Exploring Galvani's room for experiments

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On August 17th 1786, one of Luigi Galvani's nephews, Camillo, recorded that:

> The sky being covered with dense and menacing clouds ... I rushed to your house, my beloved uncle, to take part in your physics investigations (*fisiche ricerche*).[1]

Camillo had been one of Galvani's assistants for several years, helping him with his experiments and keeping records of them. During the summer of 1786 Galvani was investigating the effects of atmospheric electricity on muscular motion. August 17th was a suitable day for experiments because of weather conditions, and Camillo "rushed" to his uncle house because that was where most of his experimental activity was carried out. To this end Galvani had set up a laboratory – a "room for experiments", as he called it in his laboratory notebooks. His investigations in this room reflected the wide range of his activities: medical practice, the teaching of human anatomy and later of obstetrics, and the investigation of comparative anatomy and animal economy. These activities involved different kinds of instruments, knowledge and participants, but they all contributed to the characterisation of Galvani's professional activity and to the definition of his experimental investigation. Indeed, we can regard his laboratory as the place where his various activities converged and interacted, and where his investigation of animal electricity took shape.

In this paper I would like to focus on two points: first, to highlight the range of activities which Galvani carried out mainly at home, and which reflect his many-sided professional occupations and scientific interests; and secondly, to discuss Galvani's distinctive approach to the study of animal electricity as it emerged from these closely interwoven activities.

Galvani's laboratory is shown in a drawing made for his *De viribus electricitatis in motu musculari*, the memoir published in 1791 in which Galvani set out his theory of animal electricity (Fig. 1).[2] Some electrical instruments – the electrical machine and the Leyden jar –, are shown there, together with some other experimental apparatus, and animals. This equipment and these facilities were essential to Galvani's investigation of animal electricity, as described in the *De viribus* and in later works.[3] But in the same room, or perhaps in one nearby, there were other things, equally important: a few hundred books – their titles have been discovered only recently – were arranged on shelves along the walls;[4] a collection of surgical instruments was laid on an adjacent table or in a cabinet, ready to be used at any time; a table for anatomical dissection, maybe placed in the centre of the room as in the anatomy theatre of Bologna, was often cluttered with dead animals or even parts of human cadavers.

Galvani's use of his house as a place for teaching and research was not unique.

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[1] Luigi Galvani, *Memorie ed esperimenti inediti* (Bologna, 1937), 392 (my transl.).

[2] Galvani, "De viribus electricitatis in motu musculari commentarius", *De Bononiensi Scientiarum et Artium Instituto atque Academia Commentarii*, VII (1791), 363-418; English tanslation in Galvani, *Commentary on the effects of electricity on muscular motion* (Norwalk, 1953), 42-91.

[3] On Galvani's investigation, see Giuliano Pancaldi, "Luigi Galvani", in Walter Tega, ed., *Storia illustrata di Bologna*, 6 (Milano, 1989), 281-300; John Heilbron, "The contributions of Bologna to Galvanism", *Historical Studies in the Physical Sciences*, 22 (1991), 57-85; Marcello Pera, *La rana ambigua. La controversia sull'elettricità animale tra Galvani e Volta* (Torino, 1986); Marco Bresadola, *Medicina e filosofia naturale in Luigi Galvani* (University of Florence Ph.D. thesis, 1998).

[4] See Bresadola, "La biblioteca di Luigi Galvani", *Annali di storia delle università italiane*, 1 (1997), 167-197.

In Bologna in the second half of the 18th century there were several laboratories located in private homes, both for didactic and investigative purposes.[5] Some of the University lecturers were allowed to give their lectures at home. Moreover, most Bologna men of science carried out their research in private laboratories, instead of using the "chambers" of the Institute of Sciences.[6] In the case of Galvani, the decision to set up a room for experiments depended both on reasons of convenience, and the actual requirements of his research. His professional position gave him a good income, allowing him to buy the instruments and materials he needed. But he often complained that his many and varied occupations did not leave him that much time for experiments and research – hence the need for a laboratory at his complete disposal at all times. In addition, some of his experiments, such as those on the chemical and physical properties of the animal body, needed prolonged periods of observation extending over many days. To do this in any other place except his own home would have been very problematic. Finally, performing experiments at home allowed Galvani to decide when and where to make them public knowledge, which was important, for he was very meticulous, and hesitant over making his findings public.

