Archives Italiennes de Biologie, 149 (Suppl.): 3-9, 2011.

Carlo Matteucci and the legacy of Luigi Galvani

M. BRESADOLA

Department of Humanities and Neuroscience Center, University of Ferrara, and National Institute of Neuroscience, Italy

ABSTRACT

Carlo Matteucci (1811-1868) is considered one of the founders of electrophysiology, thanks to his research on electric fish, nerve conduction, and muscular contraction. In this essay Matteucci's early investigation into life processes is discussed in the context of the debates on Galvanism, a new scientific field inaugurated by the discovery of animal electricity made by Luigi Galvani in the 1790s. Matteucci rejected both a "physicalist" and a "vitalist" interpretation of the phenomena of Galvanism, adopting instead the same view which had guided Galvani in his research on animal electricity. In this regard, Matteucci can be considered the true scientific heir of Galvani.

Key words
Matteucci, Carlo • Galvani, Luigi • Galvanism • History of electrophysiology

Introduction

In an article published in 1964, which still remains the most relevant study of Carlo Matteucci's scientific work, Giuseppe Moruzzi claimed that "the electrophysiological work to which [Matteucci] owes imperishable fame begins in 1836" (Moruzzi, 1964; English translation in Moruzzi, 1996, p. 70). It was in that year, in fact, that Matteucci identified the nervous centres responsible for the electrical discharge of Torpedo. Then, in 1838, he published some fundamental research on the electrical nature of muscle contraction and nerve conduction, which brought him within a few years to discover the muscle demarcation current and the action current. He also made an observation of capital importance, the "negative Schwankung" (the negative oscillation), which, correctly interpreted by du Bois Reymond, marks the "beginnings of modern electrophysiology", as Moruzzi wrote in his article (Moruzzi, 1996, p. 84).

In my paper I shall not discuss Matteucci's contribution to electrophysiology, which was the topic of Moruzzi's article; instead, I shall focus on some minor works which Matteucci published in the early 1830s, in the period that preceded his major discoveries. My aim is to reconstruct the context in which Matteucci's electrophysiological research began, and to identify some interests and motives which guided Matteucci in his scientific investigation. To this end I shall examine the content of two papers which Matteucci published in 1830 and which concerned some phenomena that were included in the realm of Galvanism; then I shall outline a brief history of Galvanism in the first three decades of the 19th century, in order to highlight the multiple meanings of this term in different disciplinary and cultural contexts; and finally, I shall identify the connection between Matteucci's early investigation and a specific tradition of Galvanism. This tradition retained the fundamental aspects of the work of Luigi Galvani while developing them by adopting new instruments such as the battery and the galvanometer. In this regard, Matteucci can be considered the scientific heir of Galvani and his

Corresponding Author: Marco Bresadola, Department of Humanities and Neuroscience Center, University of Ferrara, and National Institute of Neuroscience, Italy - Tel.: +39 0532 293412 - Email: marco.bresadola@unife.it

work the fulfilment of Galvani's investigation into animal electricity.

Matteucci's 1830 papers

The first electrophysiological work published by Matteucci is a brief Memoir which appeared in Forlì, his native city, in November 1830. Matteucci was only nineteen years old, and he had just returned from a one-year period of study spent in Paris, where he had established friendly relationships with prominent scientists such as François Arago and Antoine César Becquerel (the grandfather of the discoverer of radioactivity) (Bianchi, 1874). In this work Matteucci focussed on muscular contractions that could be observed in an animal when the electrical circuit in which it was included, was interrupted. This observation had been made a long time before, but it had received a renewed attention in the previous years thanks to two Italian scientists, Leopoldo Nobili and Stefano Marianini (Mazzolini, 1986). Matteucci confirmed the observations made by Nobili and Marianini, but criticized Marianini for his explanation in terms of a condensation of the electric current in the neuro-muscular system. Instead, for Matteucci the contractions depended on the structure of muscular and nervous fibres, which reacted to the action of the electric stimulus by shortening and relaxing (Matteucci, 1830b).

