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Physics in Perspective

Between Old and New Interpretations of Life: Animal Electricity at the First Congress of Italian Scientists

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In 1839, collaborating with physicist Luigi Pacinotti, the Italian physician and historian of medicine Francesco Puccinotti announced a successful measurement of the existence of electrovital currents in live warm- and cold-blooded animals. To perform this measurement, they used the astatic galvanometer developed by Leopoldo Nobili. The experimental demonstrations took place in Pisa on the morning of October 13, 1839 as part of the First Congress of Italian Scientists. The experiment had been carefully prepared and tested ahead of the Congress in June and July of the same year. Two congressional commissions, composed respectively of doctors and physicists, discussed the results of the experiments and disclosed conflicting views. The physicists diplomatically expressed doubt, saying that the current measured might have been similar, although weaker, to that found in already dead animals and therefore could be traced to physicochemical processes. A debate developed at the Congress and continued afterwards. This significant episode helped keep the question of animal electricity open in Italy, stimulating the development of new electrophysiological studies in the following decade.

Key words: Luigi Pacinotti; Francesco Puccintti; animal electricity; *vis vitalis*; history of electrophysiology; electrovital currents.

Introduction

This work analyses an episode that revived interest in the dormant debate on animal electricity in Italy in 1839, preparing the ground for significant theoretical changes that occurred in the following decade. The episode concerns the meticulous preparation and conduct of electrophysiology experiments linked to the obstinate search for a *vis vitalis*, which was imagined as a measurable entity and driving principle of organic life. The research in question was executed in October 1839, as part of the First Congress of Italian Scientists held in the city of Pisa (Figure 1).[1]

This important Congress, the first of its kind organised in Italy, was inaugurated on October 1 under the patronage of the Grand Duke of Tuscany Leopoldo II of

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Fig. 1. Original lithographic poster (colored and gilded by hand) of the First Congress of Italian Scientists (1839) with the equestrian portrait of Grand Duke Leopold II of Tuscany in the center. *Credit*: Museo Galileo—Istituto e Museo di Storia della Scienza di Firenze and National Archive in Prague; Teca Digitale (museogalileo.it)

Lorraine with the promotion and organization of the zoologist and naturalist Carlo Luciano Bonaparte (1803–1857),[2] prince of Canino and Musignano.[3] The Congress, which lasted fifteen days, was attended by over 400 delegates from various Italian pre-unification states. Furthermore, the Congress was attended by forty foreign delegates. The congress was divided into six sections, each led by a president elected by secret ballot, who then appointed the relevant section secretary. Physician Giacomo Tommasini (1768–1846) was elected president for the medical section and Francesco Puccinotti became secretary, while physicist Pietro Configliachi (1777–1844) was elected president for the physics, chemistry, and mathematics section and experimental physicist Luigi Pacinotti (1807–1889) became secretary of the physical and chemical subsection.[4] Among the varying topics discussed, electrophysiological experiments, which were introduced and performed in the laboratory by the doctor and medical historian Francesco Puccinotti (1794–1872)[5] and Pacinotti,[6] aroused considerable interest, as can be seen from the proceedings. The two men came from very unrelated backgrounds and had different interests, but both held teaching positions in their respective fields: Pacinotti was an experimental physics teacher, while Puccinotti taught civil medicine. Puccinotti hoped that these experiments, among the first carried out in Italy, would produce an unequivocal and measurable demonstration of the existence of electrovital currents in live warm- and cold-blooded animals.[7] It was a high-profile attempt to quantitatively prove the existence of a specific type of animal electricity with the help of a new instrument invented a few years previously, the galvanometer (Figs. 2, 3).

Neo-Vitalism and Animal Electricity in Italy at the Time of the Congress

Bolognese anatomist and physiologist Luigi Galvani (1737–1798) first proposed the idea of a specific electricity's existence, internal to an animal's function, responsible for nerve conduction and muscle contraction, towards the end of the eighteenth century with his studies on the contraction of frog muscles. The idea of muscle contractions independent of the nervous system and, ultimately, of the brain became established with the advent of animal vivisection in the eighteenth century. A scholar of this new direction of research was the Swiss physiologist Albrecht von Haller (1708–1777), who investigated the problem on a more strictly experimental level, thus also inaugurating the practice of systematic experimentation on live animals. Haller's ideas had an extraordinary impact on physiological debate in the second half of the eighteenth century, tending to favour neo-vitalistic concepts, especially the animal electricity thesis. It is on this theme that Galvani began to work in Italy around 1780. The popular controversy that ensued with Alessandro Volta, who claimed a more physical explanation of the phenomenon, ended with the affirmation of Volta's ideas and the invention of the battery (1800).[8] However, after this important invention, experimental research on animal electricity was not completely abandoned. In particular, the experimental

Fig. 2. Portrait of the Italian physician Francesco Puccinotti. *Source*: Francesco Puccinotti, Collezione delle Opere Mediche del Professore Francesco Puccinotti Urbinate, Vol. I, (Macerata: Da Giuseppe Mancini-Cortesi, 1834)

Fig. 3. Portraits sketch of Luigi Pacinotti and Lapo de' Ricci drawn by Francesco Boggi. *Source*: Anonymous, *Album di 57 ritratti di scienziati intervenuti alla prima riunione in Pisa aggiuntovi la relazione del Segretario Generale* (Pisa: Tipografia Nistri, 1841). *Credit*: Museo Galileo—Istituto e Museo di Storia della Scienza di Firenze and Biblioteca Nazionale Centrale di Firenze; Teca Digitale (museogalileo.it)

observation that contractions in frog muscles could be obtained even by completely excluding metals (as observed by Galvani, Aldini, Valli and von Humboldt), kept the belief alive among physicists and physiologists about the existence of a vital principle in animal fibres. The romantic context helped this idea continue to circulate by fuelling cosmic theories that made use of fluids or vital energies. In Germany, the philosopher Immanuel Kant (1724–1804) and his disciple Wilhelm Joseph Schelling (1775–1854) strongly contributed to the affirmation of *Naturphilosophie*, a current of thought that favoured galvanism and magnetism. It placed in the principle of the forces' polarity as the explanatory basis of every natural phenomenon, including the vital functions of organic bodies. Within this broad movement of thought, electrical medicine was established within the speculative school of polarists, who envisioned living phenomena as dependent on physiological electromotive forces.[9] This school of thought was mainly supported by the German physician and botanist Kurt Polycarp Joachim Sprengel (1766–1833) and by the Hungarian physician and physiologist Michael von Lenhossék (1773–1840). The basic idea began with a strong analogy between the voltaic pile and life phenomena. Vital functions depended on a combination of the vital force's motor centers, the electromotive forces, similar to piles, which delivered vital energy in the animal body. This school of thought had a huge following among the vitalist physiologists of the early nineteenth century. Among them were Robert Bentley Todd (1809–1860), Johann Wilhelm Ritter (1776–1810), Alexander von Humboldt (1769–1859), Jöns Jacob Berzelius (1779–1848), Humphry Davy (1778–1829), Jiri Prochaska (1749–1820), and Johann Christian Reil (1759–1813). In Italy, these ideas were supported by both Luigi Rolando (1773–1831)[10] and Puccinotti. Around 1825, the astatic galvanometer's invention by the Italian physicist Leopoldo Nobili (1784–1835)[11] reopened the debate on animal electricity and fueled the hope of placing the polarists' doctrine on an experimental basis. Puccinotti was very interested in the prospect. Nobili, by using his new measuring instrument, developed a research programme that led him to demonstrate the existence of a current in animal tissues in 1827. His studies stimulated the large-scale resumption of research and experimentation on animal electricity. In addition to Puccinotti, this research was also undertaken in Italy by physicists Carlo Matteucci (1811–1868)[12] and Stefano Marianini (1790–1866).

Following Nobili: Puccinotti's Research Programme

Puccinotti's idea of preparing the experiments for the Pisan Congress was not impromptu; it had matured several years earlier. His interest in physical phenomena applied to medicine began in Florence in 1834, when he met Nobili and witnessed his experiments on electric currents. Nobili had arrived in Florence in January 1832 thanks to the interest of Giovan Pietro Vieusseux and Vincenzo Antinori (1792–1865), who had prompted Grand Duke Leopold II to invite the Reggio physicist to Tuscany. Nobili, who already enjoyed some standing among the scientists of his time, began developing a substantial research programme in Florence. With self-designed apparatus[13] and Antinori's help, he developed a series of experiments that led him to be among the first to verify the discovery of electromagnetic induction, and to carry out experiments on polarised light and metallochromes and study so-called "rotation magnetism." Thanks to these results, Grand Duke Leopold II, in February 1833, appointed him a professor of experimental physics at the Imperial Royal Museum of Physics and Natural History in Florence and, for the occasion, also decreed that the premises of the Grand Ducal Cabinet of Physics and Natural History were intended for public education. It is probably because of this directive that Puccinotti was able to attend Nobili's public electromagnetic experiments. Those experiments, as he himself wrote, allowed him to relate electric currents to the phenomena of life:

> But Florence still offered me a utility, on the other hand, which I would have sought in vain elsewhere. This was being able to witness the famous professor Nobili's experiments on electric currents and knowing from which side this eminent phenomenon of today's physics offered the most authentic relationships with the sentient system's facts and how far it could lend itself to the interpretation of them, both in the physiological and morbid state. The new laws on electric currents are not completely understood except by all those people who have the good fortune to see them tested in many and varied experiments performed by this supreme physicist…. I had read all the memoirs published by Nobili about the new electromagnetic phenomena;[14] I was able to see them on his own machines produced by his work and to understand from himself their ingenious and new explanations; nevertheless, in spite of the friendship with which he kindly honored me, I had to confess to myself that I did not have many well understood, others still remained unknown to me, and in the application that I made of them to the phenomena of sensory life, which is what to say to the nervous currents, sometimes I eliminated them, sometimes I would add them.[15]

In Italy, Nobili, influenced by Auguste de la Rive's (1801–1873) studies, with the galvanometer he invented, was among the first scientists to undertake in 1825 systematic research on the organs of live animals.[16] Nobili, in the wake of the ideas advocated by the German polarists, set out to investigate whether "electric currents dependent solely on the forces of an organisation" could exist in organic tissues and mainly in the nervous system. In search of the "forces of life," those early studies all yielded negative results (Fig. 4).