If the fact that Galvani carried out activities at home was not exceptional, what was quite exceptional was the specific kind of activity he carried out there. In 1775 he had been appointed lecturer of anatomy "with the demonstration of human anatomical parts at home" (*lectura anatomica cum ostensione partium humani corporis – domi*), a prestigious position previously held by Gusmano Galeazzi, one of Galvani's former teachers and also his father-in-law. This was the only practical teaching of anatomy officially recognized by the University, besides the anatomical dissections performed in the city hospitals. Galvani combined this duty with lectures on anatomy using wax models, held at the Institute of Sciences from 1766. He claimed, perhaps with some exaggeration, that his lectures were attended by 40 or 50 medical students, a large number for those times.[7]

Having human cadavers at one's disposal at home was quite uncommon. Apart from teaching purposes, Galvani used them to investigate the structure and the functions of the human body. The knowledge and skills thus gained were very important for several reasons. In the first place, they were basic training for a very demanding task which, like all the University lecturers of anatomy, Galvani was under obligation to perform, i.e. the public anatomy lectures given in the anatomy theatre of Bologna. The successful performance of these lectures not only gave the anatomist great prestige, but was also a powerful means of improving his academic position.[8] Galvani successfully performed these lectures four times – in 1768, 1772, 1780 and 1786 – becoming one of the leading anatomists of the University.

A second, and even more important reason, is that the anatomical dissections of human and animal bodies performed by Galvani in his teaching and research, contributed to the development of his practical skill in the use of anatomical instruments, and to the habit of manipulating the body. These were to become fundamental in his experimental investigation of animal economy – and, ultimately, in

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[5] One of the most famous and active of these laboratories was the one built by Laura Bassi and Giuseppe Veratti in their own home. See Marta Cavazza, "Laura Bassi e il suo gabinetto di fisica sperimentale: realtà e mito", *Nuncius*, 10 (1995), 715-753.

[6] On the "chambers" of the Institute of Sciences of Bologna, see the essays published in *I laboratori storici e i musei dell'Università di Bologna. I luoghi del conoscere* (Milano, 1988).

[7] Carlo Malagola, *Luigi Galvani nell'Università, nell'Istituto e nell'Accademia delle Scienze di Bologna* (Bologna, 1879), 22-23, 36-38.

[8] See Giovanna Ferrari, "Public anatomy lessons and the carnival: the anatomy theatre of Bologna", *Past and Present*, 117 (1987), 50-106.

his investigation of animal electricity.

The anatomical abilities he acquired were further reinforced by his apprenticeship in surgery, which he also practised. He had learned both the theory and practice of surgery by attending the lectures of Giovanni Antonio Galli at the University and at the "Santa Maria della Morte" hospital. After graduating in medicine and philosophy in 1759, Galvani had become Galli's assistant as surgeon-in-chief in "Sant'Orsola", another Bologna hospital, and stood in for him during his frequent absences. Most of the patients admitted to this hospital needed surgical treatment: those who suffered from "fistula, cancer, gangrene, and ulcer", and were rejected by other hospitals, went to Sant'Orsola.[9] Moreover, in 1763 Galvani obtained his first "honorary" (unpaid) position in the University of Bologna as assistant to Gaetano Tacconi, lecturer in surgery.[10]

It was during the three years he worked with Tacconi, and the long periods spent at S. Orsola, that Galvani had the chance to perfect his knowledge of the body and improve his surgical and practical skills, especially his great ability with lancets and scissors, necessary not only in the treatment of people and in the dissection of bodies, but also in experiments with animals. Surgery also helped him to become familiar with the manipulation of a living body, and stimulated him to intervene actively on the organism of experimental animals. According to some historians, such aspects of surgery played a fundamental role in the birth of modern experimental physiology at the beginning of 19th century. If we reflect on Galvani's achievements, we could perhaps usefully apply a similar perspective to a previous period, which led to modern life sciences.[11]

Galvani's anatomical skills and his readiness to intervene experimentally on the body are quite evident in his early investigations into animal anatomy. In the 1760s he carried out a series of research in the house of Gusmano Galeazzi, where he lived with his wife Lucia, Galeazzi's daughter, after their marriage in 1762. He studied the kidney and the hearing of birds and quadrupeds, and he observed with the microscope some structures never detected before. He also experimented with living animals to modify their physiological conditions, and thus improve the means to investigate the structure of animal organs.[12]

In these investigations Galvani adopted a morphophysiological approach, one that combined an understanding of the structure of the body with an explanation of its functions. Indeed, for Galvani the study of anatomy and the investigation of animal economy were strictly interconnected. At the beginning of his public anatomy lectures in 1786 he claimed:

> Those who have occupied this chair and have dealt with the human body, have shown great wisdom when they studied and examined it not only as a cadaver, as it lies on that table covered with lugubrious sheets, but as an active, standing, in one word living being. Indeed, here anatomy is taught not only in order to instruct the students in the mere knowledge of the parts of a human cadaver. Rather, we believe that, on the basis of the knowledge of these parts, their position, texture and structure, students may attain a better understanding and awareness of the parts in a living man, so that they can be more

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[9] *Regole da tenersi dalli signori medici ed assistente chirurgo per l'introduzione o esclusione degli infermi dello Spedale di S. Orsola* (Bologna, 1755).

