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The Taming of the Electric Ray: From a Wonderful and Dreadful "Art" to "Animal Electricity" and "Electric Battery"

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Introduction

The period spanning from the second half of the seventeenth century up to the end of the eighteenth century is marked by a truly paradigmatic episode of the transition between the classic science, still imbued with the themes of the wonderful and fantastic, and modern science based on experimentalism and objectivity. This episode concerns the study of strange fish capable of producing, at the simple contact of their body surface, a numbness or rather a violent shock. Two of these fishes were already known to the classical world since very ancient times (the torpedo and the Nile catfish). A third species, a singular eel of the rivers of tropical America, came to the attention of naturalists only in the second half of the seventeenth century, within the climate of the scientific revolution and of the interest for exotic countries.[1] In addition to representing a fundamental transition in the knowledge of the phenomena of the animated nature, the episode of these fish (which would be called electric) was important also because it opened the path to two of the most revolutionary episodes of the Enlightenment science: the demonstration of the electric nature of nervous conduction by Luigi Galvani and the invention of the battery by Alessandro Volta (see Piccolino & Bresadola, 2003).

[1] As to the historical aspects of the interest for the electric fish see for reviews of the old literature Kellaway (1946), Moller (1995), and Musitelli (2002).

Socrates, the Torpedo and the Nightmare

In the classic era there are frequent references, in both philosophic-naturalistic and literary texts to these singular fish, indicated by Greeks with the general names of ναρκη, and by Romans as torpedo, because of their power of "benumbing" or "paralysing" the fish or the persons coming in contact with them. These effects appeared at once wonderful and dreadful. Numerous are the artistic representations of these fish, sometimes dating to very old epochs. For instance, the Nile catfish are illustrated in some Egyptian bas-reliefs of the third millennium BC.

In the Greek literature a significant reference to the torpedo is in Plato's "Meno" where the protagonist compares Socrates to a torpedo, because of the "benumbing" effects of his conversation:

> O Socrates, I used to be told, before I knew you, that you were always doubting yourself and making others doubt; and now you are casting your spells over me, and I am simply getting bewitched and enchanted, and am at my wits' end. And if I may venture to make a jest upon you, you seem to me both in your appearance and in your power over others to be very like the flat torpedo fish, who torpifies those who come near him and touch him, as you have now torpified me, I think. For my soul and my tongue are really torpid, and I do not know how to answer you; and though I have been delivered of an infinite variety of speeches about virtue before now, and to many persons - and very good ones they were, as I thought - at this moment I cannot even say what virtue is. And I think that you are very wise in not voyaging and going away from

home, for if you did in other places as you do in Athens, you would be cast into prison as a magician.[2]

Another reference of literary value is found in the *Halieutica* of the Greek poet Oppian (I–II century AD), partially inspired by verses of Homer, in which the paralysing power of the torpedo is compared to dreadful images of nocturnal dreams:

It is like the dark images of the nocturnal dreams, when a man seized by terror would like to escape and his heart accelerates. His efforts notwithstanding, a tight tie blocks his kneels, in spite of his ardent wish to escape: they are powerful shackles that the torpedo brings about against other fish. (Oppianus, 1999, vv. 81–85)

In the Latin literature is of particular significance the poem *Torpedo* written by Claudian in the fourth century AD, and dedicated to the true torpedo (the flat torpedo of the sea), depicted as a small monster of the sea abysms ready to catch its ill-fated preys after benumbing them with its malefic power. The singular power of the fish is referred to as an "indomitable art": Claudian writes that the torpedo "scarcely does it mark the sand o'er which it crawls so sluggishly" ready to stun with its "cold venom" every creature happening to touch it; eventually it "greedily devours without fear the living limbs of its victim".[3]

Claudian's allusion to the "cold venom" ("*gelido veneno*") betrays the influence of an explanation initially suggested by Galen on the basis of the similarity between the benumbing power of the fish and the action of cold bodies[4]. Galen's hypothesis was indeed a first attempt to put forward a scientific interpretation of the fish shock, outside magic or demoniac conceptions, and well within the frame of the classic physiology. This was based on the well-known theory of the four qualities (dry, cold, moist and hot) in relation with the four elements (earth, water, air and fire) and the four humours (yellow bile, black bile, phlegm and blood).

In his poem Claudian makes allusion to the possibility that the dreadful power of the fish could act at distance, in the absence of an immediate contact. He narrates that if the torpedo:

carelessly swallow a piece of bait that hides a hook of bronze [. . .] it does not swim away nor seek to free itself by vainly biting at the line; but artfully approaches the dark line and, though a prisoner, forget not its skill, emitting from its poisonous veins an effluence which spreads far and wide through the water. The poison's bane leaves the sea and creeps up to the line; it will soon prove to much for the distant fisherman. The dread paralysing force rises above the water's level and climbing up to the drooping line, passes down the jointed rod, and congeals, e'ver he is aware of it, the blood of the fisherman's victorious hand.

The possibility that torpedo's effects might reach other fish (or persons) by the way of intermediate bodies was explicitly denied by some naturalists and philosophers but supported by others who based their contention mainly on the reports of fishermen. These claimed that the fish shock was normally transmitted through the water and the fishing nets. According to them, in order to detect torpedoes among the captured fish it sufficed to pour sea water over the net and a shock was immediately felt if live torpedoes were present. This was a clear indication that the shock could propagate through water.

Another important reference to torpedo in Latin texts is that of Scribonius Largus, a physician of the Roman Empire who advised the use of the torpedo shock for alleviating pain, particularly in the case of gout and headache:

For any type of gout a live black torpedo should, when the pain begins, be placed under the feet. The patient must stand on a moist shore washed by the sea, and he should stay like this until his whole foot and leg up to the knee is numb. This takes away present pain and prevents pain from coming on if it has not already arisen. In this way Anteros, a freedman of Tiberius, was cured.[5]
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[2] Plato, "Meno" – English translation by Jowett in 'The Dialogues of Plato' 1892, p. 39, Sect. 80.

[3] I follow here with some modifications the English version of Barrie Hall in Claudianus C. 1985, poem XLIX; see also Claudianus C. 1922.

[4] See for instance Galenus (1533, p. 10; and 1541, p. 406). Galenus was, however, uncertain as to the true nature of the torpedo's shock. Extracts of torpedo's liver were used for their medical and/or magic power, and were supposed to have anti-aphrodisiac effects (Trallianus, 1557, pp. 71–72, 115–116; Lacroix, 1868, p. 84; see, however, Redi, 1671, p. 41).

[5] The black torpedo mentioned by Scribonius is the *Torpedo nobiliana*, found in Atlantic Ocean but relatively rare in the Mediterranean sea. It is much larger than the common torpedoes (sometimes reaching the length of 180 cm) and its shock can be rather severe (more than 100 V).

> Headache, even if it is chronic and unbearable, is taken away and remedied forever by a live torpedo placed on the spot which is in pain, until the pain ceases. As soon as the numbness has been felt the remedy should be removed lest the ability to feel be taken from the part. Moreover, several torpedo's of the same kind should be prepared because the cure, that is, the torpor which is a sign of betterment, is sometimes effective only after two or three.[6]

In addition to this analgesic use of the shock of live torpedoes (likely effective as a kind of electrotherapy *ante litteram*), parts of the fish body, and notably the liver, were employed to prepare potions or ointments, supposedly endowed with curative powers (and with other actions, as for instance anti-aphrodisiac effects and the capability to facilitate parturition). In order to be effective, the preparation should be made in a particular period of the year and with the moon in a particular phase. With time the rituality for these preparations would include magic elements, such as, for instance, the need to pronounce particular formulae or magic words (see for instance Rondelet, 1574, p. 1221; Trallianus, 1557, pp. 71, 115). This contributed to progressively situate the torpedo in the territories of the fantasy and oddness in the imagery of naturalists, together with other animals endowed with extraordinary powers: such were the remora (the small fish capable of slowing down the course of big ship), the unicorn, the basilisk and many other objects typical of Renaissance *Wunderkammern* (Daston & Park, 1998; Olmi, 1992).

