CHAPTER 8

A Lofty Mountain, Putrefying Flesh, Styptic Water, and Germinating Seeds

Reflections on Experimental Procedures from Périer to Redi and Beyond

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Despite its gothic title, this is not a gothic paper. My aim is to analyze four experimental reports sharing common features and concerns. They were published from 1648 to 1697 and range over the study of the properties of air, spontaneous generation, medical investigation of a remedy for arterial wounds, and the germination of plants. The lack of disciplinary homogeneity among the cases I discuss should not hide the thread that unites them at the level of method: all the experiments were performed as sets of simultaneous parallel trials, in which one set was generally meant to provide background information on nature's unperturbed course, while the other was intended to investigate the results of the modification of one variable while keeping the rest unchanged. Mine is not a history of parallel trials but a study of a cluster of cases. My limited selection aims to provide a starting point for reflection on experimental procedures in the seventeenth century.

It is not uncommon to find in the literature references to parallel trials: Francis Bacon, for example, sought to ascertain whether the earth attracts bodies or bodies tend towards the earth, and whether gravity decreases with the distance from the center of the earth. In his celebrated aphorism introducing the "instance of the fingerpost," he proposed to synchronize two clocks placed next to each other, one moved by weights and the other by a spring;

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while the former is brought first to the top of a very high steeple and subsequently to a very deep mine, the latter is kept at the base of the steeple to test whether the weight-regulated clock runs faster in the mine and slower up in the steeple. Crucially, this parallel trial was proposed rather than executed. In other instances, several seventeenth-century iatrochemists such as Johannes Baptista van Helmont, George Starkey, and George Thomson challenged orthodox physicians to divide up the patients from a hospital into two groups and cure them according to rival views in order to see which set would fare better. These trials too were not performed; moreover, they did not involve a comparison of one type of remedy with nature's normal course, but rather chemical versus Galenic cures.[2] In other cases, such as those when bodies with different weights and shapes were dropped from high towers, for example, experiments were actually performed but they did not involve the comparison of one "tampered" or modified case with another representing nature's normal course; in fact, in those cases one may ask whether it is helpful to talk of two trials rather than a single one involving a comparison between two situations—although admittedly the demarcation line could be a thin one. These reflections characterize an important feature of the cases I will discuss and provide a preliminary justification for my selection.

Before embarking on a more detailed analysis of the four cases, I offer a synopsis of the main elements of my narrative. The first case is the celebrated Puy-de-Dôme experiment, performed in 1647 by Blaise Pascal's brother-in-law Florin Périer, in which Périer compared the heights of the columns of mercury in two barometers, one carried to the top of the mountain and back, the other kept at its foot. Since Pascal's original 1648 publication was exceedingly rare, Périer's report became known through an incomplete 1651 account by the anatomist Jean Pecquet that omitted the parallel trials; only in 1663 did the details of the experiment become known in its complete form. Given the interest in the barometer, or Torricellian tube, at the Medici court, it seems plausible that by then the full account of Périer's experiment became known in Florence. When in 1668 the Medici archiater Francesco Redi published *Esperienze intorno alla generazione degli insetti*, he too relied on parallel trials. Redi observed putrefying flesh in two containers, one exposed to the open air and the other covered in different ways: only in the first case did maggots and then insects appear, something Redi attributed to eggs deposited by the parent

[2]Francis Bacon, *The New Organon*, Aphorisms, Book II, 36 (Indianapolis, 1981), pp. 196–7. Johannes Baptista van Helmont, *Oriatrike* (London, 1662; this is a translation of *Ortus medicinae*, Amsterdam, 1648), p. 526. Harold J. Cook, *The Decline of the Old Medical Regime in Stuart London* (Ithaca: Cornell University Press, 1986), p. 160. William R. Newman, *Gehennical Fire: The Lives of George Starkey, an American Alchemist in the Scientific Revolution* (Cambridge: Harvard University Press, 1994), pp. 188–9. I thank Harold Cook for the reference to a list of medical cases involving "fair tests" that can be found at http://www.jameslindlibrary.org/index.html.