[10] See Umberto Dallari, *I Rotuli dei lettori legisti e artisti dello Studio bolognese dal 1385 al 1799*, 3, pt. 2 (Bologna, 1919). For a biographical sketch of Galvani, see "Galvani, Luigi", *Dictionary of Scientific Biography, 5*, 267-269; Bresadola, "Medicine and science in the life of Luigi Galvani (1737-1798)", *Brain Research Bulletin*, 46 (1998), 367-380.

[11] See John E. Lesch, *Science and medicine in France. The emergence of experimental physiology, 1790-1855* (Cambridge, 1984), 5-6, chapters I and II.

[12] Galvani, "De renibus, atque ureteribus volatilium", *De Bononiens Scientiarum et Artium Instituto atque Academia Commentarii*, V (1767), 500-508.

> effective in curing men's sufferings and finding a remedy to them.[13]

Galvani's idea that anatomy was both at the basis of, and directed to, the knowledge of the living being, derived from the teaching of his professors at the University, Galeazzi and Iacopo Bartolomeo Beccari. It was rooted in Marcello Malpighi's notion of "rational medicine", a notion which Malpighi developed in the controversy with Gerolamo Sbaraglia and the supporters of "empirical medicine".[14]

This view of medicine involved a strong belief in the role played by anatomical and physiological investigations in medical practice. Galvani shared this conviction when he stressed, in the passage just quoted, their usefulness to "cure men's sufferings and find a remedy to them". He was a practising physician, in the hospitals and as a private practitioner, and the problem of disease and health was at the core of his entire professional activity and research. This is quite evident also in his investigation of muscular motion and animal electricity. At the beginning of the *De viribus* he claimed:

> I wish to bring to a degree of usefulness those facts which came to be revealed about nerves and muscles through many experiments involving considerable endeavour, whereby their hidden properties may possibly be revealed and we may be able to treat their ailments with more safety.[15]

Galvani's research on animal and human bodies, carried out mainly at home, was thus aimed at a deeper understanding of their structure and functions and at the improvement of the art of healing. These two aspects, his medical interest and his more general interests in natural philosophy and in animal economy, were closely interwoven.

The roots of Galvani's investigation into animal electricity

It was Galvani's concern with medicine and the problem of health that fashioned his interest in two fields of natural philosophy, which were to remain important throughout his scientific activity. These were the investigation of electrical phenomena, and the discovery of new "airs" and their properties. In 1782 Galvani claimed:

> I cannot avoid mentioning those famous discoveries made in our times, that of electricity and of fixed air and phlogiston. For besides the many, noble and useful truths that they have taught us, these discoveries have proved very useful in the science of medicine.[16]

Phlogiston – Galvani continued – was fundamental in the explanation of vital processes like respiration, and of the properties of blood, while the discovery of fixed air opened up new paths in the study of medicinal waters and in therapeutics. During the 1780s Galvani himself explored these problems and carried out in his room for experiments a physico-chemical investigation into the airs contained in the animal body. This was particularly important for the development of his theory of animal electricity, and is discussed more thoroughly in Frederic Holmes and Raffaella Seligardi's contributions to this volume.[17]

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[13] Galvani, *Lectio prima, anno domini 1786, die 20 Januarii*, s. 3 (my trans.). Accademia delle Scienze di Bologna (AASB), Fondo Galvani, cart. IV, plico I, fasc. 3.

[14] Marcello Malpighi, "Risposta alla lettera intitolata *De recentiorum medicorum studio dissertatio epistolaris ad amicum*", in Id., *Opera posthuma* (Londini, 1697), 99-187. See Howard B. Adelmann, *Marcello Malpighi and the evolution of embriology*, 1 (Ithaca, 1966), 533-587; Cavazza, "The uselessness of anatomy: Mini and Sbaraglia versus Malpighi", in Domenico Bertoloni Meli, ed., *Marcello Malpighi, anatomist and physician* (Firenze, 1997), 129-145.

[15] Galvani, *Commentary* (ref. 2), 45.

[16] Galvani, *Orazione per la laurea del nipote Giovanni Aldini (25 novembre 1782)* (Bologna, 1888), 19 (my transl.).