The conclusion that Nobili drew was that in the nervous system, either no currents passed or, if some did, they were so weak that the galvanometer could not detect them.[17] The electrovital current's existence was also excluded in 1827 when he, among the first, revealed the presence of a current in animal tissues, measuring with his instrument a "*courant électrique propre*" in a frog.[18] The current circulated from the feet to the head. Again, Nobili excluded an organic origin of the current. Influenced by his contemporary research on thermoelectricity, he interpreted this as a thermoelectric current.[19] However, it should be emphasised that, despite the negative conclusions, his attitude towards the existence of vital electric currents remained open-minded until his death. Nevertheless, his studies had the advantage of producing a new and powerful means of observation and measurement, the astatic galvanometer.[20] It is mainly in the context of these renewed research efforts promoted by Nobili that the "trustful experiments" of 1839 by Pacinotti and Puccinotti must be framed. This aspect clearly emerges in the preface dedicated to "physicists and physiologists" that Puccinotti wrote as a preface to the account of the electrophysiological experiments:

> While the so popular Nobili lived, I often enjoyed time with him in the hope of us repeating his first attempts, the contrary results of which he was not fully

Fig. 4. Portrait of the Italian physicist Leopoldo Nobili. *Credit*: Museo Galileo—Istituto e Museo di Storia della Scienza di Firenze; Teca Digitale (museogalileo.it)

> satisfied with. There must be something there!… But everything disappeared with him, and I had to wait for more time and for new help, to purposely return to such research. Meanwhile, having become the chair of civil medicine in Pisa, I was waiting for the end of the school year to take care of it.[21]

The passage clearly shows Puccinotti's desire to continue and verify the research programme already outlined by Nobili. Traces of the programme and the hypothesis of electrovital currents can also be found in an 1834 compendium of his private lessons addressed to Bolognese students.[22] In this work, he had argued that the nervous system was able to transmit "sensations" and "sensitivity" to the peripheral organs through an "exciting" fluid that he called the "aether nerve." Following the ideas of the physicists of his time, who had traced the totality of the external world's phenomena to the imponderable fluids, Puccinotti elaborated on the idea that the vital functions of the neuro-muscular system could be traced back to the actions of a single ethereal matter that permeated the whole universe. This matter was characterised by the interaction with the organic and inorganic world, creating, in its constant flow, various changes that could generate both the electrovital fluid in organic bodies and the luminous, calorific, electrical, and magnetic phenomena in the natural world. As for the nervous system's structure, it consisted of a number of nerve centres, like electromotive force systems, which, through chemical and thermal action, produce continuous hydroelectric and thermoelectric currents.[23] Such currents were able to flow and accumulate, creating a modification "in the organic masses or circuits" to "assume a particular nature."[24] Thanks to these ideas, he reaffirmed that the functions of life depended on a combination of forces acting through a series of physiological motors[25] that controlled an electric nerve fluid that was at the basis of motor activities and senses. Therefore, there was a marked structural affinity between the organic or vital electric fluid and the physical one that circulated in the external environment, a single unitary law that had a common feature in the "variety of modifications" of imponderable fluids. To corroborate the hypothesis of a specific electrovital current in organic tissues, Puccinotti observed that the numerous therapies and experiences related to medical electricity's use were essentially due to the good receptivity of the neuro-muscular system, which channelled the external electrical fluid through narrow receptive channels. In order to support his thesis, he brought in as an example some observations from the plant world[26] and a few examples of electrotherapy, such as, in particular, electrical stimulations to treat paralysis.[27] The latter had been studied by the Italian physicist Stefano Marianini, who researched the physiological effects of currents on the tongue[28] and the eye.[29]

Puccinotti's Experimental Project

All of the two Pisan scientists' experiments were prepared and tested before the beginning of the Congress, in June and July 1839, at the Royal Cabinet of Physics of the University of Pisa, except for the last one, which was prepared in Florence. Most likely, Pacinotti and Puccinotti also prepared at the same time a written account of all the experiments carried out as, soon after the congress, they were able to publish a final report.[30] This work (Fig. 5) meticulously reconstructed and described the historical precedents, procedures, methods, and results of a long series of electrophysiological experiments.[31] The idea of preparing them was suggested by Puccinotti, who, moreover, had a more marked professional interest in the subject than Pacinotti, having already several years before proposed to interpret the pathology of nervous diseases based on the electrovital hypothesis. Pacinotti's position was initially different, with him being decidedly more sceptical and doubtful, as Puccinotti himself said: "I often discussed it with our very expert physicist, Professor Luigi Pacinotti, who, as much as I found courteous in promising me his valid help in the physical operations that I proposed to perform with his precious assistance, I was equally dismayed to find him strongly disbelieving of the neurodynamic electrical currents' existence." However, Puccinotti continued to say that "… his laudable scepticism tempered my more favorable attitude, an attitude which, amid anomalous and null first results, wanted to keep going and stay far away from giving up. In this way, if the first group of experiments seemed to confirm Pacinotti in his incredulity, the second seriously worried him; on the contrary, the third persuaded and convinced him."[32]

The physicist Pacinotti's presence, although initially a source of scepticism, gave Puccinotti balance in the interpretation of the experiments and the rigour necessary to manage the experimental data collection. In the final part of their account, dated 1839, the two scientists gave more general methodological advice with regard to conducting this type of experiment.

Hoping that other scholars would be able to verify their conclusions experimentally, their advice was to organise and perform the experiments in the presence of a doctor and a physicist, since the former had specific skills in the animal's preparation, knowing how to use the probes in the best possible way. In contrast, the latter had knowledge of the instruments, were aware of how to read and regulate them, and had practice in repeating the measurements.[33] The two practitioners thus guaranteed a fair balance of skills.[34]

The Electrophysiology Experiments

In the summer of 1839, in collaboration with Pacinotti, Puccinotti's long and meticulous experiments at the Royal Physics Cabinet of the University of Pisa began. There were thirty-three preparatory experiments in total, the results of which became the subject of communication at the October Congress. Some of them (we do not know exactly which ones) were repeated on the morning of October 13, 1839, at the same Physics Cabinet, during the First Congress of Italian Scientists. From the reports of the Congress, we know that the experiments were honoured by the Grand Duke of Tuscany Leopoldo II of Lorraine's presence, and

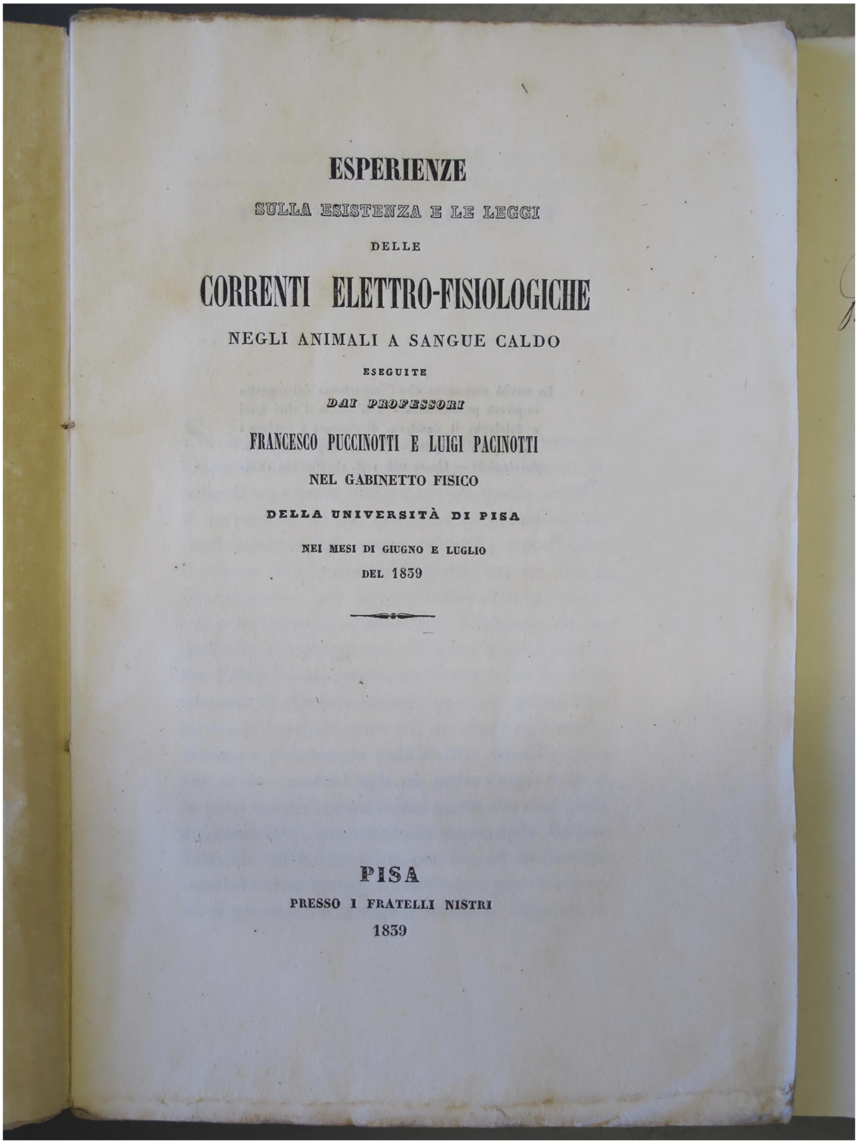
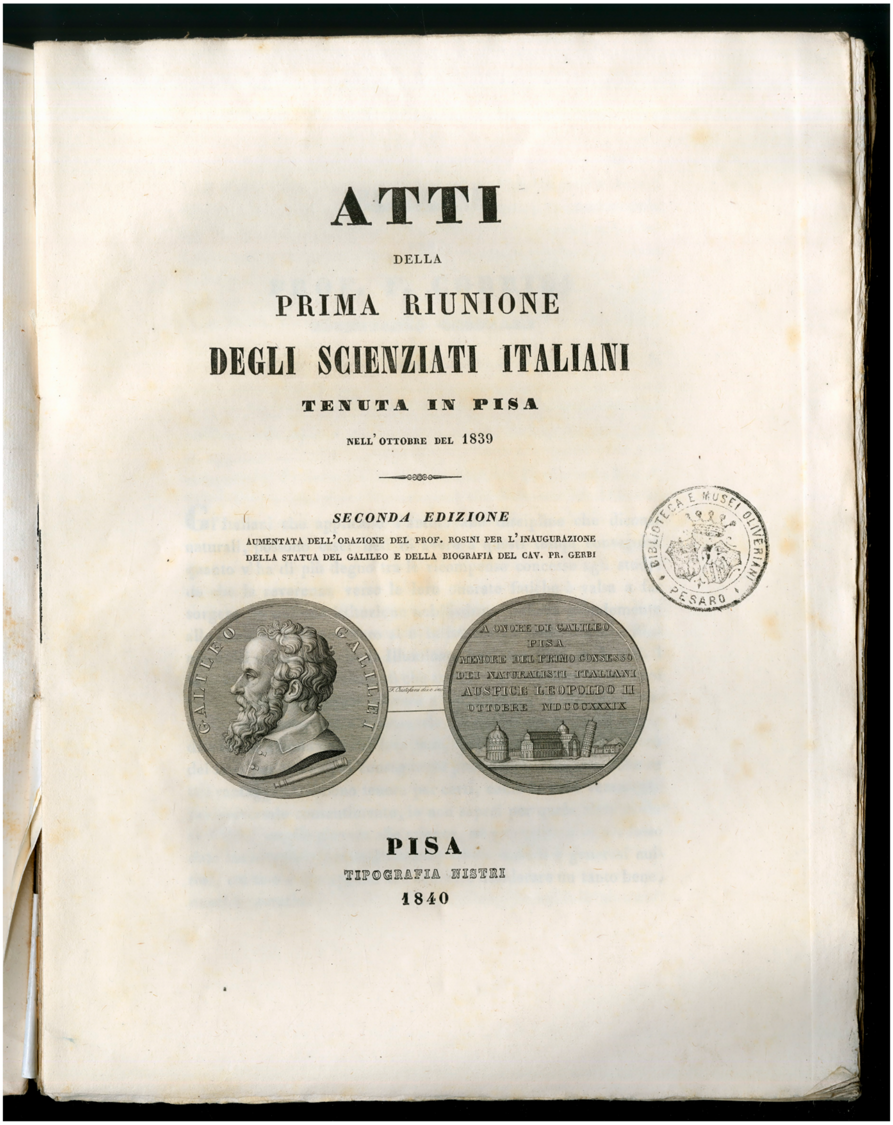


Fig. 5. Title page of the paper published in 1839 by Luigi Pacinotti and Francesco Puccinotti. *Credit*: Biblioteca Medica 'Vincenzo Pinali' Antica, University of Padua

were carefully followed and studied by two specially set up commissions by the presidents of the medical as well as the physicochemical and mathematical sections of the Congress.[35] The two commissions included important names in Italian science and medicine of the time: physicians Maurizio Bufalini (1787–1875), Giuseppe Frank (1771–1842), and Carlo Arcangioli for the medical commission; physicists Francesco Orioli (1783–1856), Gian Alessandro Majocchi (1795–1854), and Giuseppe Belli (1791–1860) for physics. The reports, drawn up separately by the two commissions, were read and discussed in the eighth and final meetings in the respective sections. As already mentioned, Pacinotti and Puccinotti occupied important positions in both sections: the first held the position of secretary of the physical and chemical subsection; the second was the secretary of the medical section (Fig. 6).