From Redi to Réaumur: The Mechanical Shock

In the second half of the seventeenth century there was a great interest for electric fish, particularly among the members of the *Accademia del Cimento,* the prestigious cultural institution founded by Leopoldo dei Medici in 1657 with the aim to contribute to a scientific renewal in the spirit of the Galileian revolution. Particularly impressive is the number of scholars (more or less directly connected to the Cimento or somewhat related with the Medici) involved in the investigation of the mechanism of the torpedo's shock, all working between Pisa, Leghorn and Florence, on fish granted to them by the Granducal court. Among them Giovanni Alfonso Borelli (1608–1679), Francesco Redi (1626–1694), Nicola Stenone (Niels Steensen, 1638–1687), John Finch (1626–1682), Marcello Malpighi (1642–1694), Lorenzo Bellini (1643–1704), Holger Jacobaeus (1650–1701) and Stefano Lorenzini (1652–post 1700).[7]

This interest was part of the program carried out by the "new scientists" (*novatores*) to provide a physical explanation to unusual and singular phenomena, often attributed to magical forces or to animistic "virtues". It is not by chance that the first observations of Francesco Redi on the torpedo are published in a book entitled: *Experiences on several natural things and particularly on those coming from the India, written to the very Reverend Father Athanasius Chircher of the Company of Jesus* (Redi, 1671). In this book, where scientific rigour and argumentation ability go along with a fine polemic humour, Redi critically surmise the various beliefs on the therapeutic power or magical virtues of minerals, plants and animals. These were the typical objects of a *Wunderkammer*, as undoubtedly was the personal museum created in Rome by the German Jesuit.

On the basis of his personal observation, Redi suggested a muscular nature of the organs responsible for the shock ("musculi falcati") and put forward the hypothesis of a mechanical nature of the shock. This hypothesis was elaborated by Redi's pupil, Stefano Lorenzini, in a work published in 1678, *Osservazioni intorno alle torpedini* famous because it contains the first report of some nervous structures of ampullar shape ("Lorenzini's ampullae") now known to be part of receptorial system capable of detecting electric fields (and thus "electroreceptors").

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[6] See Scribonius (1983), *Compositiones Medicae*, CXLII and XI.

[7] See Guerrini (1999). Some of the works of these authors dealing with electric fish are quoted in the bibliography of this essay.

As to the mechanism of the fish shock, Lorenzini postulated that it was due to a multitude of minute corpuscles ("*corpicciuoli*") emitted by the fish with great violence upon contraction of its "muscoli falcati". By penetrating deeply into the tissues of the prey (or of the experimenter) and hitting the nerves, these corpuscles would produce the commotion and the benumbing effect. As Lorenzini himself acknowledged, this hypothesis was inspired by the doctrine of the minute igneous bodies ("*ignicoli*") developed in 1623 by Galileo in the *Saggiatore* in order to account for the production of heat and for sensory processes.

A mechanical theory was also invoked by the French naturalist René-Antoine Ferchault de Réaumur (1683–1757), although it did not involve anything analogous to the Lorenzini's corpuscles. According to Réaumur the torpedo's shock was the consequence of a direct and rapid percussion of nerve trunks similar to that produced in the forearm by the action of a sharp body hitting the nerves in the region of the elbow: the shock would be produced by the fish at the moment when the dorsal surface of its body, normally flat or even concave in the preparatory phase, became suddenly convex as a consequence of a contraction of the *musculi falcati* that produced "a movement so prompt that even the most attentive eyes could not perceive it". (Réaumur, 1741, p. 351)

Réaumur developed his interpretation in 1714 on the basis of observations carried out on torpedoes caught on the coasts of Poitou, in France, near La Rochelle. It dominated the first part of the eighteenth century, and was considered a reference hypothesis also for the similar shock produced by the other species of fish that had come to the attention of the naturalists of the age.

Bancroft, Réaumur, the "Torporific eels" and the Scientific Challenge

On the wave of Galileian science and Descartes' philosophy, the principles of mechanics dominated the seventeenth century, and the law of motion and of the functioning of machines were invoked as references to account for the physiological processes, even those not immediately amenable to a mechanical interpretation (as for instance digestion, respiration and nervous conduction). New forces would attract the attention of the natural philosophers in the next century as long as the strictly mechanistic explanation reveals its inadequacies. Together with chemistry, whose development would culminate with Lavoisier's revolution, the other "force" dominating the eighteenth century was electricity. In addition to important conceptual advancements and discoveries, electricity attracted the attention for a series of practical achievements. Among them the invention of new and powerful electric machines capable of producing strong effects (see Heilbron, 1979).

Among the new instruments there was the Leyden jar, the first capacitor of the history, a device capable of accumulating huge quantities of electric charge which allowed people to easily experience the effects of strong electric shock. The similarity between these effects and the shock of the torpedo (and other singular fish) became thus rapidly apparent. It was first recognized by the French naturalist Michel Adanson in the Senegal in the years 1749–1753. Adanson investigated the shock produced by an African freshwater fish (the electric catfish) indicated as *trembleur* by the local Frenchmen because of its capacity to "produce not simply numbness as the Torpedo, but rather a trembling effect very painful in the arms of those that touch it". As to the comparison between the shock produced by this fish and by the Leyden jar, Adanson wrote:

> Its effect which did not appear to me sensibly different from the electric commotion of the Leyden experiment that I had tried many times, is similarly communicated by a simple contact, with a stick or rod of iron five or six feet long, to such a point that one drops instantaneously all the things that he kept in his hands. (Adanson, 1757, p. 135)

Besides the correspondence of the effects produced on the experimenter, the possibility that the fish shock could be communicated through a metallic body also argued for the similarity with the shock produced by the Leyden jar.

Soon after the publication, in 1757, of the *Histoire naturelle du Sénégal*, containing Adanson's account of the shock produced by the *trembleur* fish, a series of observations were collected on the similar properties of another freshwater fish, similar to an eel, found in the tropical regions of America. These observations were prompted by the Dutch physicist Jean-Nicholas Sebastien Allamand, colleague of Pieter van Musschenbroek and one of the discoverers of the Leyden jar (Allamand, 1756; see Kellaway, 1946; van der Lott, 1762). Also in the case of this eel, the shock was found to be transmitted through metallic and humid bodies. These characteristics pointed to a possible electric nature of the phenomenon, and seemed therefore to contradict the mechanical interpretation advocated by Lorenzini and Réaumur for the torpedo's shock. In the case of the latter, the possibility that the shock could be transmitted to the experimenter by some intervening matter had been taken into account by Lorenzini, who, however, excluded it outright, on the basis of a series of experimental observations. According to Lorenzini "in order that the Torpedo might produce its effects, it was necessary to touch it [directly] in some part of its naked body". (Lorenzini, 1678, p. 111)

Lorenzini's conclusion fitted in with his hypothesis that the shock depended on minute corpuscles emitted by the animal and penetrating the body of the experimenter. It was unlikely that these corpuscles could pass through a long rod, or through the chords and threads of the fishing net. In his study of the torpedo, Réaumur found that the shock could be transmitted, though with great attenuation, through a rod, but he did not investigate whether the transmission's efficacy changed according to the material the rod was made of. Réaumur's view of the torpedo's shock as due to a kind of mechanical concussion or vibration could account for the partial transmission of the shock through a relatively rigid body.

To summarise, after the middle of the eighteenth century evidence was accumulating to suggest possibly the electric nature of the shock produced by some species of fish (notably the Nile catfish and the eel of Surinam), based on the similarity of the effects produced by these fishes to the shock of electric devices. However, the reference hypothesis on the nature of the fish shock still remained the mechanical one, based on Lorenzini's and Réaumur's studies of the torpedo.[8]

[8] On a mechanical explanation, inspired by Réaumur, was also based the account of the Torpedo given in 1765 by De Jaucourt in the *Encyclopedie* (article *Torpille*, Tome XVI, pp. 428–431).