I shall return to Matteucci's interpretation, as it implies a particular view of vital phenomena which he developed from the very beginning of his scientific career. What I would like to stress here is that Matteucci placed the topic of his Memoir in a specific field, which he called "the science of Galvanism" (Matteucci, 1830b, p. 1). In fact, the observation of muscular contractions occurring when an electrical circuit was interrupted, had been already made by Luigi Galvani and Alessandro Volta in the 1790s, during the controversy on animal electricity opened by Galvani's publication of his *De viribus electricitatis in motu musculari* (1792) (Bresadola, 1998; Piccolino and Bresadola, 2003; Pancaldi, 2003). But, while Volta's merit as an early observer of the phenomenon was recognized by Matteucci's contemporaries, Galvani's was not, a clear sign of the uneven reception that the work of these two great men of science had in the first decades of the 19th century.

By the 1830s, however, Galvanism was not limited to the repetition of Galvani's and Volta's experiments, but included, more generally, all the research made on the effects of electricity on animal tissues. In this regard a second paper published by Matteucci in 1830 also belonged to the realm of Galvanism, even though it did not derive directly from Galvani's research. It appeared in an important scientific journal, the *Annales de Chimie et de Physique*, some months before the one I have just discussed. The journal was edited by François Arago and Joseph Louis Gay-Lussac, and it was a point of reference for all chemists and physicists of the time, especially in the investigation of the phenomena related to the battery. In this paper, which he published during his stay in Paris, Matteucci reported some experiments aimed at testing "the analogy between [bodily] secretions and electrochemical decompositions" (Matteucci, 1830a, p. 256). He had applied a battery of fifteen elements to the peritoneum, liver and other secretory organs of rabbits and other animals, obtaining different liquids at the two opposite poles. From these experiments Matteucci concluded that the analogy between the process of biological secretion and that of electrochemical analysis rested on positive evidence, and he proposed a research programme aimed at establishing the "electrical state [l'état electrique] of the secretory organs" (Matteucci, 1830a, p. 258). From Matteucci's words in this paper, as well as in the one on muscular contractions, the idea thus emerges that electricity had an active role in vital phenomena, and that Galvanism was a fruitful tool for exploring fundamental life processes like secretion and animal motion. But what did Galvanism exactly mean for Matteucci and his contemporaries?

Galvanism in the early 19th century

Around 1830 the term Galvanism was used in different disciplines and with different meanings. In a popular textbook on natural philosophy we find it included in the part devoted to electricity. Here Galvanism meant both a way to produce electricity, mainly through the use of the battery, and a natural agent with a problematic relation to electricity: "It is remarkable – we read in a section of this book – that among the many strong resemblances between electricity and galvanism, we nowhere find a perfect accordance" (Fischer, 1827, p. 201). Electricity and Galvanism were, instead, kept completely separated in chemistry textbooks such as the popular *Elements of chemistry* by Edward Turner, in which Galvanism was treated as one of the "imponderable substances" existing in nature, along with caloric, light, and electricity (Turner, 1827). But Galvanism appeared also in medical books, especially with regard to the treatment of some pathologies through the use of instruments such as the battery (Morus, 1992).

The epistemological status of Galvanism, at the same time ubiquitous and ambiguous, reflected its history in the early decades of the 19th century (Bresadola and Pancaldi, 1999). It is difficult to establish who first introduced the term, but we find it increasingly adopted from the mid 1790s. It replaced terms such as "animal electricity" and "Galvanic experiments", which were used either by Luigi Galvani or in the early publications about his work (Kipnis, 1987; Bresadola, 2008). The change in terminology reflected a broadening in the objectives and interests of those who took up Galvani's investigations; indeed, Galvanism designated increasingly the experimental approach, the apparatus, and the animal preparation techniques deriving not only from Galvani's work but also from the contributions of Volta and of the other protagonists of the new field. One of these protagonists, Alexander von Humboldt, wrote that "Galvanism is a new branch of physiology", and stressed the epistemological neutrality of the term: "The word Galvanism does not absolutely refer to the cause of phenomena" (Humboldt, 1799, pp. xiii, x). Although Humboldt held specific ideas about the nature of vital phenomena, his rhetorical appeal to avoid enquiring into "causes" implied the possibility of divorcing the experimental investigation from the debate on the nature of the fluid involved in Galvani's research.

