Pavlov investigated the nervous control of the pancreas with Heindenhain. With Ludwig, he investigated the nervous control of the heart (Todes, 2002, p. 58-60; 2014, p. 98-103). Both laboratories worked with animal technologies that isolated organs for experiments. For example, Ludwig removed a heart from a frog and submerged it in a nutrient enriched fluid, where he connected the heart to a circulation system for measuring its functions. Heindenhain surgically divided a dog's stomach, this division formed a pocket that was closed-off from food. It was fitted with a tube that drained gastric secretion for analysis.

From these experiences, Pavlov borrowed and synthesized elements of research style. Influenced by Heidenhain, Pavlov began his research with extensive observation, and only after all the circumstances were thoroughly understood did Pavlov formulate the experiment (Todes, 2002, p. 73 - 74). Influenced by Ludwig, Pavlov emphasized meticulous attention to detail and insistence on quantifiable results (Todes, 2002, p. 72). In these respects, Pavlov practiced the German phenomenalism characterized by inductive methods, description, and classification, but there was an important difference in Pavlov's research. In contrast to German style, English and French science was characterized by a hypothetical-deductive style, and Pavlov was committed to a theory that is best described for current purposes as homeostasis.

Claude Bernard's role in the History of Psychology

When Boring traced the origins of psychology to several physiologists, he noted with a sense of mystery, "… the most famous (physiologist, Claude Bernard (1813-1878)) … (was) the least important in the history of psychology…" (Boring, 1957, p. 17-19). If Boring asked, Where was Bernard's contribution? Today, thanks to Todes scholarship, Bernard is accounted for.

The comprehensive view of physiology that Pavlov received from Tsion was anchored in Bernard's work and theories (Todes, 2014, p.49-50). In Bernard's physiology: "… (the) focus (was) upon the investigation of organs, for here the physiologist grappled with the vital phenomena that distinguished living organisms…" (Tsion, 2014, p. 50). "Bernard insisted, physiological processes … could not be explained reductively as the simple product of (physics and chemistry) …" (Tsion, 2014, p. 50). And, "Like Bernard, Pavlov used the term *purposiveness* to denote the coordinated activity of the organism as a whole …The complexity of organisms continued to exist as a whole only as long as all its constituent parts are subtly and precisely linked, balanced both with each other and with surrounding circumstances. The analysis of this balancing of the system comprises the first task and goal of physiological investigation" (Tsion, 2002, p. 74-75). Todes said that Pavlov's lifelong preoccupation was, "… the quest for and definition of "normalcy" in physiological experiments that inevitably, to one degree or another, distorted the very processes that they were conducted to reveal" (Tsion, 2014, p. 52). Pavlov viewed the organism as a complex, sensitively interconnected, and fully determined machine. "Pavlov sought to investigate the organism's vital properties by studying organs; he was determined to study the intact, relatively normal organism…" (Tsion, 2014, p. 147).

Summary of Pavlov's education

To summarize Pavlov's education: "The result was a Bernardian vision … that incorporated … precision and quantification associated with contemporary German science" (Todes, 2002, p. 43). Pavlov's training emphasized the nervous control of organ processes. The goal was to discover vital processes in the normally functioning subject. Pavlov's ideal experiment was… an intact animal, although modified by surgery, executed with meticulous control, and with quantified results (Todes, 2002, p. 43, 74-75).

The Control of the Gastric Glands

For the current understanding of what follows: Today, the nervous system is divided into two major divisions, the central nervous system and the peripheral. The central nervous system consists of the brain and spinal cord. The peripheral system includes everything else, and it is comprised of three sub-divisions: the sympathetic, the para-sympathetic, and the enteric nervous systems. The central nervous system is in overall control (Gershon, 1999, P. 16). All reflex activity involves the brain or the spinal cord, with one exception, digestion (Gershon, 1999, p. 5).