Torpedo and "Torporific Eel" the Scientific Challenge of Edward Bancroft

The situation changed in 1769 when Edward Bancroft an American born doctor (who lately established himself in England), with an interest in natural history, published an account of observations made in equatorial America. Of particular relevance was Bancroft's description of a peculiar fish referred to as a "Torporific Eel", found "near the coasts and the rivers of Guiana". After a rather detailed description of the external morphology of the fish, which appears to be superficially similar to a Lamprey, Bancroft wrote:

> But the most curious property of the Torporific Eel is, that when touched either by the naked hand or by a rod of iron, gold, silver, copper &c. held in the hand, or by a stick of some particular kinds of heavy *American* wood, it communicates a shock perfectly resembling that of Electricity, which is commonly so violent, that but few are willing to suffer it a second time. (p. 192)

The comparison between the shock of the eel and that of the torpedo as described by Réaumur inspired Bancroft to the following reflections:

> What affinity there may be between the shock of Torporific Eel and that of Torpedo, I am unable to determine with certainty, having never felt the latter; but from all the particulars which I have been able to collect relatively thereto, I think it is pretty evident both are communicated in the same manner and by the same instruments.
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> Some years since the celebrated *Mons. De Réaumur* communicated to the Royal Academy of Sciences at Paris a Paper, in which he undertook to demonstrate, that the shock of the Torpedo was the effect of a stroke given by great quickness to the limb that touched it, by muscles of a peculiar structure. To this hypothesis all *Europe* beheld an implicit assent, and M. *De Réaumur* has either to enjoy the honour having developed the latent cause of this mysterious effect. But if we may be allowed to suppose, that is undoubtedly true, that the shock of the Torpedo and that of the Torporific Eel, are both communicated in a similar manner, and by similar means, it will be nowise difficult to demonstrate, that all of M. *De Réaumur*'s pretended discovery is perfect nonentity. You may, perhaps, think it an act of presumption in me, to dispute the authority of a man, whose literary merit is so universally acknowledged; but I am convinced, that an implicit faith, in whatever is

honoured with the sanction of a great name, has proved a fruitful source of errors in philosophical research; and whilst I have sense and faculty of my own, am resolved to use them with the freedom for which they are given. Humanity is ever exposed to deception, and charm for novelty may perhaps have precipitated *M. De Réaumur* into an error. (pp. 195–196)

Bancroft continued by exposing those characteristics of the eel's shock that made it unlikely that it could be accounted for on a mechanical basis. He mentioned the transmission of the shock through the fishing line when the fish is caught by a hook, the transmission through an iron rod to a chain of people (up to 12) touching each other in a circle ("in a manner – he says – exactly similar to that of an electric machine"); and also the transmission of the shock through the water in which the fish is swimming. On the basis of these characteristics he assumed that the shock was produced by "an emission of torporific or electrical particles", depending on the life of the animal and under the control of its will. Finally, coming back to the torpedo and to *M. De Réaumur*, he concludes provocatively:

From whence it is self-evident that, either the mechanisms and properties of the Torpedo and those of the Torporific Eel are widely different, or that *Mons. De Réaumur* has amused the world with an imaginary hypothesis: and, from my own observations, as well as the information which I have been able to obtain on this subject, I am disposed to embrace the latter inference (pp. 198–199).

If one was inclined to endorse Bancroft's statement as a veritable scientific challenge, then all that remained to be done was to investigate the characteristics of the shock of the torpedo in order to see whether they corresponded to those of the eel; or, on the contrary, were so different, as to justify, in the case of the torpedo, a mechanical explanation apparently incompatible with the eel's shock.

This was just what John Walsh, a wealthy English gentleman with interest into natural history and "experimental philosophy", decided to pursue through a journey to France in the summer of 1772.[9] Walsh was indeed well acquainted with Bancroft's views on the subject. Both were members of the Royal Society and frequented a circle of natural philosophers in London interested in the study of electrical phenomena. This circle included scientists as eminent as Benjamin Franklin and Joseph Priestley.[10] The reason for travelling to France to investigate the torpedo's shock was due to the difficulty over finding live animals in England. Perhaps we could also be justified in assuming that a further motive might be the desire to perform experiments on torpedoes from the same region, the *Poitou*, where Réaumur had carried out his experiments more than half a century before. It was for these reasons that Walsh left London for France at the beginning of the Summer season of the year 1772 accompanied by his secretary David Davies and his nephew Arthur Fowke, as Walsh annotates at the beginning of his *Journal de voyage*:

[9] John Walsh was born in Fort St. George on 1 July 1726 and died in London on 9 March 1795. He was the cousin of Neville Maskelyne, the Royal Astronomer, and also of Lord Clive who was married to his mother's niece, Margaret Maskelyne. Walsh served in the East India Company since 1742 and, in 1757, he was appointed as private secretary to Clive. In 1759, Clive commissioned him to return to London in order to support his plans for reorganizing the administration of Bengal before the English Government. Walsh's richness (estimated to about £140,000) was mostly derived from the considerable fortune amassed as a share of war conquests in India. He was member of the Parliament from 1761 to 1780. He was elected Fellow of the Royal Society on 8 November 1770. In his certificate of election, Walsh is indicated as "a Gentleman well acquainted with philosophical, & polite literature, & particularly versed in the natural history and antiquities of India". A short but accurate biographic sketch of John Walsh is contained in 'The papers of Benjamin', vol. 19, pp. 160–162 (see Franklin, 1959).

[10] As Walsh recognises in his 1773 article on the *Philosophical Transaction*, Franklin was influential in devising the plan of the experiments to be performed on the torpedoes at La Rochelle. Among the Franklin's papers there are two short notes undated but surely written before Walsh's journey to France, which attest the relation between Walsh, Franklin, and Bancroft. In the first it is written that Walsh asks Franklin for Bancroft's address in London saying that he "is very desirous of making some enquiries concerning the Torporific Eel" (p. 162, Franklin's papers, Vol. 19). From the other note we learn that Franklin had borrowed from Walsh the book of "Laurenzini]" (i.e. Lorenzini) and desired to have it back because "he wishes to look into it for some particulars" (see Franklin 1959, Vol. XIX, p. 163).

1772, June 8th. Whitsun Monday. Left London in the afternoon; Crowds of Men and Women returning from Greenwich Park and Maying. The hedges in very full Blow of May. In company with Mr. Davies, and my Nephew Arthur in Post Coach. Slept at Dartford 16 Miles.

Walsh in La Rochelle: The Taming of the Ray and the Transitions in the Eighteenth Century Science

We will provide but a rapid outline of the journey that brought Walsh to La Rochelle through a rapid *detour* and we will refer also rather briefly to the experiments he made in the small town of the French Atlantic coast and in the nearby island of the Isle de Ré. Together with other experiments that he would carry out 3 years later in London on electric eels imported from Guiana, these experiments led to the final demonstration of the electric nature of the shock of these singular fish. Walsh's journey and experiments have been diffusely dealt with in a recent book based on two unpublished manuscripts.[11] Here, we will content ourselves mostly with a discussion of some aspects of the way to do science in the second half of the eighteenth century, as they emerge from these manuscripts.

The first manuscript is the already mentioned *Journal de voyage* containing Walsh's observations on his passage from London to La Rochelle through Boulogne, Montreuil, Amiens, Breteuil, Clermont, Creil, Chantilly, Paris (where he stays for about a week in mid-June), and afterwards through the centre of France and the region of Poitou up to the Atlantic coast.