Key tools of experimental Galvanism were the frog prepared in Galvani's manner, the combinations of metals and other conductive substances investigated mainly by Volta, and electrical instruments like the frictional machine and the electrical capacitor (Bresadola, 2001).

After Volta's invention of the battery in 1800, Galvanism acquired a new and powerful instrument, which opened up entirely new fields of research. The "galvanic battery", as it was commonly called, was used in the study of animal motion and other vital processes, and it was applied to the treatment of diseases, inaugurating the field of medical Galvanism. But the battery also contributed to the emergence of novel scientific disciplines, like electro-magnetism, thermo-electricity and electrochemistry, which initially retained important connections with Galvanism. For instance, the title of George Singer's textbook *Elements of electricity and electro-chemistry* was translated into French as *Élémens d'électricité et de galvanisme*, showing a clear overlap between electro-chemistry and Galvanism (Singer, 1817). In fact, the investigation of the chemical effects of the application of the battery to organic and inorganic substances became an important investigative field after the research of Humphry Davy and Michael Faraday. As we have seen, Matteucci's early research in Paris was also concerned with the chemical composition of organic fluids investigated through the battery.

Thus, in the early decades of the 19th century the battery stimulated the research in the domain of Galvanism, as well as inaugurating new investigations into the phenomena of living and non-living beings. But this instrument played also a fundamental role in deciding the controversy between Galvani's theory of animal electricity and Volta's theory of metallic electricity. In the introduction to his *Account of the History and Present State of Galvanism*, published in 1818, John Bostock, an influential English physician and fellow of the Royal Society, wrote: "Galvanism is a branch of natural philosophy, entirely of modern origin, which derives its name from Galvani, professor of anatomy at Bologna". Then he went on: "Galvani had the good fortune to make some observations on the electricity of the muscles of frogs, that appeared to him to depend upon a new power in the animal body; […] to the supposed new power he gave the name of animal electricity, conceiving to depend upon something inherent in the animal body itself; but we now regard these effects as produced by minute quantities of the electric fluid, set at liberty by a certain [chemical] agency of substances upon each other" (Bostock, 1818, p. 1).

Bostock's opinion was shared by many scientists involved in the study of Galvanism, who used the tools and experimental procedures developed by Galvani, including his prepared frog and some of his experimental settings, refuting at the same time his idea of an electricity intrinsic to the animal body. This is the case, for instance, of Leopoldo Nobili, who in the late 1820s carried out some important research on Galvanism. He found that he could obtain the contractions of a frog's leg, prepared in Galvani's manner, when a connection between muscle and nerve was established, without the presence of any metallic material. He thus confirmed an observation already made by Galvani more than thirty years before, but Nobili was also able to ascertain, with his astatic galvanometer, the presence of an electric current flowing from the frog's muscle to its nerve. This was an outstanding result, but Nobili interpreted the existence of the "frog current" as an effect of thermoelectric phenomena of the animal parts, instead of a demonstration of biological electricity (Mazzolini, 1986; Piccolino and Bresadola, 2003).

Although Nobili's opposition to animal electricity was shared by many scientists in the early 19th century, there were some notable exceptions. In the wake of authors like the Tuscan physician Eusebio Valli and the German naturalist Alexander von Humboldt, Galvanism was taken as a vital force analogous to electricity but not identical to it, which could play a fundamental role in the phenomena of life (Strickland, 1995; Poggi, 2000). As it is well known, this idea exerted a profound influence on German *Naturphilosophie*, but it had supporters in many other cultural contexts. For instance, Francesco Orioli, professor of physics at the University of Bologna, published in 1827 a Memoir in which he discussed some electric therapies. In his Memoir he claimed that it was possible to modify the laws of life by modifying the electric condition of the bodily parts, as the title of his paper suggested (Orioli, 1827).