As previously stated, in 1889-1890 Pavlov published two experiments coauthored with E. O. Shumova-Simanovskaia (1852-1905): "The Secretory Nerve of the Gastric Glands of the Dog" (1889) and "The Innervation of the Gastric Glands of the Dog" (1890), (Todes, 2002, p. 57). These experiments were designed to prove the central nervous system's role in gastric secretion (Todes, 2002, p. 126; 2014, p. 107). In these experiments, Pavlov surgically implanted fistulas and esophagotomized the dogs (Todes, 2002, p. 126). The fistula, a tube, was surgically attached to the stomach to drain gastric secretion for analysis. The esophagotomy surgically divided the dog's throat in order to separate the mouth from the stomach. This permitted the dog to chew food and swallow, but the food fell out through a hole in the throat before it could enter the stomach. Pavlov called this "sham-

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feeding" (Todes, 2002, p. 95). Surgically altered, Pavlov's dog became a living laboratory technology; it was a dog surgically modified to investigate organ functions, but it was alive and otherwise functioning normally (Todes, 2002, p. 95).

In these experiments, after he sham-fed the dogs, Pavlov teased them with the sight of meat. After that, he cut the right branch of the vagus nerve. The dogs were again sham-fed and teased. This sequence was repeated after the remaining branch of the vagus nerve was cut. In twenty experiments with seven dogs, Pavlov was able to demonstrate gastric secretion present in the stomach without direct stimulation of the stomach lining. However, teasing the dogs with the sight of meat failed to produce convincing results. At this point in the history of the conditioned reflex, Pavlov's first interpretation of the gastric secretion was, it was caused by a "reflex from the surface of the mouth" (Todes, 2002, p. 127).

Following these experiments, in 1890 Pavlov supervised a dissertation searching for a reflex from the mouth, the results ruled out the sensations of taste, chewing, and swallowing (Todes, 2002, p. 128-129). Pavlov then supervised another dissertation that succeeded in satisfying Heidenhain's demand for proof of secretion by the sight of food alone. Six dogs were deprived of food for 18 to 20 hours and then teased with meat. The results were conclusive (Todes, 2002, p. 129-130). With evidence of the brain's mediation in digestion, Pavlov revised his interpretation of gastric control. The gastric secretion that was caused by the sight of food was named a psychic secretion. And by psychic secretion, Pavlov meant the gastric secretion was attributed to the animal's mental processes stimulated by a clear representation of food (Todes, 2002, p. 143). This was the nascent beginning of Pavlov's psychological interpretation. The definition changed as Pavlov's experimental method developed and his understanding of mental processes evolved.

The phrase "mental processes" deserves comment: In the 19th century, consensus held that the mind was in the brain, and mind was conscious. Boring said, "Psychology - even the new "physiological psychology" - was essentially the study of consciousness… Physiology came in because … "no psychosis without neurosis" (Huxley, 1874)…" The neurological foundation justified the use of scientific instruments, and the experiment controlled stimuli and recorded the effects of neural processes to study the mind through consciousness (Boring, 1961, p. 212-213). Pavlov's evolving interpretation the psychic secretion suggests it is reasonable to believe that he started out believing the mental processes influencing digestive functions were conscious. However, at this point Pavlov turned away from the psychic secretion to focus his investigation on the stimulation of the gastric gland.

Pavlov's attempts to isolate the stomach from the mind

As things stood in 1893, Pavlov's psychic secretion was the first phase of digestion followed by Heidenhain's reflex mechanism. Pavlov turned to the stomach, which was a proper object for physiology. It remained to be seen if different foods stimulated secretion of different ratios of acid to pepsin (Todes, 2002, p. 138). Ironically, after demonstrating the psychic secretion, the job of isolating the stomach from the mental processes would prove difficult, if not impossible. The psychic secretion became a ghost haunting Pavlov's experiments (Todes, 2000, p. 65).

Pavlov's next experiment was developed during the fall of 1893 through spring of 1894. Influenced by Heidenhain's isolated stomach, Pavlov surgically divided the dog's stomach and made a pocket that was closed off from food, but unlike Heidenhain, Pavlov retained the vagus nerve connection with the brain. When the dog ate, food reached the functioning stomach, acid and pepsin were secreted; Pavlov's empty pocket secreted an equivalent mixture, and a tube drained the uncontaminated sample for analysis. On April 2nd, 1894 a dog survived surgery, by April 9 its appetite was normal, on April 13 it was walking. April 14th, the dog began five months of experiments (Todes, 2002, p. 133-134).