The second manuscript, *Experiments made in La Rochelle and Isle de Ré, June and July 1772*, conserved in the Library of the Royal Society of London, is of a particular relevance for tracing the events which brought Walsh to demonstrate the electric nature of the torpedo's shock. It bears the detailed registration of the experiments on the torpedo carried out in the region of La Rochelle, together with annotations and reflections. It also contains the transcription of a letter sent by Walsh to Benjamin Franklin on 12 July 1772 which represents the first communication of the discovery of the electric nature of the torpedo shock made to a eminent member of the Republic of the Letters of the Enlightenment.[12]

Various elements emerge from these manuscripts useful to reconstruct the investigative attitude and the scientific psychology of a natural philosopher in a transition period as undoubtedly was the second half of the eighteenth century.

First of all there is what we could qualify in the case of Walsh as an "obsession for knowledge", an almost monomaniac interest for the problem underlying experimental investigation. The initial symptoms of this scientific compulsion appear in the first manuscript when Walsh betrays his anxiety for finding the torpedoes necessary to his experiments. In Calais, soon after the arrival in France, he visited the local fish market, and in the absence of torpedoes, he profited of the arrival of a boat unloading "6 or 700 Rayes of different sort", to carry out a dissection of some of these fish. This appears to be an anticipation of (and a preparation for) the dissection of torpedoes that he will carry out at La Rochelle. About a week later, on the way from "Boulogne to Montreuil", we find the first remark betraying explicitly Walsh's interest in the torpedo.

Spoke with Captain Palletti, and Captain Lobé, who commanded Coasting Vessels to La Rochelle and Bordeaux &c. They were acquainted with the Torpedo, and assured me that to their one knowledge, there were plenty of them at La Rochelle and La Tesle on the coast of Argenson. (WJ, p. 8)

During the period spent in Paris there is almost no mention of the beauty of the town, of his monuments or other interesting curiosities not related to torpedoes or to electricity. The day after the arrival Walsh visited Jean-Baptiste Le Roy, who he found engaged in electrical experiments, and discussed laboratory instruments with him. In the evening Walsh was at the *Jardin du Roy*, where he attended a lecture in chemistry and visited a naturalistic collection at the *Cabinet du Roy*:

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[11] Piccolino (2003, 2005) and Piccolino and Bresadola (2002, 2003).

[12] Library of the Royal Society of London, Ms. 609. The quotation from this manuscript will be indicated by the notation WE followed by the page number.

a good collection of natural Curiosities, open to all three times a Week. Military mounted there, in Glass Cases, with Label of the name of each Article. (WJ, pp. 16–17)

Of the various "articles" on exhibition, his curiosity was first attracted by a "Male Torpedo, as called, dryed [*sic*] small about 9 Inches", and, moreover, by "two very small ones in Spirits mention'd from the Isle de Bourbon, two inches in Diameter". "No Anguille tremblante" – he wrote, very probably with some intention to deceive – after having noticed the absence of specimens of the electric eel. Afterwards he noted in the journal:

Visited M. Jussien [i.e. '*Jussieu*']; talked of the Torpedo, he never saw it or heard much of it; mentions his having heard that the Loadstone took off its Effects. One present mentioned the Eel to be in Salt water at Mauritius. M. Jussien named M. A Surgeon now dead to have collected some particulars of the Torpedo, and to have intended to have refuted M. De Reaumur. (WJ, p. 18)

On the next day Walsh endeavoured to visit several scientists, in particular the naturalist and botanist Michel Adanson, the same Adanson that 15 years before had reported on the similarity of the shock produced by the Leyden jar and the strange fish of Senegal.

In Walsh the compulsion for torpedoes and experimental science emerges, however, in a particularly clear way during the period spent in La Rochelle. In 27 days of experimental research in the journal are registered as many as 324 experiments, carried out on 76 torpedoes. Together with his collaborators (the nephew and the secretary, and sometimes members of the local upper class) Walsh made experiments even during the Sundays (five in all) and sometimes up to late in the evening.

In this obsessive attraction for the experimental investigation of a specific and well-defined problem, we can see a first element of transition in the way of doing science in the Enlightenment. In the eighteenth century the interest for science, and particularly for "experimental philosophy", was an aspect of the education and of the cultural taste of the members of the upper classes, and under certain respects Walsh's attraction for electric experiments and for the torpedo might correspond to this general interest for science of the cultivated members of his epoch.

This is, however, only partially true. People were interested into science as they were into music, art, literature, for the pleasure to do it, and with the intention to carry out amusing and entertaining experiments. The "*amateurs*" of the Enlightenment "played"science in a relation of sane and harmonic equilibrium with their other interests and activities, as a form of spiritual recreation. The mental and physical discipline required by the experimental practice helped them to moderate the emotional excess brought about by art, poetry and music. This was not certainly the case with Walsh. His almost compulsive commitment to the investigation on the torpedo seems to anticipate the typical involvement of modern scientists in very specific and somewhat narrow research problems which often absorb in an exclusive manner all their physical and intellectual energies.

In Walsh's case the "transitional" features in the way of doing science concerned also other connotations, and particularly his interactions with people around him, both at the moment of doing experiments and when communicating his results.

The situation developed in La Rochelle with the arrival of the English gentleman interested into experiments seems to fit well in an almost idyllic frame of an old-fashioned "experimental philosophy" carried out in non-professional and non-institutional milieus and addressed to all peoples of high cultural and social rank, without any supposition of specific knowledge and competence. Walsh's studies attracted the attention of a literary party, comprising various personages typical of a provincial world of the *ancien régime*: the Bookseller, the Apothecary, the Hydrographer, the Naturalist, the Surgeon, many members of the local *Académie* and in particular the Director and the "Perpetual Secretary", who was also the Mayor of the town, the *Inspecteur des Fermes*, the Professor of Rhetoric at the Royal College, the military Governor and *Commandant en chef*, the *Ingenieur*, the *Avocat*, several Colonels and so on. Some of these personalities took an active part in the experiments, others discussed the effects of the torpedo or simply attended Walsh's demonstrations. However, after his return to London, Walsh succeeded in involving, in his electric fish studies, two of the most qualified English scientists of his time: Henry Cavendish, famous for his physical researches, and particularly for his measurement of the gravity constant of the Earth, and John Hunter, a leading anatomist and surgeon.

The collaboration among Walsh, Hunter and Cavendish was of great importance for the advancement of electric fish studies. Moreover, it is an indication of the transition towards a modern conception of scientific inquiry, based on the need of a tight collaboration among experts of different fields. Hunter provided an accurate study of the microscopic anatomy of both torpedo and electric eel. In particular he pointed to the great surface of the membranes of the elementary elements making up the columns of the electric organs and to the extreme abundance of nerves directed to these organs. As to the nerves, he concluded by saying that they are "subservient to the formation, collection, or management of the electric fluid", a statement which fitted within the framework of the hypothesis of the electric nature of nerve signals (Hunter, 1773, p. 487: On Hunter see Chapters 3 and 5 of the present volume). This hypothesis had appeared in the scientific literature in the first half of the century but since then had remained without any substantial experimental support (see Piccolino & Bresadola, 2003). Hunter's considerations were somewhat instrumental in confirming Luigi Galvani in the conclusion, developed in 1791 after an intense period of experimental investigation that nerve signals are due to the agency of an electric fluid. This fluid was indicated by Galvani as "animal electricity" (a phrase of which the first historical occurrence is in Walsh's journal of the experiments on page 143). In a memoir written in 1797, and concerning the result of his own research on torpedo shock, Galvani put a passage bearing an apparent correspondence with Hunter's consideration. In discussing his experiments aimed at ascertaining the source of the electric fluid involved in fish shock, he wrote that he wished to determine whether the brain "would be the elaborator and the collector of such electricity, and nerves the conductors" (Galvani, 1797, p. 65). According to Galvani animal electricity is accumulated in a condition of unbalance between the interior and the exterior of the muscle fibre: a nerve fibre penetrates inside it allowing, in both physiological or experimental conditions, for "the flow of an extremely tenuous nervous fluid [. . .] similar to the electric circuit which develops in a Leyden jar" (Galvani, 1791, p. 378). The neuromuscular complex was conceptualized by Galvani at a microscopic level as "minute animal Leyden jar", an image which developed the idea of torpedoes as "animate phials" put forward by Walsh in his 1773 article (p. 477) and further developed by Cavendish.