At the time Orioli was working on Galvanism, Matteucci was one of his pupils at the University of Bologna. Another of Matteucci's teachers was Michele Medici, professor of physiology and the official historian of medicine in Bologna. Medici wrote an influential history of anatomy and a number of eulogies of prominent members of Bologna University, including Galvani. His opinion about Galvani's discovery was that although "the existence of animal electricity and his action in muscular motion is not mathematically proved", there were sufficient arguments to "believe that electricity is not communicated to the living body by external causes or powers, but it is intrinsic to the body and it is the effect of vital actions" (Medici, 1845, pp. 20-21).

For scholars such as Orioli and Medici, Galvani's theory of animal electricity still represented a guiding principle in the investigation of life processes, and this certainly contributed to Matteucci's early interest in Galvanism. Matteucci then developed this interest in France, where he had the opportunity to acquire new knowledge and new experimental skills in the field of Galvanism, choosing it as his research programme. The two 1830 papers discussed above were thus the result of Matteucci's education in the cultural milieus of Bologna and Paris, as well as the beginning of his successful scientific career. The first steps of this career have not been fully studied by historians, and in the last part of my essay I shall present some aspects of Matteucci's early research on Galvanism.

Matteucci's Galvanism

Matteucci's 1830 Memoir on muscular contractions produced by the interruption of the electric circuit had an immediate resonance in the Italian scientific community. The first issue of the *Annali delle scienze del Regno Lombardo-Veneto*, edited by the Venetian physicist Ambrogio Fusinieri, published a critical response to Matteucci by Stefano Marianini, who accused the young colleague of having misunderstood his research and of having proposed a wrong explanation of the phenomena (Fusinieri, 1831). It is possible that the critique received from an established scientist like Marianini convinced Matteucci to give up, at least temporarily, the topic of muscular motion, and to focus on the other research he had started in Paris, that on animal secretions. In fact, in the following years Matteucci published four papers on this topic, the last one carrying the title *Memoir on animal electricity* (Matteucci, 1834a).

In these papers Matteucci developed his experimental research on the effects of the battery on organic substances. He confirmed that different sorts of animal fluids were produced around the positive and negative poles of the battery, and he found that the chemical elements contained in urine and bile could be explained by the different electrical state of the liver and the kidneys (Matteucci, 1832). He also explained the production of chyme by the existence of a positive electricity in the stomach, which derived from the action of the nerves on this organ (Matteucci, 1833). Finally, he confirmed the observation made by the French physician Alfred Donné (the pioneer of medical photography) that an electrical current could be detected in the stomach and in the liver. For Matteucci, all these results showed that electro-chemical phenomena played a fundamental role in life processes like secretion and digestion and that opposite electrical charges characterized all bodily organs (Matteucci, 1834a). In this regard he could claim to have fulfilled, at least partially, the research programme on the "electrical state [l'état electrique] of the secretory organs" that he had launched in one of his 1830 papers (see above).

In 1834 Matteucci felt he had already given an important contribution to Galvanism. In a paper published early that year he confidently wrote that "the existence of electrical poles in the body is certain". This did not mean, however, that animal electricity had to be seen as a vital principle proper to living bodies and completely distinct from the forces which acted in the inorganic world. Matteucci explicitly refuted the "old notion of vital forces" and saw his research as an effort to "establish physiology on the same domain of the physical and chemical sciences" (Matteucci, 1834b, p. 119). It was a clear differentiation from the tenets of Vitalism and *Natuphilosophie*, but by no means was it the same position as that of Nobili or other contemporary physicists. For Matteucci animal electricity did exist and was dependent on the specific organization of living bodies: "it is therefore – he wrote in his Memoir on animal electricity – in life and for life that these electrical states do exist and are produced in the body" (Matteucci, 1834a, p. 441).