insects that had been attracted to the putrefying flesh. Redi relied on a similar method of inquiry a few years later, when he was called by the Grand Duke to investigate the properties of some styptic water from France. Redi did not take for granted the favorable reports on the water and proceeded to test its efficacy in blocking hemorrhages through a series of trials on different animals: by comparing the French water with water from a local well, he showed that the former did not perform better than the latter. Redi's work first appeared in the Rome *Giornale de' Letterati* for 1673. Others followed his approach in the study of generation and in different areas, too. Marcello Malpighi, for example, received a dedication copy of Redi's work on the generation of insects upon its publication. Only from 1685, however, did he have recourse to similar procedures in the controversy with Giovanni Battista Trionfetti on plant growth and spontaneous generation. Malpighi had argued that the cotyledons were necessary or at least highly beneficial to growth, a claim Trionfetti denied. Originally Malpighi had studied the effects on growth of excising the cotyledons without major precautions; in rebutting Trionfetti's claims in the 1697 *Vita*, however, he had recourse to parallel trials of mutilated and whole seeds.

1. Périer and the Puy-de-Dôme experiment

The celebrated Puy-de Dôme experiment was one among many performed in France in the aftermath of the reports on the Torricellian tube in order to determine the weight and other properties of air. In the Puy-de-Dôme experiment two barometers were used: while one was carried up the mountain by Blaise Pascal's brother-in-law and court councilor in Clermont, Florin Périer, the other was kept under watch by the Reverend Father Chastin in the garden of the Minim convent as a "continuous experiment," a significant precaution given the puzzling variability of the height of the mercury column in standard fixed conditions. Although the mercury in the two barometers was at exactly the same height when the barometers were next to each other in the convent at the base of the mountain, the height of mercury in the one carried to the top of the Puy-de-Dôme progressively decreased as Périer went up and then increased again as he descended, finally to coincide again with the one left in the convent. Thus the experiment did not involve a single comparison between the barometers at the top and the bottom of the mountain, but rather a series of comparisons of the heights of the mercury column at different altitudes.

The account of the experiment appeared in a short and exceedingly rare pamphlet published in 1648, *Récit de la grande expérience de l'equilibre des liqueurs*, containing two letters, one by Pascal asking Périer to perform the experiment, and Périer's reply detailing his expedition. From Pascal's own printed report, it appears that it was Périer who thought of using two barometers and who used the expression "continuous experiment," since originally Pascal had asked him to go up and down the mountain several times in the same day using the same apparatus at the top and bottom. Thus Périer's role seems to have been more significant that that of a sheer mountaineer—or maybe he was a practical one, since it was easier to run a parallel trial at the foot of the mountain than to climb the Puy-de-Dôme several times in a day. Regardless of his motivations, Périer appears as an experimenter whose importance has so far been ignored by historians: it is regrettable that we have very little information on him. By running two parallel trials, Périer was trying to isolate altitude as the only variable. Although Pascal's pamphlet describing the trial was first published in 1648, the experiment became known mainly through the partial report by the anatomist Jean Pecquet, first published in 1651 and then often reprinted in abridged form. Pecquet simply reported that the height of the mercury column decreased with the altitude and omitted what from my present perspective is the key feature of Périer's experiment, namely the comparison between the two barometers. This case shows that a narrator can be interested in results and can legitimately neglect methodological aspects that can be of crucial significance from a different perspective; those aspects can be reconstructed only by a careful study of the texts themselves and, whenever possible, of the actual experimental procedures. Périer's original report appeared again following Pascal's death in 1663 and 1664 in the *Traitez de l'equilibre des liqueurs*, thus reaching a much wider circulation. Périer's experiment resembles the one proposed by Bacon to ascertain the decrease of gravity, except that Bacon proposed to use two different types of clocks—albeit synchronized—whereas Périer relied on two identical barometers; in both cases the instruments left alone were meant to test the role of altitude on gravity and the height of the column of mercury.[3]