Walsh–Cavendish collaboration in electric fish investigation was of particular relevance because it led to an immediate important development of broad physical interest. The problem particularly addressed by Cavendish concerned the reason why, in Walsh's experiments, a spark could not be obtained in association with torpedo's shock, even though the shock could be rather severe. This contrasted with what happened with Leyden jars. The discharge of Leyden jars were usually accompanied by visible sparks and by other perceptible phenomena (sounds, "electric winds" and odours). In the case of a strongly charged jar of small size, however, this occurred in spite of the fact that the shock perceived by the experimenter could be substantially weaker than that produced by torpedo (Cavendish, 1776).

To account for such differences Cavendish assumed, on the basis of mechanical-pneumatic analogy, that the action of electricity depended not only on the quantity of «electric fluid» but also on another factor indicated as "degree of electrification", measurable with the electrometer and relatively independent of electric fluid quantity. The sparks (and other perceptible phenomena) would be the effect of electricity present at a high degree of electrification. In the case of a strongly charged Leyden jar of small size, the shock might be weak in spite of the visible spark because of the small quantity of electric fluid involved. On the other hand, a great number of weakly charged large Leyden jars (49 in an actual experiment carried out by Cavendish), arranged in parallel, could give a severe shock (imitating in several respects that of the torpedo) in spite of the fact that the shock was not accompanied by any visible spark. It could be surmised that the shock of the torpedo is due to the discharge of a large amount of electric fluid present at a low degree of electrification. By developing an idea first advanced by Walsh, Cavendish surmised that the discs of the electric organ could behave as minute planar capacitors arranged in parallel. On the basis of Hunter's anatomical study he calculated for the ensemble of the membranes in the electrical organs a surface of about 30,500 $in.^2$ (which was of the order of magnitude of the total surface of his assembly of 49 large Leyden jars capable of giving severe shocks without sparks). In the elaboration of Cavendish to account for the torpedo's effects, there appear *in nuce* notions corresponding to those of "tension" (or potential) and "quantity of charge" and the laws of the capacitor, which would be afterwards developed by Volta and Coulomb. These notions were of fundamental importance for the advancement of electrical science in the eighteenth century (Heilbron, 1979).

In the case of Walsh, the interdisciplinary collaboration with expert scientists as Hunter and Cavendish went along, as already mentioned, with his interaction with amateurs and interested persons with no special commitment to science. It was in the circle of these local personages of La Rochelle, more or less directly involved in his experiments, that Walsh gave the first announcement of the success of his experiments in demonstrating "the Effect of the Torpedo to be Electrical". This occurred on 9 June 1772, during a dinner in Walsh's lodging. On that day Walsh could show that, similar to the "electric fluid" of a Leyden jar, the shock of the torpedo could circulate along a human chain, through a direct contact or via electric conductive bodies, whereas it was intercepted by insulating matters as glass and sealing wax.

It is worth quoting a rather long passage of the journal reporting the observations of this day, because this helps us in somewhat entering in Walsh's "room of experiments" at La Rochelle and in perceiving the intense and lively atmosphere pervading it. On that regard the journal of experiments is much more expressive that the published article (appeared in 1773 in the *Philosophical Transactions of the Royal Society* together with Hunter's anatomical study).

Walsh and his nephew Arthur Fowke touched with one hand the torpedo (one on its top and the other on the belly) and with the other hand established a mutual contact, directly or through conductive or insulating materials. In reading this passage we should take into account that the expression "signal" is used to indicate a small movement of the fish eye (usually in the form of a winking) which immediately precedes the shock. This "signal" is of particular relevance when it is necessary to ascertain the lack of transmission of the shock

> Walsh and Arthur communicating with a Spoon, and touching one above, the other below the same flank; a Shock.
>
> Communicating with Sealing wax, a Signal, felt nothing.
>
> The Spoon again, immediately a Shock.
>
> Sealing Wax twice; nothing.
>
> Arthur put his Thumb upon Walsh' hand while the sealing wax was still in their hands; two signals – nothing.
>
> Joined hands, immediately a smart Shock.
>
> All insulated; sealing wax in hand; joining hands by thumbs, pressing harder; Arthur communicating with the under side; felt a very strong Shock. Repeated the same.
>
> Changed Sides; Walsh, communicating with underside; felt nothing; but Arthur felt a Shock; plainly from being more sensible.
>
> Joined hands; felt it immediately.
>
> Communicating with Sealing wax: two signals, felt nothing.
>
> Communicated by thumbs; placing ball of one upon the joint of the other thumb; two Signals; nothing.
>
> Full hand within full hand; plain shock.
>
> Holding Sealing wax in full hands joined; strong Shock.
>
> Walsh and Arthur communicating by Spoons, and touching above and below the same flank with Spoons, felt it on touching hands. Repeated; the same effect.
>
> Communicating with Glass, short, at an Inch distance, and touching with Spoons, two Signals, felt nothing.
>
> Again communicating with Spoon, and touching with Spoons; felt it twice.
>
> Communicating with Sealing wax, at half an Inch distance; touching with Spoons; two signals, felt nothing.
>
> fish insulated; single person insulated, touched both flanks above with different hands, felt nothing.
>
> Touched the same flank with different hands; nothing. In each of these experiments there were two winks.
>
> Touched the upper and lower side of the same flank with Spoons; Shock, twice.
>
> Repeated with Spoons; a Shock.
>
> With Sealing Wax; nothing.
>
> Repeated with Spoons; Six times.
>
> With Sealing wax, twice; nothing.
>
> Tried with 3 persons communicating with Spoons; too weak for the third person to feel the Shock.
>
> Two persons communicating by a Spoon; felt it. (WE, pp. 49–53).

With regard to the page of the journal of the experiments in which Walsh registers his announcement of the electric nature of the torpedo (p. 54), it is also interesting to remark that it bears a marginal annotation, written for the second time by Walsh's proper hand and in a somewhat incorrect French: "*Je l'ai donté*". With this annotation Walsh wished to express his pride, by saying that he had "tamed" (*dompté*) with his research what Claudian had indicated as "the indomitable art of the marvellous torpedo".[13] In writing "*Je l'ai donté*", Walsh claimed in some way to have subjugated with the power of experimental science an elusive force which for many centuries had been felt at the same time wonderful and dreadful: a transition from the world of fantastic and weird to that of scientific knowledge and objectivity.

About 2 weeks later Walsh would present his results on the torpedo in somewhat more official situations, which are nonetheless expression of the typical cultural activities of a provincial town: on 22–23 July 1772 he gave two demonstrations for the members of the *Académie*, and on 24 July 1772 he also gave a third demonstration to the officials of the local garrison upon request of the Military Governor, the Baron of Montmorency.

These demonstrations were the occasion of pleasant entertainments and also gave birth to curious episodes. This was the case with the officer who appeared to be insensitive to the torpedo's shock because of the consequence of a severe war wound: he asked to try the effects of a Leyden jar, and, having well perceived the shock of the physical instrument, "went away satisfied of his sensibility" (WE, pp. 151–152). At the same time, the demonstrations were occasion for interesting discussions and remarks. A point particularly addressed by the members of the *Académie* concerned the transmissibility of the torpedo shock through the water, the natural habitat of the torpedo. It was not by chance that Walsh, who had been unable to obtain clear evidence on that regard in the first phase of his research, concentrated his experimentation on this point in his last days in La Rochelle.

[13] On the facing page Walsh quotes Claudian's verse by writing: "alluding to Claudian's epithet imdomitam applied to the Art of the Torpedo: Quis non indomitam mirae torpedinis artem audiit?"