Early in 1834 Matteucci was very confident that he had not only demonstrated the role of animal electricity in secretion, but that he had identified the nerves as the tissues which carried the electric current along the body. In fact, he was able to measure with the galvanometer an electric current in the pneumogastric nerves of a rabbit. In the following months, however, Matteucci's confidence was shaken by the failure to repeat this experiment and the ones described by Nobili on Galvani's frogs. In his *Memoir on animal electricity*, dated 10 September 1834 and published in the *Annales de chimie et de physique*, Matteucci was obliged to limit the scope of the results he had obtained in the previous four years: although he still claimed that "opposite electrical states exist in the living organs", he now admitted that he could not establish which organs produced and transmitted these electric currents. His concluding words in the paper carried a sense of disappointment but also a promise of hope, and they deserve to be quoted at length: "This electricity is hidden to us by the organization [of the living body]; one must search for this secret in the torpedo: it is there where a great discovery can be made" (Matteucci, 1834a, p. 443). It is very significant that less than two years later Matteucci was able to announce his discovery of the nervous control of the torpedo's electric organs, thus beginning the series of electrophysiological research for which his name is still so famous (Piccolino, 2011).

Concluding remarks

In conclusion I would like to stress some points that I have touched upon in this essay and which have the potential to contribute to a deeper historical understanding of Matteucci's work.

First, in the early decades of the 19th century Galvanism was a wide and ambiguous scientific field, which included different research programmes on natural phenomena and referred to different views of life processes. Matteucci entered this field when he was less than twenty years old with the experience acquired as a student in the cultural milieus of Bologna and Paris.

Second, from the very beginning of his research in the early 1830s Matteucci adopted a specific approach to Galvanism which circulated in these cultural milieus and which rested on the idea that electricity had an active role in bodily functions like secretion and muscular motion. While differing from a "physicalist" interpretation of these phenomena like that adopted, for instance, by Nobili, Matteucci also rejected a "vitalist" account of life forces. Instead, he adopted the same view that had guided Luigi Galvani in his investigation into animal electricity. In a paper published in 1832 Matteucci wrote that while "I am completely convinced that organic and inorganic matters are directed by the same forces, I feel the need to admit a different way of action of these forces, that depends on the different organization [of the physical and the biological world]" (Matteucci, 1832, p. 328). Very similar words to Matteucci's are to be found in Luigi Galvani's works, including his *De viribus electricitatis* (Piccolino and Bresadola, 2003). In this regard, Matteucci can be considered the real scientific heir of Galvani.

This leads me to make a third and last point. In 1834 Matteucci realized that the investigation of electrical phenomena of the living body had to be carried out on those animals which manifested evident electric power, such as the torpedo and other electric fish. The same conviction had led Galvani to leave Bologna and to go to the Adriatic sea in search of torpedoes about forty years earlier (Piccolino and Bresadola, 2003). For both Galvani and Matteucci this decision had momentous consequences for their future research. For Matteucci it marked a crucial step towards the discoveries that would make him one of the founding fathers of modern electrophysiology.

References

Bianchi N. *Carlo Matteucci e l'Italia del suo tempo*. Torino, Fratelli Bocca, 1874.

Bostock J. *An Account of the History and Present State of Galvanism*. London, Baldwin, Cradock, and Joy, 1818.

Bresadola M. Medicine and science in the life of Luigi Galvani. *Br. Res. Bull.*, **46**: 367-380, 1998.

Bresadola M. *Early galvanism as technique and medical practice*. In: Bertucci P. and Pancaldi G. (Eds.) *Electric bodies. Episodes in the history of medical electricity*, Bologna, CIS, 2001, pp. 157-179.