[17] On pneumatic medicine see also Simon Schaffer, "Measuring virtue: eudiometry, enlightenment and pneumatic medicine", in Andrew Cunningham and Roger French, eds., *The medical enlightenment of*

The other field of natural philosophy examined by Galvani was electricity, in particular medical electricity, and the related investigation into the effects of electricity on the animal body, and its function.[18] Galvani was well acquainted with what was being done in these fields, and aware of what still had to be done. He had studied the theory and practice of electricity during his apprenticeship at the University and at the Institute of Sciences of Bologna. He cultivated his interest in this field through some of the most important and popular books published in the second half of the 18th century.[19] In fact, his private library included many books on electricity, such as the works of Giambattista Beccaria and the *Complete Treatise on Electricity* by Tiberio Cavallo. The main publications on medical electricity, and several works by authors like Giuseppe Gardini and Pierre Bertholon, who elaborated on the role of electricity in animal economy and defended the existence of animal electricity, were also there.[20]

In 1780 Gardini and Bertholon shared a prize on medical electricity awarded by the Academy of Lyon.[21] Their works became important points of reference for those interested in medical and animal electricity. Both Gardini and Bertholon claimed the existence of an electricity proper to animal and human bodies, and argued for the electrical nature of the nervous fluid, this being the cause of muscle contraction. But these conjectures were in no way developed into an explanatory model of the mechanism of muscular motion. Besides, Gardini and Bertholon did not describe any electrophysiological experiment to support their conjectures, reporting only some scant phenomena and observations, sometimes of uncertain origin and meaning: the effects of lightning on living beings, the contractions of muscle and increased perspiration induced by electrical stimulation, some experiments that seemed to demonstrate a faster growth of "electrified" plants, research on electric fishes, or the electrical manifestations of cat's fur or some people's clothes when rubbed. Moreover, they did not answer the objections to a neuroelectrical explanation of animal motion, put forward by Albrecht von Haller and the supporters of his theory of sensibility and irritability.[22]

In the *De viribus* Galvani quoted Gardini and Bertholon with admiration, and acknowledged Bertholon as the inventor of the term "electricitas animalis".[23]

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the eighteenth century (Cambridge, 1990), 281-318.

[18] On medical electricity see Margareth Rowbottom and Charles Susskind, *Electricity and medicine. History of their interaction* (S. Francisco, 1984), and Paola Bertucci's contribution to the present volume.

[19] See John Heilbron, *Electricity in the 17th and 18th centuries* (Berkeley, 1979).

[20] On animal electricity before Galvani see Hebbel H. Hoff, "Galvani and the pre-galvanian electrophysiologists", *Annals of science*, 1 (1936), 157-172; Naum Kipnis, "Luigi Galvani and the debate on animal electricity", *Annals of science*, 44 (1987), 107-142; Pera, *La rana ambigua* (ref. 3), 58-68.

[21] Francesco Giuseppe Gardini, *De effectis electricitatis in homine dissertatio* (Genuae, 1780); Pierre Bertholon, *De l'électricité du corps humain dans l'état de santé et de maladie* (Paris, 1780).

[22] See Roderick W. Home, "Electricity and the nervous fluid", *Journal of the history of biology*, 3 (1970), 235-251.

[23] Galvani, *Commentary* (ref. 2), 73, 86, 87, 88.

[24] Giuseppe Veratti, *Osservazioni fisico-mediche intorno alla elettricità* (Bologna, 1748).

[25] On this debate see Cavazza, "La ricezione della teoria dell'irritabilità nell'Accademia delle Scienze di Bologna", *Nuncius*, 12 (1997), 359-377.

[26] Leopoldo Marc'Antonio Caldani, "Sull'insensitività, ed irritabilità di alcune parti degli animali", in Giacinto Bartolomeo Fabri, ed., *Sulla insensitività ed irritabilità halleriana. Opuscoli di vari autori,* 1 (Bologna, 1757), 269-336, on 325, 327-332.

[27] Galvani, *Commentary* (ref. 2), 82 ff.

[28] Veratti, *Sopra l'elettricità riguardo agli animali* (1769 and 1770). AASB, Tit. IV, Sez. I.

[23] Galvani, *Commentary* (ref. 2), 73, 86, 87, 88.

However, it is important to note that these quotations appeared in the fourth part of Galvani's memoir, entitled "conjectures and some conclusions", where he presented his theory of animal electricity and developed its consequences in the field of medical electricity. In the first three parts, where he described his experiments on the effects of electricity on muscular motion, there was no reference to them. It seems thus plausible to conclude that Gardini and Bertholon did not provide the basis for Galvani's experimental investigation. As a matter of fact, Galvani based his particular approach to the study of electricity and muscular motion on his own previous anatomical and physiological research, and followed paths opened up by other investigators.