Another Transition: Making Public Scientific Results in the Enlightenment

The experimental demonstration in a relatively official situation as in the case of the séances of the *Académie* of La Rochelle was for Walsh also a way to communicate in a public way the results of his experiments. This was in accordance to a custom typical of the eighteenth-century science when announcement made to the members of a learned society might sometimes be the only procedure of making scientific discoveries public. In the case of torpedo, however, Walsh supplemented these demonstrations with the publication of a printed document, appeared 1 year later in the *Philosophical Transactions* in the form of a letter addressed to Benjamin Franklin. On the other hand, in the case of the experiments made on the electric eels in London in 1775, in which he could obtain a spark from the fish, Walsh did not publish any account of his results and contented himself with demonstrations made to his colleagues of the Royal Society. He also wrote a letter to his French correspondent Jean-Baptiste Le Roy who published in 1776 an article entirely dedicated to Walsh's achievement bearing few lines of Walsh's communication:

> C'est avec plaisir que je vous apprends qu'elles m'ont donné *une étincelle électrique*, perceptible dans son passage à travers une petite fente ou séparation pratiquée dans une feuille d'étain collée sur du verre. Ces poissons étoient dans l'air; car cette expérience n'a pas réussi dans l'eau; leur électricité est beaucoup plus forte que celle de la torpille, & il y a des différences considérable dans leur effets électriques.

This passage represents the only published record of this memorable experiment written by its author. It is somewhat ironical that only a few lines remain as personal attestation of an achievement which was considered at its time a crucial event in the progress of the eighteenth century science. It concluded the cycle of electric fish research started by Walsh in 1772 and proved the electric nature of fish shock, beyond any reasonable doubt for the standards of the epoch.

Walsh's achievements went far beyond the elucidation of a specific point of natural history concerning the curious property of some peculiar fishes, and prompted the interest in a potential role of electricity in other aspects of animal physiology, and particularly in nerve and muscle functions. They undermined *de facto* the relevance of some important objections against the possible electrical nature of nerve signals (and against other types of involvement of electricity in physiological processes). Since the tissues and "humours" of animal organisms are electrically conductive – it was argued – electricity would spread from nerve fibres to neighbouring tissues and it would not flow along the definite and restricted paths required by physiological necessities. Moreover, there could not be the stable unbalance of electrical fluid necessary for the conduction of electricity along nerve fibres between two distant sites of the animal body, because any such unbalance would be rapidly dissipated due to the conductive nature of living substances. All this notwithstanding, torpedo and the eel of Guiana were able to produce an electric shock, and it was therefore possible that electricity might be involved also in physiological processes of other animals (see Piccolino & Bresadola, 2003).

In spite of the absence of a direct publication in a printed form by the author, the news of Walsh's achievement with electric fish reached the "Republic of Letters" of the Enlightenment through the article of Le Roy (and through various *résumés* published in many journals of the time) and also through other channels of communication existing between the savants of the epoch. It renewed the interest for the possible involvement of electricity in neuromuscular function. Walsh's success with electric fish undoubtedly contributed to Galvani's decision to investigate the possible role of electricity in nerve function, and there is indeed some continuity, both logical and chronological, between Walsh's and Galvani's work. In this way it opened the path to one of the most revolutionary episodes in Enlightenment science, the demonstration of the electric nature of nervous conduction. The "animal spirits", the elusive entities considered in classical science as messengers of soul for sensation and will, were thus substituted forever by an electric fluid: this represented a really paradigmatic transition from old medicine to the new science that would dominate the next centuries.

Although Walsh's achievements with the electric eel did contribute to the advancement of the science of the epoch in spite of the lack of a direct published record by their author, with time the absence of written documents contributed to the oblivion of Walsh's figure in scientific literature. Michael Faraday, who repeated the experiment of spark production from eel shock in 1839, could not find any clear written evidence of Walsh's experiment and considered its actual occurrence as doubtful (Piccolino, 2003).

The difference in Walsh's behaviour in making public the results of his experiments in the case of the torpedo and of electrical eel is another indication of the transition in the way of making science in the second half of the eighteenth century. In the case of the torpedo, private and public demonstration went along with the production of printed texts, whereas in the case of electrical eel Walsh contented himself with a demonstration to the members of an authoritative learned institution (as the Royal Society undoubtedly was).

The need of public demonstrations, which were customary in the experimental science of the Enlightenment, should not be considered simply as a way of communicating scientific results. It had also to do with the problem of the need of public credibility on both the real occurrence of the scientific events narrated and on the credibility and truthfulness of the results. These were particularly necessary for scientific results which, as in the case of Walsh's research, went against well consolidated paradigms and were difficult to account for within the framework of the physical principles of the epoch. In the paper published in 1773 Walsh comments on the need to give his public demonstrations at La Rochelle by saying that he wished "to give all possible notoriety to facts, which might otherwise be deemed improbable, perhaps by some of the first rank in science". "Even the Electrician – he wrote – might not readily listen to assertions, which seemed, in some respects, to combat the general principles of electricity" (p. 469). As to the experiments dealing with the "phenomena of the Torpedo", for which "Great authorities had given a sanction to other solutions", different from the electrical explanation, it was therefore necessary to have authoritative witnesses, because of their novelty and unexpectedness. Similar principles guided Walsh when, 3 years later, he was able to produce the spark from the eel's shock.

In modern times the ability to reproduce scientific results in a relatively easy way in various laboratories around the world limits the need of direct personal witnesses, and makes it necessary only to publish the experiments accurately in a written form, with appropriate specification on the methods, the type of preparation and the materials used. In the eighteenth century, science was not institutionalized and the possibility of checking the validity of experimental results was limited. This was particularly true in the case of the experiments, as those carried out by Walsh at La Rochelle, which depended on the availability of live animals, the torpedoes, which were difficult to obtain in the main centres of scientific inquiry of the time. There was an indirect allusion to this particular aspect of the problem in the last part of the discourse held by Walsh to the *Académie* of La Rochelle on 22 July 1772 and registered in the journal with these words:

> That what we had been able to do had only opened the door to a curious and interesting enquire: That great points remained to be examined, both by the Electrician, and by the Anatomist.
>
> That Nature had denied the animal to our Country and that the pursuit rested in a particular manner on them whose Shores abounded with it. (WE, pp. 144–145)

In addition to the public demonstration, Walsh made recourse to other strategies to attest the veracity and truthfulness of the results obtained in his work on the torpedo. These appear in a particularly evident light in the way he built up the article published in 1773 on the *Philosophical Transactions*. As already mentioned, this article was written in the form of a letter addressed to Benjamin Franklin, one of the most eminent authorities of the electric science of the eighteenth century. The importance of the addressee was by itself a warranty of the credibility of the results. But this is only one of the aspects of the more or less explicit concern for truthfulness in the article. After the initial paragraph, Walsh writes:

> . . . I will request the favour of to lay before the [Royal] Society my letter from La Rochelle, of the 12th July 1772, and such part of the letter I afterwards wrote from Paris, as relates to this subject. Loose and imperfect as these informations are, for they were never intended for the public eye, they are still the most authentic, and so far the most satisfactory I can pretend at present offer, since the notes I made of the experiments themselves remain nearly, I am sorry to say it, in that crude and bulky state in which you have had the trouble to read it. (p. 461)

Walsh also speaks of his “deficiency” as to give to the Royal Society “a complete account of [his] experiments on the electricity of the torpedo”. This deficiency, as well as his allusion to the imperfection of the letters on the subject sent to Franklin and to the “crude and bulky state” of the notes (likely his journal of experiments) should not be taken for their face value. They should instead be considered as a part of a communication strategy pointing to the veracity and to the “factuality” of the events described. Since the exordia of the modern experimental science, among the strategies proposed to reinforce the confidence in the facts narrated there was the tendency to a style overtly devoid of literary elaborations, leading to a non-systematic account, more akin to a minute verbatim: undoubtedly crude but «still the most authentic» as should clearly appear the letters written to Franklin in close temporal relation with the experiments at La Rochelle. The aim was to create a “virtual testimony” capable of attesting and making credible the events narrated. It was necessary to insist on the temporal occurrence of the events, either making recourse to a narrative type of style or presenting documents capable of certifying the time contingency of the facts (see Eamon, 1990; Shapin & Schaffer, 1985). In addition to the transcription of Franklin’s letters, in Walsh’s article there were other significant strategies of the same type. Walsh also reproduced the English translation of a short article that appeared on 30 October 1772 on the *Gazette de France* dealing with his demonstration at La Rochelle. This article was written (also in the form of a letter, sent to the publisher of the Gazette) by the Mayor of the town and “perpetual secretary” of the *Académie* “Sieur [Pierre-Henry] Seignette”. It contained the description of all most salient facts concerning Walsh’s demonstration and ended with the following conclusive remark: “the effects produced by the Torpedo resemble in every respect a weak electricity”. (Walsh, 1773, p. 468)