As we shall see, the two commissions came to substantially different conclusions, perhaps partly due to the different levels of prestige and scientific consensus enjoyed by the two experimenters in their respective sections, but above all due to differing methodologies between physicists and physicians. The academic medicine of the time was dominated by abstract theoretical systems tending to universalise knowledge in the footsteps of the great philosophical currents of the seventeenth and eighteenth centuries and by the need to provide global theoretical interpretations of diseases rather than to search for their causes through a methodology based on observation and data collection. This situation is evidenced by the proceedings of the medical section of the Congress, which often include inconclusive theoretical discussions with no experimental support. From this point of view, the electrophysiological experiments represented a substantial novelty for the medical section. Puccinotti was, in fact, one of the first Italian clinicians to support the experimental method and to use these scientific tools for research: "I go thinking that with the progress of years and experiences, the galvanometer, the battery, and the polarising microscope,[36] both for the forces and for the intimate forms of the organism, will be able to reveal such new things as to completely change the aspect of physiology."[37] Now, we will discuss in detail the thirty-three preparatory experiments that took place in the summer of 1839. Based on the different qualities of the results obtained, Pacinotti and Puccinotti divided the experiments into three groups, namely experiments of the first, second, and third types. The first two groups of experiments, thirteen altogether, turned out to be mostly negative and uncertain but served to improve the experimental method and to identify the most sensitive and effective galvanometer for measuring the electrovital current. The remaining twenty experiments of the third kind showed, instead, a notable deviation of the galvanometer needle and, therefore, a current that was interpreted as an electrovital organic reaction, irreducible to any chemical-physical factors such as, for example, chemical reactions or thermal gradients.



ATTI
DELLA
PRIMA RIUNIONE
DEGLI SCIENZIATI ITALIANI
TENUTA IN PISA
NELL' OTTOBRE DEL 1839

SECONDA EDIZIONE
AUMENTATA DELL' ORAZIONE DEL PROF. ROSINI PER L' INAUGURAZIONE
DELLA STATUA DEL GALILEO E DELLA BIOGRAFIA DEL CAV. PR. GERBI

PISA
TIPOGRAFIA NISTRI
1840

Fig. 6. Proceedings of the First Congress of Italian Scientists published in 1840. Title page of the second edition. *Credit*: Oliveriana Library in Pesaro

The Experiments of the First and Second Kind

In these experiments, the most attention was initially paid to the choice of an astatic galvanometer, at that time also known by the name of "multiplier," a term that arose with thermoelectricity's discovery. Two multipliers were used, both built primarily to measure thermoelectric currents.[38] They were, respectively, a "Nobili" astatic model and an "improved" model, the latter built by the French mechanic Gourjon[39] (Fig. 7) on the instructions of the Italian physicist Macedonio Melloni.[40] The first three experiments carried out on two pigeons and one rabbit enabled the identification of the most sensitive galvanometer. This turned out to be the one perfected by Melloni. This last model[41] was later used for all the other experiments except the last one, the thirty-third,[42] where Nobili's galvanometer that was sensitive to hydroelectric currents[43] was used. Experiments were essentially based on exploring, through the galvanometer, a certain number of animal organs, examined in their anatomical-physiological integrity.[44]

It was preferred to operate on warm-blooded animals, such as cats, lambs, sparrows, rabbits, and pigeons, but there were also experiments on cold-blooded animals such as frogs and torpedoes. Two sharp metal electrodes acting as sounders connected to the galvanometer were used to penetrate the organic tissues of the living animal, held firm by the legs by two laboratory assistants (Fig. 8). Thus, locked into the galvanometer circuit, the following organs were explored: heart, liver, brain, spinal cord, chest muscles, and thighs. The intent was to experimentally locate which of those organs acted as electromotive force of life.[45] The first negative results led the experimenters to improve their measurements as they were performed, gradually varying experimental methods and procedures. Thus, steel needles were initially used for electrodes connected to pairs of wires of different materials (iron, copper) and to tweezers with crystal handles that facilitated the immersion of the needles in the various parts of the animal's body. The choice of steel needles had been suggested by Nobili due to his use of them in some of his electrophysiology experiments,[46] but also by an analogy with the therapeutic effects of acupuncture highlighted by the French physicist Claude Pouillet (1790–1868) in 1825.[47] Before and after each experiment, the electrodes' chemical changes were constantly verified to check if the measurements carried out had been affected due to the onset of metallic heterogeneity. The verification was performed by immersing the electrodes in pure or salt water. The galvanometric findings of the lost electrodes' homogeneity, highlighted by current measurements that were often equal to or slightly lower than those measured with the animal in the circuit, led to the cancellation of many experiments.[48] New guidelines were followed after a careful critical examination, such as penetrating animal tissues with larger surface electrodes. The choice of a large surface met two important objectives: to collect more electrical charge and to minimise the electrode's resistance. Therefore, two styluses of triangular steel with wooden handles were built. They had sharp points to penetrate not only muscle masses but also the

Fig. 7. Astatic galvanometer, Nobili pattern, signed by the Parisian instrument maker T. Gourjon. The brass base ring bears the following engraved words "Matteucci's Galvanometer / 1840 / Muscular Current." Using this instrument in 1836 Matteucci studied muscular currents in a frog. *Credit*: Museo Galileo—Istituto e Museo di Storia della Scienza di Firenze; Teca Digitale (museogalileo.it)

bone tissue of small and medium-sized animal skulls, aiming to penetrate the intimate tissue structures where the special chemism of life was thought to be. The changes made to the electrodes had several benefits: some experiments showed strong currents (up to a maximum of plus eighty degrees)[49] on a pigeon and a rabbit. The styluses were fixed in the brain and thigh muscles in these cases. The same experiments also revealed abrupt reversals in opposite directions (up to a

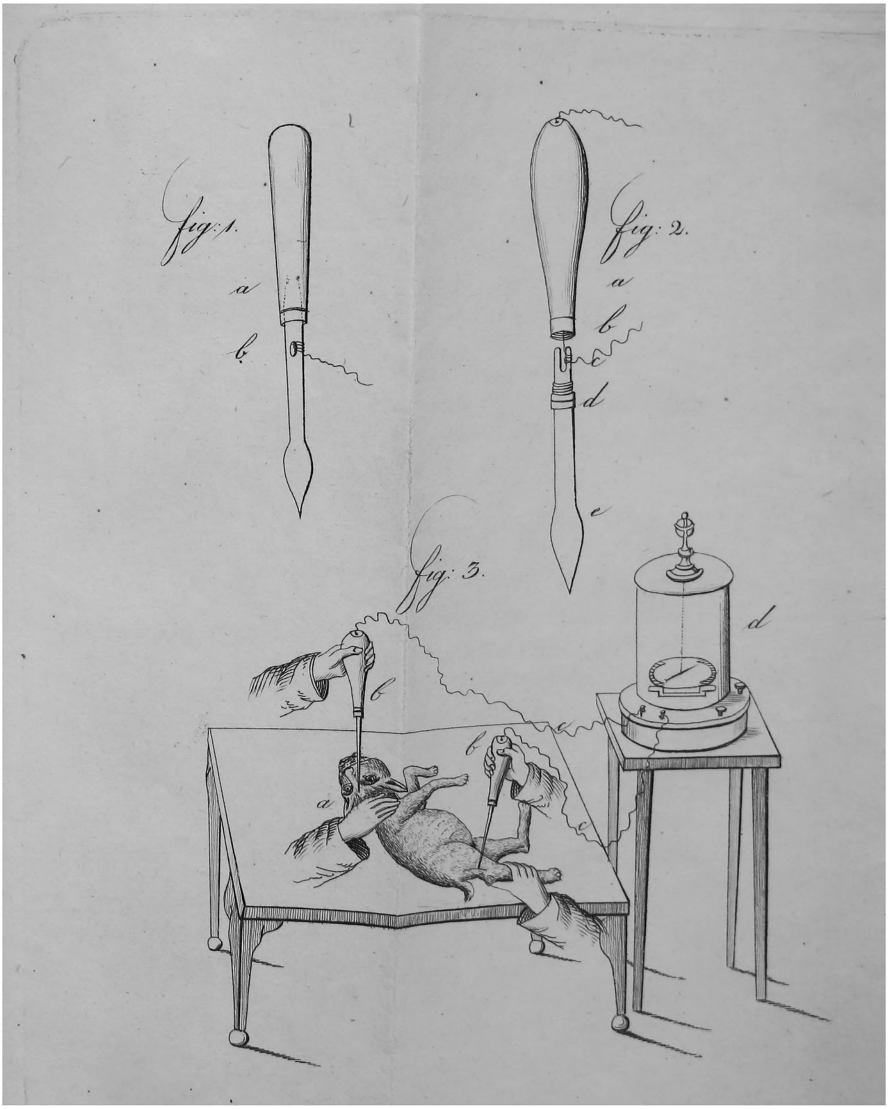


Fig. 8. Folding plate inserted in the historical paper published in 1839 by Luigi Pacinotti and Francesco Puccinotti. The plate shows the experiment carried out during the First Congress of Italian Scientists held in Pisa. Two different types of electrodes with pointed platinum blades and sharp edges are illustrated. Their handles are made of bone (Fig. 1) and boxwood (Fig. 2) respectively. In Fig. 3 a rabbit is introduced into the circuit of the astatic galvanometer and held by two assistants. One of them inserts the electrodes into the brain and muscle of the animal. *Credit*: Biblioteca Medica 'Vincenzo Pinali' Antica, University of Padua

maximum of minus eighty degrees) and the electrodes' alterability in the salty water of up to forty degrees. Therefore, in these experiments, the "currents obtained were so gigantic that, although much must be conceded to the electrochemical effect of the easy oxidisability of the sounder, something seems to us to be attributed to the electro-motive force of life."[50] The currents' inversions were attributed to the electrodes' easy oxidation. In an effort to overcome these difficulties, the steel styluses were painted with "Judaic bitumen,"[51] leaving only the tips uncovered, and later the two sharp tips were gilded with the purest gold in order to better avoid the easy formation of thin electrochemical coatings of organic animal matter which, by covering the conductors, could have made them heterogenous and generated unwanted so-called "secondary polarities" in the electrodes. Subsequent experiments revealed strong currents not only at the time of the first electrode's immersion but also many anomalies explained by electrochemical alterations suffered by the electrodes, despite the gold's lower oxidation. For example, by reversing the electrodes twice, the primary direction of the current, which also assumed different intensities, was not regained. It also aroused some astonishment that the life current did not rapidly decrease to zero when the animal was fatally wounded, but rather increased. However, despite these difficulties, the experimenters could say that the link between the animal's own current and the one that was inverted due to the electrochemical alteration of the sounders appeared "less obscure."[52]