One of these investigators, and possibly the most influential, was Giuseppe Veratti, a Bologna physician and natural philosopher. Veratti was one of the leading electricians in Bologna and was also deeply involved in the investigation of the effects of electricity on the animal body. In 1748 he had published a book on medical electricity, an early and influential attempt to apply electricity to the treatment of diseases such as paralysis, sciatica, deafness, and rheumatic afflictions.[24] In the 1750s he was involved in the debate on Haller's theory of sensibility and irritability, which took place in Bologna between Leopoldo Caldani, Felice Fontana and other supporters of Haller's views, and critics like Tommaso Laghi, who gave an alternative neuroelectric explanation of animal motion.[25] Although Veratti apparently did not take sides in the debate, he very probably participated in the performance of some experiments designed by Caldani and Fontana to test the irritability of the heart and other animal parts. These experiments were carried out in the private laboratory set up by Veratti and his wife Laura Bassi, using electricity as a stimulus and frogs as the experimental animal.[26] Two decades later, electricity and frogs were to become the main characters in the "experimental plays" carried out in another private laboratory, that of Galvani.

Veratti exerted a great influence in directing Galvani's attention to medical

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[24] Giuseppe Veratti, *Osservazioni fisico-mediche intorno alla elettricità* (Bologna, 1748).
[25] On this debate see Cavazza, "La ricezione della teoria dell'irritabilità nell'Accademia delle Scienze di Bologna", *Nuncius*, 12 (1997), 359-377.
[26] Leopoldo Marc'Antonio Caldani, "Sull'insensitività, ed irritabilità di alcune parti degli animali", in Giacinto Bartolomeo Fabri, ed., *Sulla insensitività ed irritabilità halleriana. Opuscoli di vari autori,* 1 (Bologna, 1757), 269-336, on 325, 327-332.
[27] Galvani, *Commentary* (ref. 2), 82 ff.
[28] Veratti, *Sopra l'elettricità riguardo agli animali* (1769 and 1770). AASB, Tit. IV, Sez. I.
[24] Giuseppe Veratti, *Osservazioni fisico-mediche intorno alla elettricità* (Bologna, 1748).
[25] On this debate see Cavazza, "La ricezione della teoria dell'irritabilità nell'Accademia delle Scienze di Bologna", *Nuncius*, 12 (1997), 359-377.
[26] Leopoldo Marc'Antonio Caldani, "Sull'insensitività, ed irritabilità di alcune parti degli animali", in Giacinto Bartolomeo Fabri, ed., *Sulla insensitività ed irritabilità halleriana. Opuscoli di vari autori,* 1 (Bologna, 1757), 269-336, on 325, 327-332.
[27] Galvani, *Commentary* (ref. 2), 82 ff.
[28] Veratti, *Sopra l'elettricità riguardo agli animali* (1769 and 1770). AASB, Tit. IV, Sez. I.
[25] On this debate see Cavazza, "La ricezione della teoria dell'irritabilità nell'Accademia delle Scienze di Bologna", *Nuncius*, 12 (1997), 359-377.
[26] Leopoldo Marc'Antonio Caldani, "Sull'insensitività, ed irritabilità di alcune parti degli animali", in Giacinto Bartolomeo Fabri, ed., *Sulla insensitività ed irritabilità halleriana. Opuscoli di vari autori,* 1 (Bologna, 1757), 269-336, on 325, 327-332.
[27] Galvani, *Commentary* (ref. 2), 82 ff.
[28] Veratti, *Sopra l'elettricità riguardo agli animali* (1769 and 1770). AASB, Tit. IV, Sez. I.
[26] Leopoldo Marc'Antonio Caldani, "Sull'insensitività, ed irritabilità di alcune parti degli animali", in Giacinto Bartolomeo Fabri, ed., *Sulla insensitività ed irritabilità halleriana. Opuscoli di vari autori,* 1 (Bologna, 1757), 269-336, on 325, 327-332.
[27] Galvani, *Commentary* (ref. 2), 82 ff.
[28] Veratti, *Sopra l'elettricità riguardo agli animali* (1769 and 1770). AASB, Tit. IV, Sez. I.

and animal electricity. We have no direct evidence that Galvani actually used medical electricity as a practising physician, one of the activities he carried out at home. However, he was certainly interested in the therapeutic applications of electricity, and in his room for experiments there were some instruments that could be used for this purpose. Moreover, Galvani devoted the final part of the *De viribus* to the discussion of paralysis, epilepsy, tetanus and other "disorders" of the nervous system, suggesting the use of electricity to cure them.[27]