One should not underestimate the complex interplay of variables involved. Temperature, for example, varies according to different factors, including altitude, and plays a role on the height of the column of mercury because both mercury and glass expand when heated and contract when cooled; thus the decrease of the height of the column of mercury at the top of a mountain as tall as the Puy-de-Dôme—that Périer pointed out is covered with snow for many months—might have something to do, partly at least, to temperature variations. Both the Jesuit Francis Line and Robert Boyle discussed the role of temperature with regard to taking a barometer to the top of a mountain.[4]

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[3]The original pamphlet, [Blaise Pascal], *Recit de la grande experience*, (Paris, 1648) was reprinted in *Traitez de l'equilibre des liqueurs, et de la pesanteur de la masse de l'air* (Paris, 1663) is also available at http://gallica.bnf.fr/. Peter Dear, *Discipline and Experience: The Mathematical Way in the Scientific Revolution* (Chicago: Chicago Unviversity Press, 1995), pp. 196–201; Christian Licoppe, *La formation de la practique scientifique* (Paris: Le Découverte, 1996), chapter 1, esp. pp. 31–3. William R. Shea, *Designing Experiments of Games and Chance. The Unconventional Science of Blaise Pascal* (Canton, MA: Science History Publications, 2003), pp 105–16 and 120–2.

[4]Steven Shapin and Simon Schaffer, *Leviathan and the Air-Pump. Hobbes, Boyle, and the Experimental Life* (Princeton: Princeton University Press, 1985), pp. 161 and 164.

In Florence, members of the Cimento Academy devoted several experiments in the 1667 *Saggi* to the barometer. Since the manuscript was ready for publication a few years before 1667, the text relied on Pecquet's incomplete account of the Puy-de-Dôme experiment. The academicians could confirm that the height of the column of mercury decreased with altitude and thought at one point that they could use the Torricellian tube to provide an accurate measure of it; however, they soon became also aware of the puzzling variability of the height of the column of mercury left fixed at the same location and of the role of temperature. This realization led Vincenzo Viviani to invent an elaborate instrument, whose effectiveness was questioned by Giovanni Alfonso Borelli and Carlo Rinaldini, to be sealed with a flame and rapidly hoisted to the top of a tower with a contraption when the temperature at the top and bottom was the same. It seems peculiar that Viviani conceived such an intrinsically problematic procedure rather than using two barometers, especially since in discussing the role of the seemingly empty space above the mercury column Torricelli had already compared two differently shaped barometers and the Cimento Academy relied routinely on a rich set of instruments that were contrasted and compared with each other. The idea that sealing a glass pipe with the flame would not affect the result was unconvincing given that the very act of reading the barometers was problematic: at one point the academicians recommended that the experimenter stay away from the barometer and avoid breathing close to it in order not to affect the result. The experiment highlights the difficulty in determining the combined role of altitude and temperature on the height of the column of mercury.[5]

2. Redi and putrefying flesh

In 1668 Francesco Redi published *Esperienze intorno alla generazione degli insetti*, a treatise probably intended both for the literary Accademia della Crusca as well as for the experimental Accademia del Cimento. Redi's treatise displays