The Experiments of the Third Kind

The subsequent experiments followed with greater confidence, focusing firstly on probes and using silver-plated copper wires. They were respectively welded to platinum electrodes in the shape of quadrangular plates (with sharp edges) and to styluses with a wide spear-shaped tip about three and a half inches long, called *lancettoni*. The choice of electrodes, made with a less oxidisable metal such as platinum, led to an immediate improvement in experimental results with the polarisation current's elimination: "The results produced by the more extensive contact of the platinum sheets, compared with those obtained from the steel styluses, are infinitely less, but safer and more decisive, since the sheets, both during and after the experiments, have preserved their homogeneity so that those inversions which made the results of the steel styles so varied have not been seen".[53] After carrying out these modifications, some cold-blooded animals such as frogs and torpedoes were studied. In study number seventeen, a live torpedo[54] was carefully analysed. The skin covering the electric organ and the bone surrounding the brain lobes were removed. Several measurements were made by immersing the platinum plate electrodes. All measurements gave weak currents except when the electrodes penetrated both the fourth lobe and the electric organ of the fish. In the latter case, a significant deviation of the galvanometer needle (plus ninety degrees), directed from the lobe to the electrical organ, was detected. It was also found that reversing the probes caused the current to reverse. As mentioned in the 1839 account, this experiment had the merit of verifying that Carlo Matteucci's studies, published in 1837, were correct: "In the experiment on the torpedo, we confirmed what Matteucci established around the fourth cerebral lobe of this animal, a lobe that he recognised correctly and called the electric lobe."[55] From this study, the conclusion was also drawn that there had been found an important similarity between warm- and cold-blooded animals: "The brain seems to be the site of the electricity's development in all vertebrate animals, and the electric organ of the torpedo appears as the reservoir where the current produced accumulates; and this is, maybe, the substantial difference between electric fish and other animals."[56] In this position, we still recognise a certain continuity with the ideas that had been expressed by Galvani, according to which the electric fluid, secreted by the brain, was channelled along the nerves of the muscle fibres which, behaving like Leyden jars, positive internally and negative externally, were excited and caused the muscle's contraction. The experimental observation of always detecting that a current's direction led from the brain to the muscle, both in frogs and torpedoes as well as in warm-blooded animals, strengthening the researchers' conviction that "the phenomena of animal electricity behave according to the same laws, and are measurable in the same way in both cold-blooded and warm-blooded animals."[55] Having established this, subsequent experiments aimed at identifying and separating the electrovital current from those of a chemical-physical nature. In this aspect, the researchers clearly stated that the number of currents measurable with the galvanometer could be restricted to only three types: the vital current proper, the common thermo-electric current, and the common electrochemical current.

The Chemical-Physical Currents

Continuing the analysis of the obtained results, the researchers distinguished the currents into two different types: those obtained from the heterogeneous products of the secretions present on the animal excretory organs' surfaces and those that arose from the structural heterogeneity of certain organs. The former had "transitive characteristics" between the organic and the inorganic world. They were not to be confused with the electrovital and were obtained "with the simple contact probes system," even after organic life[57] had ceased entirely. The latter, on the other hand, were intrinsically intertwined with life and not part of ordinary chemical processes. This last kind of current "if it is not the cause of life, it is that special proximate effect that life alone can produce, life alone can maintain. Therefore, the current that starts from this intimate chemism is only vital and cannot be confused with common electrochemical currents."[58] The rule for exploring the electrovital current was not, therefore, that of touching the surfaces of the organs supplied with the heterogeneous secretions' products, as some experimenters practised. It was to penetrate the internal structure of the organs with wide-surface probes in order to arouse an "instantaneous automatic or voluntary reaction in the animal." In this last operation, the use of platinum sounders was essential to avoid possible alterations due to contact with blood and the organic liquids inside the organ. Finally, a certain number of experiments were carried out to highlight the possible presence of thermoelectric currents. For example, some live animals' brain and muscle temperatures were measured without finding appreciable differences. The head of a sparrow was heated with an alcohol flame up to a temperature of fifty degrees centigrade. When two electrodes were inserted into the brain and chest muscles, no thermoelectric current was detected where, with the sparrow alive, a "vital current" was recorded, which reached ten degrees. The researchers concluded that in animal life, the thermoelectric current must be either zero because of the equality of temperatures in all parts or very weak. However, this current could not relate to the vital reactions of the animal in life but could appear after death due to the unequal cooling of the various body parts.

The Electrovital Current

Except for experiment number twenty-one, where researchers measured an unexpected "discharge current" of ninety degrees in a lamb, the other experiments of the third kind provided currents that ranged from nine to sixty degrees and were classified as electrovital currents. The last experiment, the thirty-third, was performed in the Royal Museum of Physics and Natural History in Florence, on September 10, 1839, at 11 a.m., in the presence of Puccinotti, Vincenzo Antinori, the Director of the Museum, and the laboratory assistant Tito Politi (1809–1870), then in charge of preparing the museum's experimental physics lectures. The experiment made use of Antinori's cooperation. He, for the occasion, made available his astatic galvanometer that was sensitive to hydroelectric currents.[59] Given the positive results obtained, Antinori suggested to Puccinotti the idea to use a galvanometer more sensitive to hydroelectric currents than thermoelectric ones, which would be the most suitable and direct means to isolate the "vital" from other common currents. The suggestion was picked up by Puccinotti.[60] In repeating the electrophysiological experiments at the Pisa Congress, the two scientists decided to use Nobili's hydroelectric galvanometer that was also sensitive to hydroelectric currents.[61] Overall, the results of the third kind of experiments were judged to be positive and "enough to put the fact out of any doubt." For other experimenters' benefit, the two researchers endeavoured to describe the main characteristics and properties attributed to this electrovital current which, according to their conclusions, did not correlate with chemical-physical phenomena and, therefore, should not be confused with the electrochemical currents of the neuro-muscular system. In summary, researchers attributed the following properties to this current: it was not obtained by immersing wires nor by applying electrodes to the nerves or muscles by simple contact; it had the characteristic of being an "automatic or voluntary" reaction current in the live animal like the discharge current of electric fish and increased with the animal's age and development; unlike what happened in cold-blooded animals, in warm-blooded ones, it was released with more difficulty (the difference was seen above all with electric fish); in order to be able to measure it, it was necessary to make a cut in the tissues and collect it "inside the organs' plasma," so that the animal's simultaneous reaction communicated the required impulse to divert the vital current towards the inserted electrode; it showed an impulsive movement that had some relation to the animal's shaking;[62] in both warm-blooded and cold-blooded animals the current had a constant direction from the brain to the muscle; anatomical preparations of the animal caused torment and haemorrhages that weakened the current considerably; finally, the current followed the phases of animal life, i.e. it decreased and extinguished with the decreasing and extinguishing of neuro-muscular life.[63]

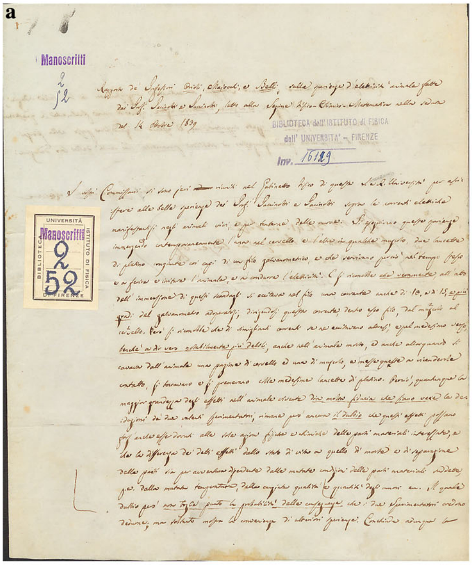
The Judgments of the Examining Commissions

On the morning of October 13, at the Physics Cabinet of Pisa University, in the presence of the Grand Duke and the two judging commissions of physicists and doctors specially set up by the Congress, some of the electrophysiological experiments prepared by Pacinotti and Puccinotti during the summer were repeated. From the proceedings of the Congress, we learn that the experiments produced generated "long discussions between the professors on that subject and the examination of the experimental facts." From the report of the medical section, we are aware of the type of experiment performed:

> The experiment is carried out by introducing into the circuit of a galvanometer having a long and very fine multiplier wire, or rather, more sensitive to hydroelectric currents than to thermo-electric currents, a living animal in its perfect physiological state; and, at the same time, two strong platinum lancets having points shaped like olive leaves are immersed, one in the brain, the other in a muscle of the extremities, and these *lancettoni* are joined with the ends of the galvanometric wire. In the act of immersion, and when the animal is shaken, currents of fifteen, twenty-five, forty, and even sixty degrees arise.[64]

The reports drawn up by the two commissions were read and discussed the following day in their respective physical and medical sections. The two commissions came to substantially different conclusions. The medical commission, adopting the report presented by the secretary Puccinotti at the meeting on October 14, judged "such experiences as true and very important. It invited the experimenters to publish them, and to continue them courageously."[65] In order to understand this judgment, it is necessary to observe that the vitalistic doctrine professed by the president of the medical section Tommasini was still widely followed in Italy. Vitalists professed a particular distinction between physical and chemical phenomena on the one hand and biological ones on the other. These ideas, albeit tempered by some concessions made to experimentalism and physiochemistry, dominated the schools of medicine and physiology throughout Europe. In Germany, the physiologists were mostly vitalists and in France a physiologist of the stature of François Magendie (1783–1855) expressed himself in 1837 on the phenomena of life with these words: “I distinguish in vitality two great classes of phenomena: the one comprises physical phenomena, the other vital phenomena; in each class are grouped those admirable functions which our human body is charged with performing, and whose marvellous whole constitutes life.”[66] As for Maurizio Bufalini, one of the members of the medical commission, we know that he was not at all in agreement with the positions of the vitalists. Indeed, Bufalini supported the introduction of auxiliary sciences such as physics and chemistry into medicine, although he did not assign them a decisive role in the interpretation of living systems. Still, in 1838, by commenting that year on Matteucci’s torpedo experiments, he wrote that it was not yet “the time to apply the doctrine of electricity to the intelligence of organic phenomena,” and in a subsequent passage, he added that “if physicists will be unable to measure with experimental means the electrical actions in the phenomena of life and recognise the laws, it would be reckless vanity to wish to argue their existence by considering only the events of the actions of inorganic bodies.”[67] From this last thought, we could deduce that Bufalini evaluated the experiments of Pacinotti and Puccinotti positively. From all this, therefore, the very favourable conclusions expressed by the medical commission are not surprising. Conversely, the report presented by Giuseppe Belli (Fig. 9) in the eighth meeting of the physical section was of a different tone, purposely more cautious and with more exact observations:

> These experiments were carried out by immersing at the same time two platinum lancets joined with the ends of a galvanometric wire, one in the brain and the other in some muscle; they thus served at the same time to wound and irritate the animal but also to conduct electricity. And it was recognised that at the moment of these probes’ immersion, a current of even ten, or fifteen or more degrees of the galvanometer used was excited in the wire, directing from the brain to the muscle. It was also observed, however, that a current of a similar nature and direction of flow, though of a much smaller intensity, could also be induced in the dead animal, and also when a portion of the brain and a portion of muscle were extracted from the animal and placed in contact with each other and touched and pressed with the same platinum lancets. Therefore, although the greater magnitude of the effects in the living animal gives great confidence that the deductions of the two talented experimenters are true, the doubt remains that these effects may perhaps also be due solely to the physical and chemical actions of the material parts involved and that the difference of the said effects from the state of life to that of death and separation of the parts is by chance dependent on the changed conditions of the material above parts,