Throughout April and May of 1894 Pavlov evaluated his isolated stomach. It reliably produced a psychic-secretion, and, as a bonus, Pavlov discovered that the amount of secretion and its strength varied independently of one another. This was evidence of a specialized nervous system capable of deferentially processing foods (Todes, 2002, p.137). But, although the isolated stomach sample was uncontaminated by food, with the nerves connected to the brain, Pavlov could not rule out the possibility of a psychic secretion contaminating the gastric gland secretion. In June of 1894, Pavlov made changes to eliminate the threat of confounding interactions (Todes, 2002, p. 142). Pavlov inserted food directly into the dog's stomach through a long tube down its throat (Todes, 2002, p. 138). Although Pavlov's feeding tube eliminated chewing and swallowing, a few drops of food always fell on the dog's tongue, and this potentially confounded the results (Todes, 2002, p. 141-142).

There were problems in the teasing manipulation. If a dog became aware that it was being teased, it would become recalcitrant. Pavlov resorted to deception. Food was carried into the experiment and prepared extremely slowly in front of the dog to the point of torturing the dog with anticipation.

In June of 1894, Pavlov was once again confronted with the puzzling connection between the brain and digestion (Todes, 2002, p. 142), and in the fall of 1894, he surgically fitted the normal stomach with a feeding tube. From February 1895 through October 1896, Pavlov attempted to block the dog's thoughts of food by injecting food directly into the stomach. If the dog noticed it was being fed, Pavlov could not rule out a psychic-secretion contaminating the results. Pavlov's solution was wait for the dog to go to sleep, then he quickly injected food directly into the stomach with a plunger. With these extreme efforts to control for a brain-stomach interaction (Todes, 2002, p. 145-147), Pavlov graphed the relative strengths and combinations of gastric secretions for various foods and substances.

Some results were unexplainable. For example, when Pavlov compared drinking milk with injected milk, he found the gastric secretions chemically equivalent. Todes noted that these results suggested that food in the gut might have stimulated the brain. Pointing to biasing factors that the individual researcher's psychology plays in scientific progress, Todes said: "… perhaps the (dog's) psyche could be excited by processes in the stomach itself. This suggestion, which might have undermined basic elements of the laboratory view and laboratory methodology, … was not pursued further" (Todes, 2002, p. 148).

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In fact, today, one hundred years on, the relationship between the stomach and the brain is known as the Gut-Brain Axis. Thoughts and emotions can disrupt the digestive process, and diseased digestion can cause psychopathology. The enteric nervous system that is embedded in the gut is also known as 'the second brain' (Gershon, 1999). Pavlov could not have known this, and his commitment to maintaining normal nervous functions negated any possibility of isolating the independent gastric nervous system from the brain. What Todes's scholarship does affirm is this: In the context of the history of the gut-brain research, Pavlov has so far been overlooked as one of the pioneers of neurogastroenterology.

A Summary of Pavlov's Gastric Research

In 1897, Pavlov published the *Lectures on the Work of the Main Digestive Glands* (Todes, 2000, p. 63; 2002, p. 211-212, 206). In his synthesis, Pavlov analyzed digestion in terms of the coordinated nervous control of the animal machine adapting to its environment. Pavlov's work stands as evidence of his commitment to discover physiological laws with normally functioning animals and with methods that are precise and quantified. Pavlov also acknowledged the important mental role in digestion. As evidence of this work's significance, in 1904 Pavlov was awarded the Nobel Prize for Physiology or Medicine (Todes, 2000, p. 65).

The Discovery of the Conditioned Reflex

During the 1890s, while the stomach dominated his attention, Pavlov simultaneously proceeded to investigate the salivary glands. Saliva moistens dry foods, it coats food with mucus to facilitate the passage down the esophagus, it begins the digestion of some foods, and watery saliva cleans the mouth of debris (Todes, 2002, p. 218). Although saliva was the beginning of digestion, as Todes observed and noted, Pavlov gave little attention to the salivary glands in his "Lectures." Todes suggested that given Pavlov's focus on the nervous control of digestive glands, this omission raises questions.