[5]W.E. Knowles Middleton, *The Experimenters: A Study of the Accademia del Cimento* (Baltimore: Johns Hopkins University Press, 1971), pp.129–33; *The History of the Barometer* (Baltimore: Johns Hopkins University Press, 1966), pp. 23–4. For an interesting comparison see Albert van Helden, "The Accademia del Cimento and Saturn's Ring," *Physis*, 15, (1973):244–59 and "'Annulo cingitur': The Solution of the Problem of Saturn, *Journal for the History of Astronomy*, 5, (1974):155–74; Domenico Bertoloni Meli, "Shadows and Deception: from Borelli's 'Theoricae' to the 'Saggi' of the Cimento," *British Journal for the History of Science*, 31, (1998):383–402, on 391; Maria Luisa Righini Bonelli and Albert Van Helden, *Divini and Campani: A forgotten chapter in the history of the Accademia del Cimento*, Monografia 5 of *Annali dell'Istituto e Museo di Storia della Scienza di Florence*, 1981; Paolo Galluzzi, "L'Accademia del Cimento: 'gusti' del Principe, filosofia e ideologia dell'esperimento," *Quaderni Storici*, 16, (1981):788–844; Luciano Boschiero, "Natural Philosophizing Inside the Late Seventeenth-Century Tuscan Court," *The British Journal for the History of Science*, 35, (2004):383–410.

remarkable erudition and experimental acumen; his denial of spontaneous generation relied on his most impressive experiments in which he studied a wide range of rather repulsive putrefying animal meats, from snakes and frogs to pigeons, beef, fish, chicken, bull, deer, and dozens more. A variety of maggots devoured them and then turned into flies of different species. Having seen insects of exactly the same type as those later produced hovering over those meats, Redi became suspicious of the origin of those maggots. He relied also on classical sources and everyday observations in the marketplace or in the hunting lodge, for example that hunters in the summer, butchers, and women (*donnicciuole*) who presumably are in charge of purchasing and storing the meat, keep flies away from it with cloths and nets in order to preserve it. Moreover, he quoted two passages in Greek from the Iliad in which Achilles asked his mother Thetis to preserve the corpse of his friend Patroclus so that flies did not fill his wounds with worms, a request to which Thetis promised to comply. Redi here relied on everyday knowledge and classical sources in conjunction with his experimental research, as if to mean that Homer, butchers, and even market women were wiser than some contemporary philosophers.

To test his suspicion, Redi employed four pairs of glass containers, filling each pair with different meats, from a snake, freshwater fish, eels from the Arno, and veal. He sealed one from each pair of containers with paper and thread, leaving the others open in the air. Not long afterwards he noticed that maggots appeared in the open containers, whereas in the sealed ones the meat rotted away but did not generate insects. Redi also buried some pieces of meat and found in this case too that no maggot was generated, unless the meat had been in contact with flies. Thus Redi questioned and ridiculed Athanasius Kircher's views and bizarre recipes about spontaneous generation, such as that described in the twelfth book of his *Mundus subterraneus* for generating flies from their own corpses by covering them with honey water and placing them on a copper plate with warm ashes. In case fresh air played a role in the generation process, Redi refined his experiments by introducing a variant. Instead of sealing half the containers with paper, he chose a very large container and closed it with a very fine cloth; then, as an added precaution, he placed it in a box covered with the same cloth and, again, found that no maggots or insects appeared. In this way he believed he had conclusively refuted spontaneous generation from putrefying meat.[6]

It would be inaccurate to argue that parallel trials marked a revolution in experimental procedures in the mid-seventeenth century, since matters were considerably more complex and experimental practices varied considerably.

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[6]Francesco Redi, *Esperienze intorno alla generazione degli insetti* (Florence, 1668; edited reprint with an introduction by Walter Bernardi, Florence: Giunti, 1996), pp. 86–9 and 91. On Redi see the recent collection edited by Walter Bernardi and Luigi Guerrini, *Francesco Redi: Un protagonista della scienza moderna* (Florence: Olschki, 1999).