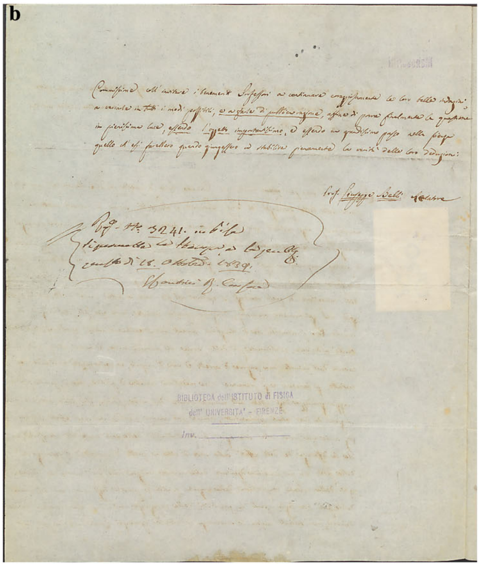


Fig. 9. Handwritten report, dated October 14, 1839, of the commission formed by the physicists Francesco Orioli, Giovanni Alessandro Majocchi and Giuseppe Belli, in charge of examining the experiments carried out by Luigi Pacinotti and Francesco Puccinotti on animal electricity during the First Congress of Italian Scientists. *Credit*: Museo Galileo—Istituto e Museo di Storia della Scienza di Firenze; Teca Digitale (museogalileo.it)

> for example, on the changing temperature, on the changed quality and quantity of the humours, etc. This doubt, however, does not remove the probability of the consequences that the two experimenters believe in deducing from it; it only shows the convenience of further experiments.[68]

The explanation given by the physics section, even if it presented a diplomatic way, was correct in substance. Puccinotti attempted a reply with some of his "annotations to the report of the illustrious commission,"[69] in which, while acknowledging the existence of electrochemical currents due to the "heterogeneity in the products of acid and alkaline secretions" during life and to the "heterogeneity in the organic parts" after death, maintained that there was a major difference in characteristics between the latter and the electrovital current, both in method and in measurements. In essence, he emphasised that the ability to identify electrovital currents, essential for the organic functioning of life, depended on the implementation of an experimental protocol and the ability to be able to read a characteristic galvanometric trend of the current. The protocol provided for the use of platinum probes and their immersion inside the organs of live animals. This last procedure allowed Puccinotti to claim the priority of having discovered electrovital currents over the experiments performed some time before by Matteucci and Alfred François Donné (1801–1878). In the report that Puccinotti read in the meeting of October 14, we find this interesting passage:

> It can be claimed without presumption that these experiments were the first in which it was finally possible to obtain a current from the nerve and muscle masses of warm-blooded animals in a living state. The currents obtained by Donné and Matteucci are electrochemical, given by the products of acid and alkaline secretions of the skin, mucous membranes, or hepatic surfaces sprinkled with bile.[70] The neuro-muscular current is of a different nature and is the only one to which the character of its own, or vital, or discharge current can compete. In his last study on the frog's own current, Matteucci said, "The traces of the own current are not found only in the torpedo and in the frog. I instituted several experiments on other animals immediately after they were killed, and in all of them, the current showed the same direction" (V. Bibl. Univ. of Geneva. May and June 1838, p. 167).[71] But, besides the differences that this declaration presents in the method, having experimented on animals in their full state of life, Matteucci never accounted for such experiences; and a simple announcement could have no other value for us than to assure us of the faith of the illustrious physicist that the currents were there; but, it was still necessary to imagine a way of obtaining them.[72]

Beyond revealing a veiled controversy against Matteucci, rather typical of scientists of these years, the passage highlights Puccinotti's knowledge of the electrophysiological research undertaken by Matteucci in that period. He had begun to study animal electricity in 1834,[73] then, from 1836, torpedoes. Then, in

1838, the bioelectric currents present in frogs' striated muscles were prepared according to the method inaugurated by Galvani in 1792. These activities were part of the research programme that Nobili had drawn up starting from the mid-twenties of the nineteenth century. The work of 1838 carried out by Matteucci, mentioned in the passage, is particularly important since, for the first time, the thermoelectric interpretation given by Nobili of the origin of the frog's own current was corrected. In this work, there are already some acute experimental observations that formed the basis for his subsequent discoveries, although not immediately understood. In fact, he developed an experiment that highlighted the electric potential difference between intact and cut surfaces (thigh, sciatic nerve, and leg) relating to the lower limb of a frog in a state of rest.[74] This was the first step toward discovering that demarcation current, which would later show that muscular activity generated a current or, more precisely, that this activity stimulated the propagation of an electrical impulse due to the polarisations of each muscle fibre membrane. Even the observation that the muscle fibres of a frog's thighs lost the ability to decontract in the presence of a solution containing strychnine[75] was not immediately understood. In modern terms, this was because all the musculature was depolarised. Only in 1842 did Matteucci realise that muscle activity was nothing more than a bioelectrical phenomenon caused by the muscle action potential. This conclusion was stimulated by the fundamental experiment of the induced muscle shock that generated the negative demarcation potential oscillation due to the depolarization of the muscle membranes.[76] Without any doubt, the method proposed by Matteucci for measuring the potential between injured and healthy parts would prove to be much more fruitful in the long run than the method chosen by Puccinotti. Still, the latter's statements seem honest in the passage. If anything, Puccinotti, still firmly anchored to a dichotomous ideological framework that could not benefit from physical–chemical phenomena alone, could be criticized for following Nobili's indications in a not very innovative way. Nobili, shortly before dying, in a controversial article against Matteucci, had reiterated the need to establish the existence of electric currents in the intact organs of live animals (Fig. 10).[77]

The Bitterness of Puccinotti and Subsequent Developments

The events of the Congress[78] and the relentless defence by Puccinotti, who maintained faith in his ideas for many years, kept alive and aroused the question of the electrovital current both in Italy and abroad. In Italy, the experiments generated many summaries and journalistic reports.[79] The result was a lively scientific debate that had, as an immediate effect, the experimental reproduction, between the end of 1839 and 1840, of the Pisan experiments in Modena,[80] Venice, Bologna, Turin, Naples, Malta, and Edinburgh. In Venice, the results of the professors from Pisa had experimental confirmation from the similar experiments[81] carried out by the physician Leovigildo Paolo Fario (1805–1863) and by the physicist Francesco

Fig. 10. Portrait of the Italian physicist Carlo Matteucci. *Source*: Nicomede Bianchi, *Carlo Matteucci e l'Italia del suo tempo* (Turin: Fratelli Bocca, 1874)

Zantedeschi in December 1839.[82] However, scepticism and distancing were not long in coming. An eloquent example of this is the bitterness that transpires in a passage from one of Puccinotti's letters, dated December 4, 1839 and addressed to Vincenzo Valorani (1786–1852), professor of theoretical-practical medicine at the Medical-Surgical College of the University of Bologna:

> Dearest Valorani, do you see how things are going in the world of scientists? Do you present a theory? They laugh at you because you only care about hypotheses. Do you turn to experiences? Then they immediately theorise to discredit the facts. It even goes so far as to say "that the galvanometer is not an instrument capable of resolving the question." Saying it is cheap: the reasons must be given, and it is also a profession to point out by what other means or instruments the currents are made discernible. As long as the current of the torpedo passes in the galvanometer's wire and will make the needle make very rapid turns, there will always be a fact which will prove the possibility of passing any other animal current into the said instrument.[83]

Scepticism intensified in the summer of 1840 with new and more accurate experimental tests carried out by physicists and physiologists, increasingly united in common research programmes. In Bologna, one of the first research centers to show themselves "incredulous" towards Pisan experiments,[84] the Bolognese physiologist and academic Ulisse Breventani (1808–1848), assisted by physicist Silvestro Gherardi (1802–1879) and physicians M. Paolini and L. Benfenati, repeated in the months of May, June, and July, at the physics cabinet of that university, the electrophysiological experiments from Pisa, finding experimental results contrary to the latter. In a report read by Breventani in the session of December 26, 1840, at the Academy of Sciences of the Institute of Bologna, the Bolognese physiologist, after having explained the experiments they had "instituted," concluded as follows:

> For this reason, if we are not mistaken, it seems to us that we are sufficiently authorised not to admit as a demonstrated fact the existence of electrovital or vital electrochemical currents properly so-called, that is to say, of those currents only that are manifested during life, not having us, as we have said, been able to obtain any signal even during the strongest reactions of the animals: or rather, we esteem ourselves authorised to believe that through the means considered today the most suitable to demonstrate them, it has not been possible to have so far any clear, sure, and incontrovertible evidence of their existence.[85]

In support of this judgment, similar experiments also came to the rescue, twenty-two to be exact, "instituted" between June 16 and August 8, at the university of Turin, by the professor of physiology at the university, Giovanni Secondo Berruti (1796–1870), assisted by the professors of the same university, Girolamo Botto (1789–1863), professor of clinical medical, and Lorenzo Girola (1802–1875), professor of theoretical-practical medicine, and by the physicians C. Bellingeri, G.

Demarchi, and G. Malinverni. The results of these experiments were first published in Turin[86] and then exhibited in the Second Congress of Italian Scientists, held in Turin in September 1840. Following is a summary of the communication given by Berruti at the meeting of the medical section on September 28, 1840:

> Prof. Berruti communicates to the section the results of experiments … on electrophysiological currents in warm-blooded animals. He believes that the existence of these currents cannot, in the current state of science, be admitted…. The experiments carried out by him, which include two animals in a single galvanometric circuit, seem to demonstrate evidently the non-existence of the alleged electrovital currents, since in such experiments, the electrochemical currents being destroyed, the electrovital current if it existed, should be all the more apparent as it would be alone and no longer obscured by the coexistence of electrochemical currents. He does not claim, however, not to have been able to deceive himself because his learned colleagues would have certainly known how to mislead him, which, however, seems to him very difficult, especially since some of them were previously inclined to admit the supposed electrovital currents, and only after these experiments did, they abandon such a preconceived opinion. He, therefore, invites all physicists and physiologists to repeat his experiments and those of the distinguished professors of Pisa.[87]

Puccinotti, who was present at the Congress, attempted a lukewarm defence at the following meeting on September 29, criticising Berruti's experiments in terms of both substance and method and reiterating that they could not invalidate "the probability of electrovital current."[88] However, despite Puccinotti's defence, the electrovital hypothesis had reached its last jolt in Italy by now, supplanted shortly thereafter by the fundamentally electrophysiological work of Carlo Matteucci, who stimulated in Germany the interest of Emil Du Bois-Reymond (1818–1896),[89] thus paving the way for modern electrophysiology.[90] Indeed, between 1840 and 1844, Matteucci reached the fundamental discoveries of muscle demarcation current and the phenomenon of induced contraction (due to the action currents), thus denying the existence of specific neuroelectric currents (in the sense of a fluid flowing in the nerves, as Pacinotti and Puccinotti understood them) and tracing the muscular and nervous activities to bioelectric phenomena already pre-existing in their organic tissues. These studies were carefully repeated and verified in Berlin by Du Bois-Reymond through the use of some much more sensitive galvanometers than the one Matteucci had used. As early as the spring of 1842, Du Bois-Reymond had measured weak currents in the muscles and nerves using a galvanometer he built, whose coil was hand-wound with 4,650 turns.[91] In later years, he used even more sensitive galvanometers[92] to detect electrical activity in nerves without any external electrical stimulus. Du Bois-Reymond was thus able to confirm at least a couple of Matteucci's earlier observations. The first verified that the demarcation current in a nerve was interrupted when its muscle was made to contract. The second confirmed that a muscle contraction could somehow stimulate the cut end of a nerve located on its surface.[93] During his life Du Bois-Reymond led a sharp opposition to any form of vitalism by arriving at a materialistic, mechanistic, and deterministic conception of reality mixed with a gnoseological skepticism about the possibility of fully penetrating certain phenomena of nature and life. Famous was his aphorism *ignoramus et ignorabimus*.