In 1893 Pavlov began preparations to investigate the salivary glands by developing fistulas to collect saliva from the parotid, the submaxillary, and sublingual mucus glands (Todes, 2002, p. 219). The first experiments evaluated the reliability of the fistulas and tested the chemical composition of saliva. Pavlov compared the saliva from both feeding and teasing experiments. The chemical composition was the same. The results were a break in the normal pattern. Salivation did not conform to the two phase model for the gastric functions, where secretion came in two phases, the psychic secretion followed by stimulation of the mucus membrane where the precise secretion for specific foods occurred (Todes, 2002, p. 220-222).

Unknown to Pavlov, the enteric second brain ingrained in the stomach that controls digestion, extends only partway up the esophagus. Salivation is a function of mediation in the brain. Pavlov's interpretation was characteristically bold, and in this instance lucky. He was basically correct when, in his presentation to the Society of Russian Physicians in Oct. 1897, Pavlov attributed the precise adjustment of salivary responses to the mind. From the beginning of his digestive research Pavlov treated the mind with vague abstractions. He attributed the psychic-secretion to appetite. Now, Pavlov added judgment and the ability to generalize to his interpretation (Todes, 2002, p. 221). At this point in the story, Pavlov re-defined the psychic-secretion as "…the recognition of objects with a corresponding salivary reaction that resulted from a previously established association." Pavlov believed that when the phrase the 'mind of glads' was applied to salivation, it must be taken literally (Todes, 2002, p. 222).

The Mind of Glands

When Pavlov interpreted salivation as a psychological phenomena, there was no way forward for a physiologist (Todes, 2002, p. 228). Today, a clinical psychologist would have predicted that Pavlov was struggling with conflicts. On one hand, Pavlov was motivated to fulfill his duties as director of a laboratory. He had to have a research program. The best predictor of future behavior is past behavior, or the psychoanalytic position, which is when people are presented with frustrating circumstances they often regress to previously acquired habits. You could reasonably expect to see Pavlov follow current research trends and surgically isolate the salivary glands by cutting nerves; or, he could remove the glands to an organ bath. On the other hand, Pavlov was committed to experiments with normally functioning animals, inclusive of the psychic ghost haunting the processes (Todes, 2000, p. 65). Putting speculations aside, Pavlov's decision will remain a mystery, his solution was unprecedented. In 1900 Pavlov went outside his expertise and discipline, and he enlisted the help of assistants who had been trained in mental and nervous illnesses (Todes, 2002, p. 223).

Pavlov recruited a psychiatrist from the Alexander III Charity Home of the Mentally Ill, and Pavlov assigned him to investigate the salivary gland. The psychiatrist was trained by Vladimir Bekhterev (1857-1927) at the Military Medical Academy in St. Petersburg, where Bekhterev had a laboratory and a clinic for mental and nervous illnesses. Following this addition to Pavlov's research staff, his publications included citations from recognized psychologists, e.g. William James, T.A. Ribot, and Wilhelm Wundt (Todes, 2002, p. 222-223).

New Ideas

When seen in hindsight, the experiment that persuasively proved the phenomenon known today as the conditioned response appears astoundingly simple and disarmingly elegant. Pavlov's assistant insisted that the nervous control of digestion was due to a low level process of "Visual Associations" (Todes, 2002, p. 224). This interpretation can be traced to Bekhterev. Pavlov's assistant was a student of Bekhterev's, and Bekhterev believed the psychic-secretion was a reflex. The introduction of Bekhterev expands the Zeitgeist influencing Pavlov. Bekhterev studied with: Flechsig, Wundt, du Bois Reymond, and Charcot, people important in the history of psychology. And I. M. Sechenov (1829-1905) cannot be overlooked as an influence.

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In 1870 the Russian physiologist published *Who Must Investigate the Problems of Psychology and How?* In that book, Sechenov speculated that the psychic life was the product of complex reflexes (Todes, 2014, p. 284).

Students of Bekhterev's learned reflexes because they were useful diagnostics for nervous and mental diseases. Salivation was similar to known reflexes in the following respects: The involuntary knee jerk reflexively occurred when the knee was struck by a doctor's hammer, and it also occurred in diminished form afterwards when the hammer was seen by the patient. The kick by sight alone was not as robust as a hammered response; likewise, the saliva from teasing was not as much as when food was present in the mouth. Significantly, both the knee reflex and salivation by sight obeyed the law of extinction (Todes, 2002, p. 237). Extinction was the key.