There is, however, an even more evident link between Veratti and Galvani. At the end of the 1760s Veratti performed a series of experiments on frogs and other animals, in order to study the pernicious effects of lightning on human and animal bodies. These investigations were not published, but Veratti read an account of them at the Academy of Sciences of Bologna in 1769 and 1770.[28] Galvani, who was himself a prestigious member of the Academy and one of the Professors of the Institute of Sciences, was well aware of Veratti's investigations. Indeed, Galvani's first recorded electrophysiological experiments, which date from November 1780, were a replication of those performed by Veratti.[29]

Galvani's practice in his room for experiments

Galvani began these electrophysiological experiments in order to investigate the mechanism of muscular motion. His choice of the frog as the experimental animal was not original: the use of this animal in the study of animal economy is documented since ancient times and, as we have seen, had also been adopted in Bologna in the previous decades.[30] Galvani himself had used dead frogs in a series of experiments carried out during the 1770s on the motion of the heart and the nervous system. It was probably during this investigation that he worked out a special kind of preparation of the frog, similar to that adopted in the laboratory of Bassi-Veratti in the context of the debate on Hallerism.[31] The frog was cut just below the upper limbs, leaving only the lower limbs with their crural nerves and spinal cord attached and uncovered (Fig. 2). This preparation required manual dexterity and great care, and was fundamental for the successful performance of the experiments:

> We are convinced – Galvani claimed in the *De viribus* – that most of the facts we discovered from these experiments are the result of this technique of preparing and separating the nerves.[32]

Needless to say, Galvani's anatomical and surgical skills proved very important in the process of devising and implementing this particular preparation of the frog.

Like many other investigators in the eighteenth century, Galvani thought animal motion depended on an intrinsic fluid or force – Galvani called it "nervous force" – flowing through nerves and acting on muscles to produce their contraction. In a manuscript dated "Christmas day, 1780" he defined this force as follows:

> The nervous force is that unknown force existing in the nerves, due to which, when the will or a mechanical prick induces a mutation in the substance of a nerve, the corresponding muscle contracts.[33]

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27 Galvani, *Commentary* (ref. 2), 82 ff.
28 Veratti, *Sopra l'elettricità riguardo agli animali* (1769 and 1770). AASB, Tit. IV, Sez. I.
28 Veratti, *Sopra l'elettricità riguardo agli animali* (1769 and 1770). AASB, Tit. IV, Sez. I.
29 Galvani, *Memorie* (ref 1), 233 ff.
30 See Frederic L. Holmes, "The old martyr of science: the frog in experimental physiology", *Journal of the history of biology*, 26 (1993), 311-328.
31 See ref. 26.
32 Galvani, *Commentary* (ref. 2), 56.
33 AASB, Fondo Galvani, cart. III, plico IIAA, fasc. 1, s. 4 (my transl.). On the various conceptions of animal motion in the 18th century and their roots, see Roger K. French, "Ether and physiology", in G.

Galvani's aim in the experiments of late 1780 was to investigate the nature of this force and the mechanism which produced the muscular contractions.

Among the "mechanical" agents capable of stimulating the "substance of the nerves" and the nervous force, Galvani included electricity; and it was precisely electricity that he adopted in his investigation. This choice was certainly influenced by the idea, proposed by many authors including Gardini and Bertholon, that the nervous fluid could be of an electrical nature. But more importantly, it depended on the observation that electricity was the most effective stimulus for muscular contraction. This observation had been made by Caldani and Fontana during their experiments in the Bassi-Veratti laboratory, had been confirmed by Veratti's experiments, and was stressed also by Galvani in the manuscript quoted above.

In November 1780 Galvani began a series of experiments aimed at investigating the effects of electricity in muscular motion. In his room for experiments there were one or more electrical machines, several Leyden jars and Franklin squares, electrical dischargers and conductors, and other electrical apparatus.[34] Indeed, Galvani had the complete equipment of the electrician of the period, as described, for example, in Tiberio Cavallo's *Treatise on Electricity*.[35] He approached his problem in a wide variety of ways. He applied different sources of electricity - Franklin squares, Leyden jars, and the electrical machine - to the prepared frog. He discharged them through various parts of the animal body, observing whether contractions occurred. He modified the path of electricity in the body, legating nerves or muscles, in order to understand on which part of the body electricity acted. He varied the place where the animal was laid, placing it on a glass or metal panel, or directly on the wooden table of his laboratory.[36]

These various operations show that Galvani was exploring a wide range of phenomena. This was due in part to the fact that he was at the beginning of an enquiry that was new to him, so that he had to learn how to manipulate the animal, the instruments, and the experimental techniques. But it was also quite a new field of enquiry. It was fraught with theories and speculations about the existence of an electricity intrinsic to the animal body or about the electrical nature of nerve transmission and muscular motion. Galvani was aware of them, and was well informed on the recent developments in the field of medical electricity. But no one else before Galvani had undertaken a systematic experimentation to test these conjectures, and there were no specific interpretative models or methodological approaches to refer to.