Conclusions

The Pacinotti and Puccinotti's paper of 1839 closed with the following words:

> Having established the existence of the vital current, its constant direction, its relationship with life and the special characteristics which distinguish it from other common currents,… our experiences do not allow us, for now, to advance further things with the corollaries which result from them: being very limited, as the philosophers know, the license to extract from so rich a sacred repository as life is, any precious and useful truth.[94]

So, what was this electrovital current they sought so zealously and claimed to have found? Was it perhaps the materialisation of that *vis vitalis* characteristic of life, a measurable entity but not attributable to anything known at that time? And if considered as such, what happened at the instant of death? Reading the two scientists' accounts, some general considerations might lead us to believe that they identified the bioelectrical properties of living organisms as something characteristic of life, a sort of driving principle believed to be also susceptible to instrumental measurement. In fact, in their paper, a clear distinction is definitely made between the electrical currents of chemical-physical origin, obtained from the secretory and heterogeneous animal organs' products, and the electrical ones of vital origin (electrovital), the latter having specific and characteristic galvanometric trends and more easily isolated from the others by using a particular galvanometer, the one sensitive to hydroelectric currents. In the account of experiment ten (experiments of the second kind), it was said that a current of forty-five degrees had been obtained when "the sounder came into contact with greater muscle mass, and where there was presumably more life force…," thus placing a logical relationship, and perhaps pre-constituting a hypothesis of identity, between the intensity of the electrovital current and the "force of life." These considerations suggest that the authors sought a measurable equivalent that corresponded with the essence of life itself in the electrical readings. Furthermore, great care and attention were paid to the experimental observation of what happened to the electrovital current in the vicinity of the animal's death; the expectation was that "when life is extinguished, the animal current also disappears, nor does it reproduce anymore."[95] In the experiments' accounts, this point was always explicitly noted, and where currents appeared after death, they were described with great care and classified among those of chemical-physical origin.

Based on current knowledge, what could be the significance of the results obtained? The care and critical spirit with which the results were analysed lead us to accept the thesis that a current was indeed observed from the brain to the muscle through the galvanometer. Two types of measurements were made: a direct current from the brain to the muscle in the resting state of the muscle and a variation of this current coinciding with the animal's movements. We now advance the hypothesis that the experimental conditions and the animal's struggle against introducing the electrode into its brain have not introduced pronounced artefacts in the measurements. Under these conditions, the first measure is not very credible, at least in the interpretation given by the researchers, as there is no substantial difference in the ionic electrical condition between nervous and muscular tissue in a resting situation. Regarding the second measure, two possible interpretations can be attempted: (a) that it was related to the muscle's depolarisation, or rather with the inversion of the membrane potential preceding the contraction, with the electrode in the brain at a higher potential than that of the muscle; (b) that the observed currents were related to the electrode's movement in the wound during contraction. We do not know the inertia characteristics of the galvanometer used, but the depolarisation speed of the muscle fibre membrane, which is of the order of ten milliseconds,[96] and the low sensitivity galvanometers of that time had would suggest the second interpretation.

Then, what is the significance of the electric potential that gave rise to the observed current? The extreme variability of the results between the various experiments, the presumably greater caution when introducing the electrode into the brain (compared with introducing it into the muscle) to avoid the animal's death and the same observations already mentioned contained in the report of experiment ten, suggest that what was observed was what later became known as a demarcation potential (today perhaps interpretable as an index of the presence of a "membrane potential at rest"). In fact, the current's direction, the relatively low ratio of the intracellular and extracellular volume of the nervous tissue with respect to the muscle, the presumable smallness of the lesion operated in the brain compared to that operated on in the muscle, the fact that the observed current increased when a more extensive lesion was operated in the muscle, indicate that the electrode placed in the brain could be considered substantially extracellular or, at least, "more extracellular" than the muscular one. Ultimately, while not neglecting issues such as the instrument's readiness and the electrodes' "impurity," it could be argued that the observed currents essentially depended on the lesions' asymmetry (enormous in the muscle compared to the brain) and the consequent demarcation potential. However, the fact remains that the measurements were carried out not between an injured surface and an intact one but between two injured surfaces, a technique that was not very successful and today not easily interpreted due to the probable presence of an accumulation of experimental artefacts. Unfortunately, experiment ten, which could contain the crucial indication if one wanted to take the experimental situation to extremes by bringing one electrode into the lesion and the other touching the tissue surface, was interpreted according to the old conceptual scheme of the vital force. This conception, to some extent, could have been useful in the past as a metaphor for the description of the phenomenon of "life." In this specific case, it revealed itself to be a very limiting conceptual paradigm at a time when the improvement of measuring instruments could offer the opportunity for a deeper understanding of the matter.

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Data availability

As the topic is the History of Science, no datasets were generated or analyzed during the present study. The author declares that this study's historical-scientific texts and manuscripts are available to the public under a Creative Commons license.

References

[1] The Congresses continued uninterruptedly from 1839 to 1847 and then resumed, in the different climate of the Italian unification, from 1862 to 1875.

[2] Carlo was Luciano Bonaparte's son, brother of Napoleon I. In Italy he was one of the main creators of the "Italian Scientists' Congresses." For more information on Bonaparte see Patricia Tyson Stroud, *The Emperor of Nature: Charles-Lucien Bonaparte and his World* (Philadelphia: University of Pennsylvania Press, 2000).

[3] The idea of setting up periodic scientific congresses in the divided pre-unification Italy, similar to those that had long been widespread in Europe (Switzerland, the German Confederation, France, and England), was launched by the Italian writer, linguist, and patriot Niccolò Tommaseo (1802–1874) in 1822 from the pages of a famous Florentine journal, the *Anthology of Sciences, Letters and Arts*, founded by the writer, bookseller and publisher Giovan Pietro Vieusseux (1779–1863). This idea was concretely realized thanks to a project made by the zoologist and naturalist Carlo Luciano Bonaparte drawn up with Vieusseux and his friends' help.

[4] The decision to divide the Physics, Chemistry, and Mathematics section into two subsections was taken by Configliachi. The second subsection was that of Mathematics and Astronomy and its secretary was Vincenzo Amici.

[5] Francesco Puccinotti (figure 2) was born in Urbino in 1794 and died in Siena in 1872. He enrolled in the Faculty of Medicine of the University of Rome, where he graduated in 1816. From 1826 to 1831, he held the professorship of pathology and forensic medicine at the University of Macerata. In 1834, he fled to Florence in Tuscany, where he published a short course on nervous diseases and came into contact with the Italian physicist Leopoldo Nobili. In 1838, he moved to Pisa in order to hold the chair of civil medical institutions, to which, the following year, a clinical medicine chair was added. In 1846 the Grand Duke of Tuscany conferred on him the history of medicine chair at Pisa. He kept this position for the rest of his life even when, in 1860, he had to move to Florence. By resolution of the Italian Parliament, he had the very high honour of being buried in the Santa Croce church in Florence.

[6] Luigi Pacinotti (figure 3) was born in Pistoia in March 1807, and he died in Pisa in 1889. In October 1831, he was appointed professor of experimental physics at the Medical Physics College of Pisa University. Thus began his career as an experimental physicist, an activity that would keep him active in that university for over fifty years until 1881. In this year his position was taken over by his son Antonio (1841–1912), who became a prominent Italian physicist and patriot.

[7] These electrophysiological experiences were not the only ones discussed in Congress. Alongside those of the two Pisan scientists, the discovery by Italian physicist Carlo Matteucci of the so-called "fourth lobe" of the torpedo, a nerve structure that controlled the electrical discharge, was also discussed. In reality, as we will see (ref. 55), the verification of the fourth lobe as the organ responsible for the discharge had already been experimentally confirmed by Pacinotti and Puccinotti in one of the preparatory experiments (number seventeen) prior to their communication at the Pisan Congress. Matteucci was absent at the Pisan Congress.

[8] For a detailed discussion of Volta's responses to Galvani's experimental results and his interpretations of animal electricity in the 1790s, see chapter six of Giuliano Pancaldi, *Volta: Science and Culture in the Age of Enlightenment* (Princeton: Princeton University Press, 2003).

[9] Niccolò Celle, *Nuovi elementi fisio-patologici di Medicina Eclettica* (Pisa: Presso Mariano Lieto, 1841), 85–86.

[10] Rolando was an Italian anatomist, physiologist, and physician. He had identified a physiological electromotive force in the cerebellum whose laminate and superimposed layer structure was in his opinion very similar to Volta's electric pile. From this motor, passing through the nerves, a nerve fluid, identified as an electrical fluid, which excited and stimulated the motor muscles' functions. See Luigi Rolando, *Saggio sopra la vera struttura del cervello dell'uomo e degl'animali e sopra le funzioni del sistema nervoso* (Sassari: Nella Stamperia da S. S. R. M. privilegiata, 1809), 77.

[11] Nobili was one of the most important Italian physicists of the first half of the nineteenth century. He conceived the metallochromes (electrochemical phenomena displayed by metal plates), the astatic galvanometer and many other devices for the study of dynamic electricity. In partnership with Macedonio Melloni (1798–1854) he became deeply interested in thermoelectricity. For his studies with galvanometer Nobili is also considered one of the pioneers of modern electrophysiology's birth.

[12] Born in Forli, a town near the Adriatic Sea, Matteucci (figure 10) began an important series of electrophysiological research projects in 1830, which made him famous within a few years. In 1840, on the advice of Alexander Von Humboldt, the Grand Duke of Tuscany, Leopold II, appointed him to the chair of experimental physics at the University of Pisa.

[13] Among these we remember, in addition to the famous astatic galvanometer, made around the mid-twenties of the nineteenth century, also the simple sparking magnet and the double type (conjugate magnets).

[14] It is likely that Puccinotti refers to Nobili's work in two volumes published in 1834, entitled *Memorie ed osservazioni edite ed inedite del Cavaliere Leopoldo Nobili colla descrizione ed analisi de' suoi apparati ed istrumenti*, 2 vols (Firenze: David Passigli e Socj, 1834). The first volume, in fact, was a collection of almost all the memoirs that Nobili had published from 1825 to 1833.

[15] Francesco Puccinotti, *Lezioni sulle malattie nervose per servire di prolegomeni ad un trattato completo intorno alle medesime del Professore Francesco Puccinotti* (Firenze: Presso Ricordi e Compagno, 1834), 14–15. All translations are by the author unless otherwise noted.

[16] Using his galvanometer, Nobili had performed some electrophysiological experiments in the city of Reggio Emilia, availing himself of the help of three "very skilled doctors and surgeons" present in that city with regard to the anatomical preparation of some live animals. See Leopoldo Nobili, "Esperienze elettro-fisiologiche. Del Cavaliere Leopoldo Nobili," Giornale di Fisica, Chimica, Storia Naturale Medicina ed Arti **8** (1825), 269–77.

[17] Leopoldo Nobili, *Sopra l'elettricità animale. Lettera, Firenze 30 Settembre 1834* (Firenze: Tipografia Allegrini e Mazzoni, 1834), 1. Also published in French: "Expériences sur l'électricité animale", *Bibliothèque Universelle* **57** (October 1834), 174–79.