Another psychiatrist enlisted by Pavlov was Ivan Tolochinov (1859-1920). Tolochinov believed it was not rational for a physiologist to use psychological terms. He argued that they were still dealing with the stimulation of an organ, and the salivation reflex was best understood as equivalent to muscle physiology (Todes, 2002, p. 236). In this context, saliva was a response to waves of light reflected off objects at a distance and processed through brain functions. Note the evolution of the concept: Beginning with the traditional methods of the physiologist (ablation and stimulation), now the stimulation of receptors occurred from a distance, and the locus of mediation occurred not in the cord but in the brain.

Pavlov's definition of the psychic secretion was questioned. Did Pavlov mean that it was instinctive, or was it conscious, or was it a reflex. Again, Pavlov re-defined the psychic-secretion, it was now "a corresponding salivary reaction as a consequence of the established visual association" (Todes, 2002, p. 224-225). And as a simple reflex over a neural pathway, it was the result of an adaptive function that formed associations (Todes, 2002, p. 226).

The Discovery of the Conditioned Reflex

From the archived records, it looks like Pavlov accidentally stumbled across the conditioned reflex. While much remains unexplained, it is known that in 1902 Pavlov recruited Tolochinov. He was a psychiatrist who had completed a dissertation with Bekhterev on the alterations in nerve fibers of the brain during "paralytic imbecility" (Todes, 2002, p. 232). Pavlov assigned him to study the mental processes of the saliva glands. Tolochinov was credited with the crucial experiment; although, it had to be replicated, and Pavlov made the important interpretations that prepared a way forward for an experimental program.

It is worth pausing here to note that within the context of Pavlov's development as an experimental physiologist, the circumstances now handed Pavlov his perfect experiment. While elsewhere physiology was proceeding by ablation and stimulation, histology, and isolating organs, Pavlov was now presented with an organ that he could experiment on in a normally functioning animal. No invasive surgery was required that might confound the results. And with astounding luck, this experiment by-passed the confounds associated with the enteric nervous system. Pavlov was connected directly to brain processes. The experiment involved known sensations, principally vision, and it also consisted of recognized mental functions, discrimination and memory. After a decade of gastric research, Pavlov had found his ideal experiment, or from another point of view, the experiment found Pavlov prepared to take advantage of the possibilities.

At first, Pavlov's experiments were aimed at establishing consistency, reliability, and measuring saliva. By testing different foods, he was probably looking for the optimal food to encourage saliva flow. These experiments also tested other sensory organs, distance, and time intervals. They were conducted in October and November of 1901. From October 1901 through March 1902, three dogs were used, one was a good subject, one was bad, and one had its frontal lobes removed. Todes speculated that the lobotomy might have been done in response to Bekhterev's localization theory (Todes, 2002, p. 234). It also served as a control in this experiment.

Then, beginning in November of 1901 bread was slowly waved in front of the dog a specific number of times. When the dog was given the bread, the resulting saliva was called an "unconditional reflex." The saliva that flowed when the dog was teased with the bread was called a "conditional reflex."

Todes constructed the following narrative from Pavlov's laboratory records: On February 2nd, Tolochinov terminated his experiments without recording the amount of saliva secreted in the final trial. This omission suggested to Todes that even if Tolochinov previously noticed that repeated teasing brought the saliva flow to zero, it was not considered important. And records going back to 22 December 1901 supported this interpretation. Tolochinov terminated all previous experiments without regard to the amount of secretion in the last trial (Todes, 2002, p. 234) Then, in 10 trials conducted on one dog from February 2 to February 20, the records show that the experiments were intentionally continued until the saliva stopped (Todes, 2002, p. 235).

The crucial experiment began with feeding and recording the saliva. When the association was created, the dog was repeatedly teased until the secretion was reduced to zero. Next, again the association was re-establishing by feeding, and again that was followed by teasing until the saliva stopped. This was recorded beginning February 2, 1902. Consistent with Pavlov's habitual practices, over the next two weeks the experiment was extensively replicated. Tolochinov called the results of teasing until the conditional reflex stopped 'extinction with various irritations at a distance' (Todes, 2002, p. 235) or 'reflex at a distance' (Todes, 2002, p. 33).