Bresadola M. Animal electricity at the end of the eighteenth century: the many facets of a great scientific controversy. *J. Hist. Neur.*, **17**: 8-32, 2008.

Bresadola M. and Pancaldi G. (Eds.). *Luigi Galvani International Workshop. Proceedings*. Bologna, CIS, 1999.

Fischer E.S. *Elements of natural philosophy*. Boston, Hilliard, Gray, Little, and Williams, 1827.

Fusinieri A. Delle scosse che provano gli animali tanto nel chiudersi quanto nell'aprirsi il circolo elettrico di Volta, di cui formano parte. *Annali delle Scienze del Regno Lombardo-Veneto*, **1**: 342-345, 1831.

Humboldt A. von. *Expériences sur le galvanisme, et en general sur l'irritation des fibres muscolaires et nerveuses*. Paris, Didot jeune, 1799.

Kipnis N. Luigi Galvani and the debate on animal electricity, 1791-1800. *Ann. Sci.*, **44**: 107-142, 1987.

Matteucci C. Action de la pile sur les substances animales vivantes. *Annales de Chimie et de Physique*, **43**: 256-258, 1830a.

Matteucci C. *Sulla contrazione provata dagli animali all'aprirsi del circolo elettrico in che trovansi*. Forlì, Tipografia di Matteo Casali, 1830b.

Matteucci C. Sulle secrezioni animali. *Annali delle Scienze del Regno Lombardo-Veneto*, **2**: 326-328, 1832.

Matteucci C. Sulla digestione. *Annali delle Scienze del Regno Lombardo-Veneto*, **3**: 220-222, 1833.

Matteucci C. Mémoire sur l'électricité animale. *Annales de Chimie et de Physique*, **56**: 439-443, 1834a.

Matteucci C. Analisi d'una nuova specie di calcolo intestinale. *Annali delle Scienze del Regno Lombardo-Veneto*, **4**: 117-119, 1834b.

Mazzolini R. Il contributo di Leopoldo Nobili all'elettrofisiologia. In: Tarozzi G. (Ed.) *Leopoldo Nobili e la cultura scientifica del suo tempo*, Bologna, Nuova Alfa, 1986, pp. 183-199.

Medici M. *Elogio di Luigi Galvani*. Bologna, Tipografia alla Volpe, 1845.

Morus I.R. Marketing the machine: the construction of electrotherapeutics as viable medicine in early Victorian science. *Med. Hist.*, **36**: 34-52, 1992.

Moruzzi G. L'opera elettrofisiologica di Carlo Matteucci. *Physis*, **6**: 101-140, 1964.

Moruzzi G. The electrophysiological work of Carlo Matteucci. *Br. Res. Bull.*, **40**: 69-91, 1996.

Orioli F. *D'un nuovo genere di rimedi dell'ordine de' meccanico-chimici, ossia d'una nuova maniera di modificare le leggi della vita modificando lo stato elettrico delle parti*. Bologna, 1827.

Pancaldi G. *Volta. Science and culture in the age of enlightenment*. Princeton, Princeton University Press, 2003.

Piccolino M. Electric fishes research in the nineteenth century, following the steps of Carlo Matteucci and Giuseppe Moruzzi. *Arch. It. Biol.*, **149** (Suppl): 10-17, 2011.

Piccolino M. and Bresadola M. *Rane, torpedini e scintille. Galvani, Volta e l'elettricità animale*. Torino, Bollati Boringhieri, 2003.

Poggi S. *Il genio e l'unità della natura. La scienza della Germania romantica (1790-1830)*. Bologna, Il Mulino, 2000.

Singer G. *Élémens d'électricité et de galvanisme*. Paris, Chez Bachelier, 1817.

Strickland S. Galvanic disciplines: the boundaries, objects, and identities of experimental science in the era or romanticism. *Hist. Sci.*, **33**: 449-468, 1995.

Turner E. *Elements of chemistry, including the recent discoveries and doctrines of the science*. Edinburgh, W. Tait, 1827.