Redi's work, however, became widely known in the world of learning thanks to the Latin translation of his treatise first published in Amsterdam in 1671. In subsequent experiments on generation performed later in the century, such as those on infusoria, Christiaan Huygens, Antoni van Leeuwenhoek, and the French microscopist Louis Joblot, adopted similar precautions and used two phials, one open and the other sealed, a sign that Redi's method was becoming widespread practice in studies of generation. At the Paris Académie Royale des Sciences in 1693, Wilhelm Homberg also performed experiments on the germination of plants in a vacuum and in air running two parallel trials. Homberg, who had spent time in northern Italy and worked on generation, found that air made a significant difference to the germination of seeds, in that some did not germinate at all whereas others did grow but growth soon stopped.[7]

3. Redi and styptic water

Similar methodological precautions must have appealed to Redi, since he employed them again on other occasions. In 1670, for example, while testing the effects of the poison of vipers, Redi inserted arrows dipped in the poison in the chests of ten pigeons: they all died. Subsequently, concerned that the pigeons may have died because of the wound rather than the poison, he wounded the chests of four pigeons with arrows that had not been dipped in poison: none of the pigeons died. Notice that in this case the trials were not simultaneous.[8]

In 1673, Redi tested the properties of a special styptic water, allegedly able to heal arterial wounds and promoted by the French royal physician Jean-Baptiste Denis, a European celebrity for his pioneering experiments on blood transfusion in the late 1660s. Initial reports from Paris and London suggested that experiments performed there by Denis as well as by the celebrated anatomist Walter Needham and others pointed to total success: bandages wet with the styptic water healed the wounded artery and only in one case did a lamb die, allegedly because a piece of cloth was inadvertently left in the wound. The other thirty animals used for the trial survived and so did a horse whose tail had been amputated, this being one of the most probing cases to

[7]Dear, *Discipline*, p. 198. Francesco Redi, *Opere*, 9 vols. (Milan, 1809–11), 4:269–78. Bernardi's claim in Redi, *Esperienze*, p. 15, that Redi's procedure was entirely novel is not justified in the light of Périer's Puy-de Dôme's trial; Alice Stroup, *A Company of Scientists: Botany, Patronage, and Community at the Seventeenth-Century Parisian Royal Academy of Sciences* (Berkeley: University of California Press, 1990), pp. 161–5. See the entry on Homberg in *New Dictionary of Scientific Biography*, ed. Noretta Koertge, 8 vols. (Detroit: Thomson Gale, 2008), by Lawrence M. Principe.

[8]Francesco Redi, *Lettera ad Alessandro Moro e Abate Bourdelot, sopra alcune opposizioni fatte alle sue Osservazioni intorno alle vipere* (Florence, 1670), in Redi, *Opere*, 4:233–4.

test the water's properties. Some experiments were also performed on human patients, such as a mastectomy on a woman with breast cancer and a bandage on a man with a severe hemorrhage.

Ferdinando II urged Redi to test the French styptic water; experiments performed on animals at the Tuscan court by Redi with the assistance of Tilman Trutwyn, the prosector at the Pisa anatomy theater, however, mostly failed. Initially arteries were completely severed, giving the animals apparently no chance of healing. Subsequently the arteries were cut first transversally and then longitudinally. In the latter case, occasionally a wound was healed, as it happened in the case of a sheep. It seems as if, following initial failures, Redi progressively decreased the severity of the incision until he became unsure whether the healing was actually due to the styptic water itself or whether it would have occurred anyway because occasionally some wounds heal by themselves. At this point he decided to perform parallel simultaneous trials with water from a well alongside those with the styptic water. He apparently wanted to render the comparison as close as possible by having wet bandages in both cases, and saw water from a well as "neutral," comparable in some respects to the barometer kept at the base of the Puy-de-Dôme and to the meat in the container left in the open air. Redi, however, did not run perfectly symmetrical trials varying only the type of water used, since he applied the two types of water to different numbers of animals, for example, much as he had done with the pigeons. He claimed that some animals treated with water from a well were healed. In an especially interesting and unusually symmetrical case, he amputated a wing from eighteen capons and treated six with the styptic water, six with water from a well, and six with nothing at all: they all survived, thus confirming that some healing processes occur naturally. The last trial is especially interesting from our perspective in that Redi compared the effect of the styptic water not only with water from a well, but also with nature's undisturbed course, with no bandage at all: we have here a triple trial. Since generally the styptic water did not perform better than water from a well, or even no remedy at all, Redi could conclude that the healing properties attributed to the styptic water would be better attributed to nature than to art.[9]