Remember experimental control and the necessary requirement for assigning causality? By creating a reflex, then killing it, and then restoring it, a difference was demonstrated. The alternating results served as comparison-controls. Tolochinov's later account indicates that extinction proved to be the turning point and conceptual breakthrough (Todes, 2002, p. 233). In July of 1902 Pavlov introduced the terms 'conditioned reflex' and 'extinction' at the Northern Congress of Physiologists in Helsinki. In April 1903, Pavlov delivered his first public address on conditional reflexes at the 14th International Congress of Physiologists in Madrid.

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Conclusion

This narrative ends when Pavlov's conditioned reflex enters the history of science and before Pavlov begins the next phase of his career for which he is widely known today, classical conditioning. Did Pavlov consider his gastric research for which he was awarded the Noble Prize his best work? In the context of his long career, I doubt it. Although it is debatable, the discovery of the conditioned response may very well be his greatest contribution. For Pavlov, the realization that he had discovered a means to investigate brain functions with non invasive rigorous experimental methods must have made him feel like being the first person to walk on the moon.

What stands out in Pavlov's gastric research that makes it noteworthy? It is worth noting precisely because Pavlov was asking answers from an intractable problem. There was no chance of Pavlov discovering the causal neural control of the gastric gland. The necessary histology, endocrinology, and neurotransmitter science was unavailable. It would be 1980 before Pavlov's questions were beginning to be answered. But, historical cases of research in the face of the impossibly complex issues presents interesting questions: In the face of the overwhelmingly complex nature of interrelated biological systems, where does research begin? Pavlov insisted that he used physiological methods to investigate the activities of the cerebral hemispheres (Pavlov, 1927). Were the results physiology or psychology?

Today, in the pluralistic world of the sciences, it is difficult to summarized one meaning for Pavlov's research and its subsequent influences. In the context of science, perhaps the most general comment is, Pavlov's discovery fostered continuous research for over one hundred years to date. But, any comprehensive summary of Pavlov's influence must include culture and politics. Pavlov's experiments contributed to the emerging materialistic philosophy of human nature, which in turn supported revolutionary ideas, ideas that challenged the traditional understanding of the relationship between mind and body, specifically the problems of Free Will and unconscious motivation. In that respect Pavlov became part of the 20th century political discourse by shaping the opinions of not only scientists but also politicians, clergy, scholars, and the public. Accept him or reject him, it forced those making public policy decisions to hold an opinion of Pavlov. For a transnational description of the role Pavlov played in this cultural debate see (Ruiz & Sanchez, 2020).

In the context of the new psychology, experimental psychology, Pavlov contributed to psychology's stature as a science, and in gratitude psychology claimed Pavlov as one of its pioneers. One example of was comparative psychology. Inspired by evolutionary theory and the problem of adaptation, comparative psychology first chronicled animal intelligence and then began to experimentally demonstrate the learning and adaptation function (Clark, 2019). Pavlov's conditioned reflex provided a biological mechanism that accounted for adaptive survival in a changing environment.

In the 21st century Pavlov's psychology may again prove important for neurogastroenterology. Advances in gastric physiology emphasize the gut-brain axis, the enteric nervous system in the gut that consists of the nerves controlling digestion. "Surveys have shown that over 40 percent of patients who visit internists do so for gastrointestinal problems. Half of those have "functional" complaints, where the gut is malfunctioning, but no one knows why…. (They) are often dismissed as mentally unbalanced,…" (Gershon, 1999, p.. xiv). The causal connection between digestion and mental health is now recognized. Once again digestion seems available for psychological research based on methods introduced by Pavlov.

In closing with a brief comment on the question where the scientist begins in the face of overwhelmingly complex phenomenon, as Pavlov looked back on these events in 1927, he said, "In the course of a detailed investigation into the activities of the digestive glands I had to inquire into the so called psychic secretion of some of the glands… It became clear that the only satisfactory solution of the problem lay in an experimental investigation by strictly objective methods. For this purpose I started to record all the external stimuli falling on the animal at the time its reflex reaction was manifested… at the same time recording all changes in the reaction of this animal" (Pavlov, 1927, p. 6).

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