[18] Leopoldo Nobili, "Comparaison entre les deux galvanometres les plus sensibles, la grenouille et le multiplicateur a deux aiguilles, suivie de quelques résultats nouveaux", *Annales de Chimie et de Physique* **38** (1828), 225–245; Leopoldo Nobili, "Analyse expérimentale et théorique des phénomènes physiologiques produits par l'électricité sur la grenouille; avec un appendice sur la nature du tétanos et de la paralysie, et sur les moyens de traiter ces deux maladies par l'électricité," *Annales de Chimie et de Physique* **44** (1830), 60–94.

[19] Nobili interpreted this current as generated by the temperature difference that arose due to the different evaporation between the frog's muscle and nerve tissues. See Nobili, "Analyse expérimentale et théorique" (ref. 18), 87.

[20] The use of this sophisticated and very sensitive instrument laid the foundations of modern experimental electrophysiology.

[21] Luigi Pacinotti and Francesco Puccinotti, *Esperienze sulla esistenza e le leggi delle correnti elettro-fisiologiche negli animali a sangue caldo eseguite dai professori Francesco Puccinotti e Luigi Pacinotti nel Gabinetto fisico della Università di Pisa nei mesi di giugno e luglio del 1839* (Pisa: presso i Fratelli Nistri, 1839), 3.

[22] Puccinotti, *Lezioni sulle malattie nervose* (ref. 15).

[23] The influence of Nobili's thought is clear here. He had designed his astatic galvanometer to measure both hydroelectric currents (produced by chemical actions) and thermoelectric currents (produced by a temperature gradient).

[24] Puccinotti, *Lezioni sulle malattie nervose* (ref. 15), 79.

[25] Taking up an observation already present in writing by Nobili (Nobili, *Esperienze elettro-fisiologiche*, ref. 16, 269), Puccinotti emphasizes that this vision was supported by "Ritter, Humboldt, Berzelius, Davy, Prokaska [Prochaska], Reil, Rolando, and others of equal prestige." See Puccinotti, *Lezioni sulle malattie nervose* (ref. 15), 77.

[26] Among the examples he cites are the studies by Giovan Battista Amici (1786–1863) and John Frederick William Herschel (1792–1871) on the morphological structure of *Chara vulgaris*, an aquatic plant whose lymph circulation appeared to move under the action of a kind of electric battery, as that plant's internal structure seemed to indicate. Puccinotti, *Lezioni sulle malattie nervose* (ref. 15), 76.

[27] The lost sensitivity was stimulated through the administration of repeated electric shocks of varying intensity along the paralyzed nerves. According to Marianini, the absence of painful sensations was explained by the obstruction of some parts of the nerve to the passage of electrical fluid. The effect of the administration of repeated shocks of varying intensity and the consequent effect of the accumulation process, had the sole purpose of opening a passage and thus causing the painful sensation. See Puccinotti, *Lezioni sulle malattie nervose* (ref. 15), 78.

[28] The reference is to the mid-eighteenth-century experiments of the philosopher Johann Georg Sulzer (1720–1779) who had recreated the sensation of taste by putting two different metals in contact with each other and with the tongue. Volta also experienced that the tongue was sensitive to electric current. Finally, Puccinotti mentions the experiments on the tongue carried out by Leopoldo Nobili.

[29] Puccinotti mentions Nobili's apparatus known in Italy as a "calamite conjugate" (see ref. 13) and its ability to reproduce the sensation of light by connecting the electrical wires of the machine respectively to the inner corner of the eye and to the apex of the incisor tooth of the upper jaw. See Puccinotti, *Lezioni sulle malattie nervose* (ref. 15), 76.

[30] Pacinotti and Puccinotti, *Esperienze sulla esistenza* (ref. 21), 1–83, appxs 1–4.

[31] The original manuscript of this account is preserved in the Pacinotti Archive (AP), owned by the University of Pisa. See "Sulle correnti fisiologiche, appunto di L. Pacinotti e F. Puccinotti", AP, I.76. This account was cited in many scientific journals of that time and had four reprints in 1845, 1846, 1856 and 1858. See Pacinotti and Puccinotti, *Esperienze sulla esistenza* (ref. 21) in: (Livorno: presso Bertani Antonelli e C., 1845), 1–48; *Opere di Francesco Puccinotti Urbinate*, Part. II, (Livorno: Tip. G. Antonelli, 1846), 329–375; *Opere Mediche di Francesco Puccinotti professore già di Clinica Medica ed ora di Storia della Medicina nella I. R. Università di Pisa*, Vol. 2 (Milano: Per Borroni e Scotti, 1856), 959–996; *Opere Complete edite ed inedite di Francesco Puccinotti già professore di Clinica ed ora di Storia della Medicina nell'I. R. Università di Pisa,* Vol. II (Napoli: Presso Agostino Pellerano Libraio-Editore, 1858), 655–80.

[32] Pacinotti and Puccinotti, *Esperienze sulla esistenza* (ref. 21), 4.

[33] Pacinotti and Puccinotti, *Esperienze sulla esistenza* (ref. 21), 73.

[34] In this type of experiment, Puccinotti had been strongly influenced by the method used by Leopoldo Nobili in 1825 (see ref. 16).

[35] The president Configliachi also invited Vincenzo Antinori to attend the experiments, who thus joined the two commissions elected from among the physicists and doctors. See Anonymous, *Atti della Prima Riunione degli Scienziati Italiani tenuta in Pisa nell'Ottobre del 1839* (Pisa: Tipografia Nistri, 1840), 42.

[36] Through this instrument he was a tenacious supporter of the importance of optical microscopy, the surprising effects of which he showed in his treatise on "nervous diseases."

[37] Pacinotti and Puccinotti, *Esperienze sulla esistenza* (ref. 21), ”Ai Fisici e Fisiologhi“, foreword by Puccinotti, 5.

[38] Pacinotti and Puccinotti, *Esperienze sulla esistenza* (ref. 21), 69. After the discovery in 1821 of thermoelectricity by the German romantic physicist Thomas Seebeck (1770–1831), the electric currents' origin had been traced to only two causes: that generated by a temperature difference existing between the welds of two different metals (thermoelectric currents) and that produced by the electrochemical pile of Volta (hydroelectric currents).

[39] Gilles Toussaint Gourjon, born in Rouen in 1795, was a skilled Parisian scientific instrument maker and one of Macedonio Melloni's trusted builders. He worked at the Ecole Royale Polytechnique in Paris, first as conservator of the *Cabinet des Modèles* and, starting from 1837 and until at least 1852, as conservateur of scientific collections. His name can be found in the list of participants in the Pisa Congress of 1839 with the following caption: "*Gourjon di Rouen, addetto alla Scuola Politecnica di Parigi.*" See Anonymous, "Elenco dei componenti la prima riunione de' naturalisti, medici ed altri scienziati italiani tenuta in Pisa nell'Ottobre 1839", in *Nuovo Giornale de' Letterati* **106** (1839), 8; Anonymous, *Il Congresso di Pisa. Lettere di Gottardo Calvi* (Milano: Vedova di A. F. Stella e Giacomo Figlio, 1839), 27.

[40] The modification of Nobili's galvanometer arose in 1833 due to Melloni's need to improve his thermo-multiplier, an apparatus consisting of a galvanometer and a thermoelectric pile for measuring radiant heat. See Macedonio Melloni, "Nouvelles recherches sur la transmission immédiate de la chaleur rayonnante par différens corps solides et liquides. Présentées à l'Académie le 21 Avril 1834," *Annales de Chimie et de Physique par MM. Gay-Lussac et Arago* **55** (1833), 393.

[41] According to the judgment of the Italian physicist Francesco Zantedeschi (1797–1873), Gourjon's multipliers were "the most exquisite and most perfect that science possesses." See Francesco Zantedeschi, *Trattato del Magnetismo e della Elettricità dell'Abate Francesco Zantedeschi,* (Milano: Dalla Tipografia di Gio. Silvestri, 1846), 58. [citing volume 2 of this series] An instrument of the same type had already been used in 1838 by Carlo Matteucci. This last apparatus (figure 7), built by T. Gourjon and equipped with a coil of 2500 windings, enabled Matteucci to measure the muscular current in a frog. See Carlo Matteucci, "Sur le courant électrique ou propre de la grénouille par M. Charles Matteucci. Second mémoire sur l'electricité animale, faisant suite à celui sur la torpille," *Bibliotheque Universelle de Genève* **15** (1838), 159.

[42] This experiment, as we will see, was performed not in Pisa but in Florence, at the Imperial Royal Museum of Physics and Natural History.

[43] The main constructive difference between this model and the one capable of detecting thermoelectric currents was the different type of coil with several turns (insulated with silk wire) that could be mounted on the instrument. The coils with a low number of turns (100–200 windings) but with a large diameter wire (typically 0.5–1 millimetres) allowed the measurement of low intensity thermoelectric currents; vice versa, coils with a high number of turns (1,500–3,000 windings) and with a thinner diameter (typically 0.1–0.15 millimetres) were more suitable for detecting hydroelectric currents. See Zantedeschi, *Trattato del Magnetismo* (ref. 41), 58.

[44] It was a belief of the experimenters that a long and painful anatomical preparation (such as trepanation of the skull) before immersion of the electrodes could weaken the intensity of the electrovital current.

[45] In this scheme the testing of the ideas brought forward in Germany by the polarist movement are evident. In Italy, this research programme began in 1825 thanks to Leopoldo Nobili's work: Nobili, "Esperienze elettro-fisiologiche" (ref. 16), 269–77.

[46] Nobili, "Esperienze elettro-fisiologiche" (ref. 16), 272.

[47] Claude Servais Mathias Pouillet, "Note sur les phénomènes électro-magnétiques qui se manifestent dans l'acupuncture," *Journal de Physiologie Expérimentale et Pathologique* **5** (1825), 5–16.

[48] The same experimental procedure was adopted by Nobili in 1825 to invalidate the galvanometric measurement of a small electric current found by inserting the tips of two metal needles into the artery of the thigh of a live sheep: Nobili, "Esperienze elettro-fisiologiche" (ref. 16), 274.

[49] This measurement referred to the deflection, in the astatic system, of the upper needle of the galvanometer. This could rotate on a graduated disk with a central split. There was a relationship between current intensity and needle deflection.

[50] Pacinotti and Puccinotti, *Esperienze sulla esistenza* (ref. 21), 35.

[51] This is a waterproof mineral bitumen paint, sometimes also called "asphalt," extracted from hard coal.

[52] Pacinotti and Puccinotti, *Esperienze sulla esistenza* (ref. 21), 39.

[53] Pacinotti and Puccinotti, *Esperienze sulla esistenza* (ref. 21), 47.

[54] The fish, which came from Pisa's seacoast, had a diameter of 27.9 cm and the electrical organ measured 10.65 cm.

[55] Pacinotti and Puccinotti, *Esperienze sulla esistenza* (ref. 21), 48.

[56] Pacinotti and Puccinotti, *Esperienze sulla esistenza* (ref. 21), 43–44.

[57] A current with these characteristics was detected on a wounded but alive rabbit (experiment number twenty) through electrodes placed in simple contact between the animal's liver and stomach.

[58] Pacinotti and Puccinotti, *Esperienze sulla esistenza* (ref. 21), 77.