In his room for experiments Galvani developed an original and particular approach to the investigation of animal motion. In his almost daily activity in the laboratory he learned to play a sort of combinatory game, whose items consisted in the prepared frog, its parts, the electrical instruments and other experimental apparatus, and whose rules could only be discovered step by step, experiment after experiment. Putting together these items on the same table, Galvani soon realized that the way in which they were arranged was fundamental for the phenomena under

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N. Cantor and M. J. S. Hodge, eds., *Conceptions of ether. Studies in the history of ether theories, 1740-1900* (Cambridge, 1981), 111-134; Max Neuburger, *The historical development of experimental brain and spinal cord physiology before Folurens* (Baltimore, 1981); Mary A. Brazier, *A history of neurophysiology in the 17th and 18th centuries* (New York, 1984).

[34] Part of Galvani collection of scientific instruments, although not entirely original, was purchased by the Wellcome Historical Medical Museum of London in 1910 and is still kept by the Science Museum in London: see Bresadola, *Medicina e filosofia naturale* (ref. 3), in part. Appendix II.

[35] Tiberio Cavallo, *A complete treatise of electricity in theory and practice, with original experiments* (London, 1777), 129 ff.

[36] Galvani, "Esperimenti di novembre e dicembre 1780", in Id., *Memorie* (ref. 1), 233-244.

investigation. The decisions he had to take every time he designed an experiment were many and complex: what part of the frog to consider and how to prepare it, where to put it, which electrical instrument to use, how to produce the electrical stimulus, on which part of the animal to apply it and in what manner, and where to place all these various items on the table of the laboratory. Each decision produced a different combination of the items of the game, i.e. a new experimental arrangement of the frog and the instruments. Each particular arrangement was the defining characteristic of the experiment and any change of that arrangement on the table determined a new experiment.[37]

During his investigative pathway, as his laboratory notebooks testify, Galvani invented several different experimental arrangements in order to explore problems drawn from the study of electrical phenomena (such as the insulating or conducting properties of nerves and muscles or the quantity of electricity that was sufficient to produce the contractions) or suggested by previous experiments. Sometimes he drew a sketch of a particularly important or complex arrangement, like those illustrated in fig. 3. These sketches had certainly a mnemonic function, that is to say, they gave him the chance to replicate that particular experiment or to modify some of its circumstances. The first sketch of fig. 3, for example, represents an arrangement that Galvani used as the basis for a series of important experiments in January 1781. These culminated in the observation of muscular contractions while the frog and the electrical machine were not connected, Galvani's the so-called "first experiment".[38]

These sketches had, however, another very important function. They fixed on paper the essential circumstances of an experiment, excluding all the mess of the animal parts, the blood, and the instruments that must have been on the experimental table, and thus enabled Galvani to focus and reflect only on those circumstances. This is quite evident if we look at the second sketch of fig. 3, where the only difference between "A" and "B" is whether the apparatus containing the frog is connected to the prime conductor of the electrical machine, or not. It was indeed an essential difference: this experiment contributed to the rejection of a theory of animal motion that Galvani had worked out a month earlier.[39]

In his laboratory, then, Galvani repeatedly varied the experimental arrangements of the frog and the instruments in order to adapt the experimental conditions to the particular problem he wanted to investigate or to find out the fundamental circumstances of an observed phenomenon. We may consider a further example, taken from Galvani's laboratory notebooks and reported very similarly in the *De viribus*. On January 26th 1781, Galvani observed a "marvellous" phenomenon (referred to above as his "first experiment"): a frog's limbs contracted when one touched the nerves or spinal cord with an "anatomical knife" and, at the same time, a spark was discharged from the conductor of the electrical machine, which was in no way connected to the frog. Struck by the new and particular circumstances of the phenomenon, on January 31st Galvani repeated the experiment, varying the experimental arrangement. He used an insulating instrument (made of glass) to touch the nerves, instead of the anatomical knife, which was metallic and therefore a conductor of electricity. He also tried to excite the contractions by touching the