The statement whereby Seignette’s article is introduced by Walsh clearly betrays the testimonial character attributed to it:

> As it [the article] came from a very respectable quarter. Not less so from the private character of the gentleman, than from the public offices he held, I must desire leave of the [Royal] Society to avail myself of such testimony to the facts I have advanced, by giving a translation of that narrative. (p. 466)

After reporting in its entirety Walsh declares:

> This exhibition of the electric powers of the Torpedo, before the Academy of La Rochelle, was at a meeting, held for the purpose in my apartments, on the 22nd July 1772, and stands registered in the journals of the Academy. (p. 468)

We note here *en passant* that the *compte rendu* of Walsh's demonstration can still be found among the Registers of the *Académie* of La Rochelle (see Piccolino, 2003). Moreover, we cannot abstain from remarking that Walsh seems to have, at the time of his torpedo research, purposely left traces of his experiments, useful in a later time as a documentary and verifiable testimonies of their occurrence. Indeed the plan of Walsh's article on the *Philosophical Transactions* is, on that regard, rather elaborated: a letter to Franklin based on two previous letters to the same personage and containing an article in the form of letter sent by an eminent citizen of La Rochelle to the official French journal. We could also remark that the article of the Mayor of La Rochelle on the French Gazette makes in turn allusion to another article concerning Walsh's experiments also published on the *Gazette* (in the date of 14 August 1772) and also based on a communication by Seignette. All this contributes to give the impression of a Chinese box strategy of unquestionable efficacy in attesting the occurrence and verifiability of the events narrated, and thus capable of accentuating their "factuality".

Other Relevant Aspects of the Journal of Experiments

In recent years a great attention has been given by science historians to the manuscripts where scientists used to annotate the progress of their studies together with private reflections and remarks of various types (Grmek, 1973; Holmes, 1974; Holmes, Renn, & Rheinberger, 2003; Holmes, 2004). When preserved from the ravages of time, these texts appear to be useful both for the possibility they offer of tracing the discovery process and various aspects of the scientific psychology in addition to the published texts. The articles or memoirs written for the aim of publication, because of their communication scope, might tend to privilege the most successful and straightforward aspects of the investigation leaving aside the difficulties, the errors, the complex and tortuous pathways leading to the discovery. These aspects appear more clearly in the experimental protocols manuscripts, particularly when, as in the case of Walsh's journal of the experiments, they present a precise day-by-day narrative of the research development together with various annotations and reflections. Here we can only survey rapidly some of these aspects that better emerge from the analysis of Walsh's manuscripts (in addition to those already discussed).

Among these aspects there is what we could call "didactics of the experiment", a form of learning acquired in the course of the investigation (and often not explicitly recognized by the scientist), by which he becomes progressively more capable of effectively pursuing his further research. There are various phases in which this emerges clearly in Walsh's experiments. One is when (attentive as he is to possible movements of the fish that could justify Réaumur's mechanical hypothesis) Walsh perceives a small motion of fish eye in the preparatory phase immediately preceding the shock. As already mentioned, this "winking" would henceforth represent a "signal" for ascertaining the production of fish shock, particularly useful in the condition in which the shock might not be perceived in other ways (as for instance when insulating matter is used to complete the discharge circle). Another interesting characteristic of the shock exploited by Walsh (even before he explicitly recognizes it in his annotations) is the fact that its intensity is significantly stronger when the fish is investigated "in the air" than when plunged in the water. Although Walsh recognized only in the late phase of his investigation (i.e. on 26 July 1772) that in water the shocks were "greatly weaker than in air, perhaps not a quarter part of the strength, at least to our sense of it" (WE, p. 170), nevertheless he started to examine more and more frequently the animal "in the Air" since the first casual observation made during the initial week of experiments (on 6 July 1772) of the stronger shock intensity with the animal outside the water.

The problem of the different intensities of the perceived shock in air and in water would be particularly addressed by Cavendish who succeeded in accounting for the difference on the basis of the shunting effect of the water and was also able to build an "artificial torpedo" capable of exactly reproducing the action of the natural one also under that point of view.

The mention of the subjective estimation of the intensity of the torpedo's shock brings us to consider another aspect of the transition in the way of doing science in the eighteenth century: the recourse to the experimenter's body as a measuring instrument that still persisted in spite of the development of objective physical measuring devices. Given the apparently crude and subjective character of these estimations of laboratory events, one may be astonished by the precision of the results obtained by the scientists of the *ancien régime*. Using a method introduced by the famous Italian electrician Giovan Battista Beccaria, Henry Cavendish succeeded in estimating, with impressive precision, the relative electric resistance of water, showing that it was much smaller than that of metals (about 400 million times). He did this by comparing the intensity of the shock perceived when an electric discharge was transmitted through a metallic wire of a given length and section, and tubes of various lengths and diameter, full of water (Cavendish, 1776; See Maxwell, 1879).

By estimating the taste sensation produced by a bimetallic arc applied to the tip of the tongue, Alessandro Volta was able to detect, in 1792, a feeble current, too weak to be measured by the physical electrometers of the age. Moreover, on the basis of the same physiological sensor he could establish the polarity of this current. These experiments were milestones in Volta's path to the discovery of the battery, a path that not only led to the invention of the epoch-making electrical device, but also resulted in an important series of physiological discoveries (Piccolino, 2000, 2003; Piccolino & Bresadola, 2003). Volta was able to show the eminently transient character of the responsiveness of the visual system, that contrasted with the tonic responses of the gustatory and nociceptive system. He anticipated, by about half a century, the fundamental idea of the functional organization of the nervous system, Johannes Müller's doctrine of "specific nervous energies". This stipulates that the physiological effects of nerve stimulation depend on the type of nerve stimulated, and not on the type of stimulus used to achieve the stimulation (Müller, 1826). Moreover, Volta showed that the effect of the electric stimulation of nerves depends on the polarity of the stimulus, again anticipating important laws of electrophysiology, to be fully clarified only in the nineteenth century. Finally, he measured with an impressive precision the time during which there was a partial time summation of the physiological effects of a prolonged electric stimulation ("integration time" in modern words).

Among the other aspects of the way of doing research in the eighteenth century emerging from Walsh's work (and also from a comparison with the endeavour of other scientists of the age involved in a similar research, as Cavendish, Galvani and Volta) there is the interchangeable (and effective) way in which the investigator passed from the study of the animal preparation to that of physical instruments. Even though we cannot deal with this aspect, we cannot abstain from quoting a statement made by Walsh during his demonstration at La Rochelle:

> as Artificial Electricity had led to a discovery of some of the operations of the Animal, the Animal if well consider'd would lead to a discovery of some truths in artificial Electricity which were at present unknown and perhaps unsuspected.

From Walsh to Volta

The passage just quoted (also reported in a slightly modified form in the 1773 article) might appear *a posteriori* somewhat prophetic, particularly if we consider the importance of the electric fish experiments for the research that led Alessandro Volta to the invention of the electric battery (Heilbron, 1978; Pancaldi, 1990, 2003; Piccolino, 2000; Piccolino & Bresadola, 2003). We have already alluded to the relevance of Walsh's studies in prompting the research of Luigi Galvani towards the demonstration of the electric nature of nerve signals. As already mentioned, in the case of Galvani, Walsh's demonstration of the electric nature of shock of the torpedo and of the electric eel undermined the significance of the physical objections against a role of electricity in physiological processes. Moreover, in the model of the "minute animal Leyden jar" elaborated by Galvani in order to account for neuromuscular function there is an echo of Walsh's conception of the torpedoes as "animate phials".