[59] This instrument could perhaps be identified with a portable galvanometer (suitable for hydroelectric currents) now in the *Museo Galileo* in Florence (Inv. No. 366). The Florence Royal Museum of Physics and Natural History purchased it in 1835 from the Florentine instrument maker Corrado Wolf. See Willem Hackmann, *Museo di Storia della Scienza. Catalogue of Pneumatical, Magnetical and Electrical Instrumens* (Prato: Giunti Editore, 1995), 168.

[60] Pacinotti and Puccinotti, *Esperienze sulla esistenza* (ref. 21), 69–70.

[61] It is not known whether in addition to the two sensitive galvanometers for thermoelectric currents, a third galvanometer for hydroelectric currents was also available in Pisa that year. It could be hypothesized that Antinori brought his portable galvanometer from Florence at Puccinotti's request.

[62] More precisely, researchers observed that, immediately after the first immersion of the electrodes, the current increased in intensity (indicated by the motion of the needle) until it reached a maximum displacement and then slowly receded towards zero unless the animal was shaken (for example, by pricking it with a small knife) in such a way as to make the needle resume its initial path in proportion to the shaking.

[63] Pacinotti and Puccinotti, *Esperienze sulla esistenza* (ref. 21), 77–80, appxs 5–6; Anonymous, *Atti della Prima Riunione* (ref. 35), 259–60.

[64] Anonymous, *Atti della Prima Riunione* (ref. 35), 259.

[65] Anonymous, *Atti della Prima Riunione* (ref. 35), 261.

[66] François Magendie, *Leçons sur les Phénomènes physiques de la Vie* (Paris: J. Angé et C[le] Editeurs. 1837), 14.

[67] Maurizio Bufalini, "Osservazioni sul sangue umano e considerazioni sui metodi di più conveniente investigazione intorno ai fenomeni dei corpi organici, lettera al Prof. Bartolommeo Panizza," *Giornale per servire ai progressi della Patologia e della Terapeutica* **9** (1838), 46–47.

[68] Anonymous, *Atti della Prima Riunione* (Ref. 35), 51–52.

[69] Pacinotti and Puccinotti, *Esperienze sulla esistenza* (ref. 30), appxs 5–7.

[70] This same judgment, related to Matteucci's currents, is also found in a text by Nobili where harsh criticisms of Matteucci's studies are expressed. In this paper, Nobili explicitly disputes the claim that the currents measured by Matteucci were the result of "life forces." See Nobili, *Sopra l'elettricità animale* (ref. 17), 4. Donné, however, in an experimental work of 1834, refuted Matteucci's claim by stating that the processes of animal secretion were the result of electrochemical effects that persisted even after death. See Alfred François Donné, "Recherches sur quelques-unes des propriétés chimiques des sécrétions, et sur les courants électriques qui existent dans les corps organises," *Annales de Chimie et de Physique* **57** (1834), 398–416.

[71] Matteucci, *Sur le courant électrique* (ref. 41), 157–68.

[72] Anonymous, *Atti della Prima Riunione* (ref. 35), 258.

[73] Carlo Matteucci, *Mémoire sur l'électricité animale* (Firenze: Tipografia Galileiana, 1834). Republished in *Annales de Chimie et de Physique* **56** (1834), 439–443; *Bibliothèque Universelle des Sciences, Belles-Lettres et Arts* **57** (1834), 174–79.

[74] Matteucci, *Sur le courant électrique* (ref. 41), 161.

[75] Matteucci, *Sur le courant électrique* (ref. 41), 164–65.

[76] Carlo Matteucci, "Expérience rapportées dans un paquet cacheté déposé par M. Dumas, au nom de M. Matteucci, et dont l'auteur, présent à la Séance, désire au-jourd'hui l'ouverture," *Comptes Rendus Hebdomadaires des Séances de l'Académie des Sciences* **15** (1842), 797–98.

[77] "Mr. Matteucci deceived himself in this, as in his first pneumogastric experiments; and it is a benefit this deception, because in this way the hope of discovering, in some favourable case, the existence of electric currents inside certain organs is not completely extinguished, without mutilating them, without cutting them in two parts. This is the research that matters radically": Nobili, *Sopra l'elettricità animale* (ref. 17), 3.

[78] Exhaustive reports on the Pisan Congress had been published in various European countries, for example in England, in the scientific journal *Philosophical Magazine*. For an exhaustive press review of the newspapers of the various Italian pre-unification states, see Natalina Crevani and Alessandra Pesante, "Il Primo Congresso degli Scienziati nei periodici italiani. Bibliografia: 1839–1840," in Beatrice Bargagna, Natalina Crevani, Edith Moscatelli, Alessandra Pesante and Renato Tamburrini, eds., *La prima riunione degli scienziati italiani (Pisa 1839). Notizie biografiche e bibliografiche* (Pisa: Giardini editori e Stampatori in Pisa, 1989), 115–54.

[79] See, for example, the following articles that appeared in some scientific journals of the time between late 1839 and 1840: Anonymous, "Esperienze sulla esistenza e le leggi delle correnti elettro-fisiologiche negli animali a sangue caldo, eseguite dai professori Francesco Puccinotti e Luigi Pacinotti nel Gabinetto di Fisica dell'Università di Pisa ne' mesi di Giugno e luglio del 1839," *Il Filiatre-Sebezio. Giornale delle Scienze Mediche* **108**, no. 9 (1839), 415–23; Anonymous (signed D. G. C.), "Sull'elettricità animale: esperienze dei professori Francesco Puccinotti e Luigi Pacinotti," *Il Politecnico* **2** (1839), 318–24; Telemaco Metaxà, "Esperienze sulla esistenza e le leggi delle correnti elettro-fisiologiche negli animali a sangue caldo, eseguite dai Professori Francesco Puccinotti e Luigi Pacinotti nel Gabinetto Fisico dell'Università di Pisa nei mesi di Giugno e Luglio del 1839," *Annali Medico-Chirurgici compilati a cura del Dott. Telemaco Metexà* **2**, no. 1 (1839), 35–43; Adolfo Benvenuti and Leovigildo Paolo Fario, "Sunto delle esperienze sulla esistenza delle correnti elettro-fisiologiche negli animali a sangue caldo, eseguite dai prof. dell'Università di Pisa Puccinotti (Francesco) e Pacinotti (Luigi)," *Memoriale della Medicina Contemporanea* **2** (1839–1840), 315–20 and **3** (1839–1840), 103–18; Anonymous, "Esperienze sulla esistenza e le leggi delle correnti elettro-fisiologiche negli animali a sangue caldo, di F. Puccinotti e L. Pacinotti," *Biblioteca Italiana o sia Giornale di Letteratura, Scienze ed Arti* **98** (1840), 81–87.

[80] Geminiano Grimelli, Osservazioni ed esperienze elettro-fisiologiche dirette ad istituire la elettricità medica (Modena: Coi tipi Vincenzi e Rossi, 1839). Reprinted in Memoriale della medicina contemporanea **3** (1840), 282–305, 603–21.

[81] These experiences also aroused some interest abroad. Consider, for example, the report by the Belgian zoologist François-Joseph Cantraine (1801–1868) which later had a wide international circulation. See François-Joseph Cantraine, "Rapports. Electro-physiologie. Rapport de M. Cantraine sur le mémoire de MM. le professeur Zantedeschi et le docteur Favio, présenté à la Séance de l'Academie Royale de Bruxelles le 4 avril 1840," *Bulletin de l'Académie Royale des Sciences et Belles-Lettres de Bruxelles* **7** (1840), 43–50. Also published in *Archives de L'Electricité* **1** (1841), 474–77; *The London, Edinburgh and Dublin Philosophical Magazine and Journal of Science* **18** (1841), 271–76; *Froriep Robert. Neue notizen aus dem gebiete der natur- und heilkunde* **18** (1841), 129–33.

[82] Leovigildo Paolo Fario and Francesco Zantedeschi, "Esperienze intorno alle correnti elettro-fisiologiche negli animali a sangue caldo," *Memoriale della medicina contemporanea* **3**, nos. 2 and 3 (1840), 223–60.

[83] Alessandro Checcucci, *Lettere scientifiche e familiari di Francesco Puccinotti* (Firenze: Successori Le Monnier, 1877), 166.

[84] In the letter to Valorani, Puccinotti stated: "If Bologna remains incredulous, it will take patience. I wish this disbelief showed no unfavourable difference between Galvani's luminous period and this one today in your learned city": Checcucci, *Lettere scientifiche* (ref. 83), 166.

[85] Ulisse Breventani, "Relazione di Esperienze elettro-fisiologiche istituite assieme al prof. Silvestro Gherardi, ed ai dottori M. Paolini, e L. Benfenati, nel Gabinetto di Fisica della nostra Università nei mesi di Maggio, Giugno e Luglio di questo stesso anno. Relazione letta da Ulisse Breventani nella seduta del 26 Dicembre 1840," *Bullettino delle Scienze Mediche pubblicato per cura della Società Medico-Chirurgica di Bologna* **12**, no. 2 (1841), 41.

[86] Carlo Francesco Bellingeri, Secondo Giovanni Maria Berruti, Girolamo Botto, Giovanni Demarchi, Lorenzo Girola, and Germano Sisto Malinverni, "Sulla esistenza delle correnti elettro-fisiologiche negli animali a sangue caldo eseguite nel gabinetto di fisica della R. Università di Torino dal professore di fisiologia Berruti in compagnia dei chiarissimi professori Botto e Girola, e dei dottori collegiati cav. Bellingeri, Demarchi e Malinverni," *Giornale delle Scienze Mediche Compilato da Varii Membri della Facoltà Medico-Chirurgica di Torino* **9**, no. 3 (1840), 57–87.

[87] Anonymous, *Atti della Seconda Riunione degli Scienziati Italiani tenuta in Torino nel Settembre del 1840* (Torino: Tipografia Cassone e Marzorati, 1841), 565–66.

[88] Anonymous, *Atti della Seconda Riunione* (ref. 87), 592–93.

[89] The publication, in 1840, of the *Essai sur les phénomènes électriques des animaux* by Matteucci (Paris: Carilian-Goeury et V^{r}. Dalmont), aroused the German physiologist and anatomist Johannes Peter Müller's (1801–1858) interest. The latter pointed out the work to his pupil, Du Bois-Reymond, who thus, in 1841, began to deal with animal electricity. See Margaret Rowbottom and Charles Susskind, *Electricity and medicine. History of their interaction* (San Francisco: San Francisco Press, Inc., 1984), 91.

[90] Giuseppe Moruzzi, "The electrophysiological work of Carlo Matteucci," *Brain Research Bulletin* **40**, no. 2 (1996), 69–91.

[91] Laura Otis, Müller's Lab (New York: Oxford University Press US, 2007), 94.

[92] He used different galvanometric coils: 6,000 turns, then doubled and finally, in 1848, 24,160 turns. This last, compared to Matteucci's galvanometric coil, which, as mentioned, had 3,000 turns of fine copper wire, was eight times longer, amounting to more than five kilometers of silk-coated fine copper wire. See Galina Kichigina, *The Imperial Laboratory. Experimental Physiology and Clinical Medicine in Post-Crimean Russia* (Amsterdam: Rodopi Editions, 2009), 50.

[93] Alan J. McComas, *Galvani's Spark. The Story of the Nerve Impulse* (London: Oxford University Press, 2011), 24.

[94] Pacinotti and Puccinotti, *Esperienze sulla esistenza* (ref. 21), 82.

[95] Pacinotti and Puccinotti, *Esperienze sulla esistenza* (ref. 21), 80.

[96] This order of magnitude varies according to the size of the muscle.

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