[37] In this case, the term "experimental arrangement" seems more pregnant than that of "experimental apparatus", both because the animal was as fundamental as the instruments and apparatus in Galvani's experiments, and because the term "arrangement" conveys a spatial dimension, which was essential to the way Galvani organized his experimental activity.
[38] See Pera, *La rana ambigua* (ref. 3), 76 ff.
[39] On Galvani's investigative pathway, reconstructed from his laboratory notes, see Bresadola, *Medicina e filosofia naturale* (ref. 3), chapt. 3 and 4.

muscles instead of the nerves, and changed the place and the material on which the frog was laid. Then he changed the conditions of the frog, leaving its nerves surrounded by the contiguous parts or rubbing their surface and that of the spinal cord with an oily matter.[40]

As intimated above, all these small variations in the experimental arrangement were duly aimed at isolating the fundamental circumstances in the phenomenon, and thereby understanding its mechanism. From the experiments of late January 1781 Galvani concluded that the "agent" of the contractions was a very subtle fluid flowing through nerves and acting on muscles to produce their contraction. Moreover, he believed these experiments provided evidence of the electrical nature of the nervous fluid. The explanation of animal motion he developed in January 1781 contained all the fundamental elements of his theory of animal electricity, as presented ten years later in the *De viribus*.[41]

This example, and a detailed study of Galvani's investigative pathway through his laboratory notebooks, demonstrate that "variation", or the systematic exploration of experimental circumstances and arrangements, was one of the main features of his experimental practice. This marks a fundamental difference between Galvani's scientific practice and that which Haller developed in the study of sensibility and irritability. Haller insisted on the importance of replicating the same experiment with different animals in order to exclude accidental and variable conditions that could suggest a mistaken conclusion to the experimenter. Some historians have called this procedure "repetitive experimentation".[42] In the case of Galvani, on the other hand, one may speak of "variational experimentation", as a means of identifying the fundamental circumstances of a phenomenon and investigating how they affected the experimental results.

The ways in which Galvani arranged the animal and the instruments, and the systematic way he did so, are one of the most original aspects of his experimental practice. Physiological and electrical perspectives converged and combined to form an original approach to the investigation of animal electricity. It was in Galvani's room for experiments that his various activities – the medical practice, the study and teaching of anatomy and animal economy, and the investigation of animal electricity – merged to produce a new and lasting achievement in the study of living bodies. His laboratory was the space where the cross-fertilization occurred between his skills, experience, and knowledge, all deriving from the wide range of his scientific interests and practices. It was cross-fertilisation of this kind that allowed him to achieve the results that have given him such stature in our eyes.

One of the early readers of Galvani's *De viribus* was Alessandro Volta. In the *Memoria prima sull'elettricità animale*, dated May 5th 1792, he claimed:

> The existence of a real animal electricity … is what is manifestly proved in the third part of this work [that is Galvani's De viribus] by many well-combined and accurately described experiments.[43]

In stressing the novelty of Galvani's experimentation and its importance, Volta was giving an authoritative opinion. In his words, however, we can also find a hint for the historian: that more attention should be paid to Galvani's experimental practice, to the

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[40] Galvani, "Esperimenti del 26 e 31 gennaio 1781", in Id., *Memorie* (ref. 1), 254-258; see Galvani, *Commentary* (ref. 2), 45 ff.

[41] Galvani, "Corollari del 31 gennaio 1781", in in Id., *Memorie* (ref. 1), 257; see Galvani, *Commentary* (ref. 2), 73 ff.

[42] See Francois Duchesneau, *La physiologie des lumières. Empirisme, modèles et théories* (The Hague, 1982), 148-156; Maria Teresa Monti, *Congettura ed esperienza nella fisiologia di Haller* (Firenze, 1990), 94-106.

[43] Alessandro Volta, *Opere*, 1 (Milano, 1918), 15 (my transl.)

variety of his professional activities and skills, as well as to the scientific interests that underlay the development of his investigative approach, and to the interplay between instruments, experiments and interpretations along the pathway that led Galvani to his theory of animal electricity. A deeper look into Galvani's room for experiments can, I think, illuminate the specific qualities of his research, and can offer a new contribution to explain why Galvani's work was considered by many of his contemporaries as original or even revolutionary.[44]

[44] On the reception of Galvani's work on animal electricity see Pera, *La rana ambigua* (ref. 3), chapters IV-VI; Water Bernardi, *I fluidi della vita. Alle origini della controversia sull'elettricità animale* (Firenze, 1992), and the contributions by Christine Blondel, Stephen Jacyna and Maria Trumpler to the present volume.