In the case of Volta the relevance of electric fish research was even more significant. From a reflection on the electric organs of the fish Volta derived in the years 1798–1799 the decisive inspiration in the attempt he was pursuing to obtain a strong electric action from the weak "electromotor" power of a bimetallic contact. Volta had a long interest in electric fish research. He had personally met Walsh and discussed with him on the subject in the occasion of a visit to London in 1782. However, in his writings the reference to the singular properties, very frequent in 1792 at the beginning of his research on animal electricity declined progressively in the following years. Suddenly, however, in 1798 electric fish started to dominate again Volta's elaboration during an intense period of the investigation on the electromotive action of bimetallic contacts. This renewed interest was motivated by the publication in 1797 of a memoir in which Galvani described his own experiments on torpedo and, moreover, by the appearance (also in 1797) of an article of William Nicholson proposing a physical model to account for the mechanism of fish shock (Pancaldi, 1990, 2003). In this article Nicholson suggested that the discs of the electric organs could behave like the plates of an "electrophore". The electrophore, an electric tool invented by Volta himself, consisted of a movable metallic plate and of another plate made of an insulating material (usually resin). Manifest electric effects were produced by the manipulation of the metallic plate that resulted in a change of its capacitance. Nicholson's model revived, in a somewhat modified form, the hypothesis formulated by Walsh, and elaborated by Cavendish, that electric organs could work as an assembly of minute planar capacitors.

Nicholson's article undoubtedly contributed to reorient Volta's attention on electric fish, but it acted somewhat "by contrast". As was the case with Walsh and Cavendish's model of the electric organ as composed by a multitude of planar capacitors, Nicholson's artificial electric organ was based on the interposition of insulating laminas between conductive plates. As a matter of fact, an insulating material was a constitutive element of all instruments of the age capable of maintaining an electric equilibrium (Leyden jars, Franklin's planar capacitors) and a proper insulation was also necessary in instruments capable of generating it (such as friction electric machines and electrophores). For Volta, however, the idea that an insulating matter could be a constituent of the electric organ was in evident contrast to the knowledge of "animal physics". This he will state in a clear-cut way in his 1800 letter to Banks on the invention of the battery, where, with reference to Nicholson's hypothesis, he wrote:

> such a hypothesis falls entirely, these pellicles of the organ of the torpedo are not, and cannot be, in any manner insulating or susceptible of a real electric charge, and much less capable of retaining it. Every animal substance, as long as it is fresh, surrounded with juices, and more or less succulent of itself, is a very good conductor. I say more, instead of being as *cohibent* [i.e. *insulator*] as resins or talc, to leaves of which Mr. Nicholson has compared the pellicles in question, there is not, as I have assured myself, any living or fresh animal substance which is not a better *deferent* [i.e. *conductor*] than water, except only grease and some oily humours. But neither these humours nor grease especially semi-fluid or entirely fluid, as it is found in living animals, can receive an electric charge in the manner of insulating plates, and retain it: besides, we do not find that the pellicles and humours of the organ of the torpedo are greasy or oily. This organ therefore, composed entirely of conducting substances, cannot be compared either to the electrophore or condenser or to the Leyden flask, or any machine excitable by friction or by any other means capable of electrifying insulating bodies, which before my discoveries were always believed to be the only ones originally electric. (p. 430).

After the demonstration of the electromotive power of the contact of two different metals obtained in 1796, Volta had tried to multiply the weak electric effect of a single metallic contact by staking, one above the other, numerous bimetallic couples in a way that was similar to what happened with the discs of the fish electric organs. For a long time, these attempts were unsuccessful. Upon reflecting more deeply on the structure of the organs, Volta eventually decided to interpolate, between the bimetallic couples, a disc of paper or cloth soaked in a saline or acid solution which appeared to be more physically akin to the matter of the fish organs. This resulted in the invention of the electric battery, the realization beyond any hope of his scientific dream. In the letter to Banks on 20 March 1800 communicating the invention of this extraordinary device, Volta called it "*organe électrique artificiel*" in order to acknowledge – he wrote – that it was "similar at bottom", as he constructed it, "in its form to the natural electric organ of the Torpedo or electric eel" (p. 405).

According to Volta, in addition to an obvious similarity in the form, there was a deeper analogy between the natural and the artificial organs. As in the case of the newly invented tool, in the fish organ, the production and maintenance of a strong electric power occurred "by the mere contact of conducting substances of different species" (p. 419), in the absence of the interposition of any insulating matter, i.e. according to the new physical principle of the electromotive action he had discovered. The final passage of Volta's letter to Banks asserts this conception in a particularly expressive way:

To what electricity then, or to what instrument ought the organ of the torpedo or electric eel, &c. to be compared? To that which I have constructed according to the new principle of electricity discovered by me some years ago, and which my successive experiments, particularly those with which I am at present engaged, have so well confirmed, *viz*. that conductors are also, in certain cases, exciters of electricity in the case of the mutual contacts of those of different kinds, &c. in that apparatus which I have named the *artificial electric organ*, and which being at bottom the same as the natural organ of the torpedo, resembles it also in its form, as I have advanced. (p. 430)

The Battery and the Ancient Characters

Nobody could deny the importance of the battery for both the development of physics and for technological progress in the last two centuries. From the battery would originate electrochemistry and electromagnetism. On one hand, this will serve to orient physical investigation towards the study of the properties of ions and atoms, thus laying the grounds for the birth of modern physics. On the other hand, the battery would make possible discoveries and inventions rich in deep consequences for the progress of technology. Consider for instance Faraday's discovery of the reciprocity of electric and magnetic actions, which cortically depended on flow of constant electric current (feasible with the battery, but outside the reach of the friction electric machines of the age). On the reciprocity of electric and magnetic phenomena is based the possibility of producing great amount of electric energy (through the action of powerful alternators or dynamos), and thus the large-scale utilization of electric energy in everyday life. On it also depends the production of electromagnetic waves (and thus a large part of the science and technology of modern communications).

Compared to the historical importance of the invention of the electric battery, the pathway leading from Walsh to Galvani might appear less significant and less revolutionary. One could say many things on the importance of the electric hypothesis of nervous conduction which closed a millennial epoch of the science dominated by the doctrine of the "animal spirits" and opened the way to the development of modern electrophysiology (and thus to neurosciences). Through such paths scientists have succeeded in deciphering the nature of the signals that unceasingly flow along the circuits of our brain, the elements of the "electric storm" alluded to by Charles Scott Sherrington (1951) in a famous book. These signals allow us not only to see a distant castle, the visage of a nearby friend, but also to hear a voice, a beautiful music, to feel emotions, to speak and to think.

Even more than the "minute characters" (*caratteruzzi*) of the alphabet alluded to by Galileo in his *Dialogo sopra i massimi sistemi del mondo* (Galileo, 1632, p. 98), these electric signals represent the primordial characters underlying all that allow us to go beyond the more elementary level of animality. In the absence of these "electric characters" of our nerve cells, immensely more ancient of Galileo's *caratteruzzi*, writing itself would be impossible.

It has been said (Wu, 1984) that modern electrophysiology was born at the moment that Walsh produced for the first time a spark from the shock of an electric eel. This statement sounds a little paradoxical, but it is not totally devoid of foundation.

If one thinks of the continuity existing between Walsh's research on torpedoes at La Rochelle and the London experiment on the electric eel, we might perhaps say that modern electrophysiology initiated when Walsh wrote in his journal "*je l'ai donté*": I have tamed the "indomitable art of the wonderful torpedo".

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