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[9]"Esperienze fatte in Francia, e in Inghilterra dal Signor Denis, Medico ordinario del Ré Christianissimo, e da altri, intorno a quell'acqua, che si dice, che stagna subito tutti quanti i flussi di sangue," *Giornale de' Letterati* 7, (1673):115–9; "Esperienze fatte dal Signor Francesco Redi alla presenza del Serenissimo Gran Duca di Toscana intorno ad un acqua, che si dice dotata della suddetta virtù," ibid., 119–24. Subsequent editions of Redi's works omit the initial essay with the reports from France and England, thus curtailing somewhat the context of Redi's trials. Marian Fournier, *The Fabric of Life* (Baltimore: Johns Hopkins University Press, 1996), pp. 173–7. Edward Ruestow, *The Microscope in the Dutch Republic* (Cambridge: Cambridge University Press, 1996), p. 219. It is interesting to compare Redi's trial to the celebrated—and often used in the sociology of science literature—poisoned chicken oracle of the Azande, a population from central Africa, as described from the Metropolitan Museum of Art's page on African Art and Rituals of Divination, http://www

It is not clear what impact Redi's trial had, if any, on medical practice. Andrew Wear claims that "there were no clinical trials in the sixteenth and seventeenth centuries" and it is worth recalling that Redi's trial was on animals, not humans. Moreover, he and his assistant knew which was the water from the well and which was that from France, so the experiment was not blind. In the eighteenth century, the Edinburgh naval surgeon James Lind performed an important test on scurvy, when on 20 May 1747, at sea aboard the *Salisbury*, he divided twelve sick sailors in six groups of two and administered to each group different common remedies, such as cider, elixir of vitriol, vinegar, sea water, oranges and lemons, and a special electuary the size of a nutmeg. The test showed that oranges and lemons provided the best cure, followed only in part by cider. Lind's test differed from Redi's in several respects, since Lind wished to compare six different remedies rather than to assess the efficacy of one against simple water, and he worked with human subjects; yet it would be interesting to know whether Redi's work became directly or indirectly known and discussed in Europe and his strategy was adopted elsewhere.[10] The history of clinical trials remains to be written.

4. Malpighi, Trionfetti, and Germinating Seeds

In 1675 and 1679 Malpighi published the two parts of his largest work, *Anatome plantarum*, in which he established systematic parallels between plants and animals and studied the process of growth. Malpighi performed a long series of experiments on plants, my favorite being his planting young twigs of fig, plum tree, and blackberry upside down; he succeeding in making them grow, albeit somewhat smaller than normal, thus showing that there are no valves in the vessels of plants. Malpighi performed a number of experiments concerning growth too, wishing to test the notion of spontaneous generation in plants from simple earth. Probably inspired by Redi's trials on the generation of insects discussed above, Malpighi collected earth from well under the surface of the earth and placed it in a glass jar covered by several silk veils to prevent tiny seeds carried by the wind from germinating in the soil, while ensuring access to air and water: no plant ever grew in that soil. The analogy with Redi's experiments involves only the idea of testing spontaneous generation and of covering samples of earth in a jar with textiles to allow for

.metmuseum.org/explore/oracle/essay1.html; a standard source on the Azande is E. E. Evans-Pritchard and Eva Gillies, *Witchcraft, Oracles and Magic among the Azande* (abridged ed., Oxford: Clarendon, 1976).

[10]Andrew Wear, "Early Modern Europe, 1500–1700," in *The Western Medical Tradition*, eds. Lawrence I. Conrad et al. (Cambridge: Cambridge University Press, 1995), pp. 227–29; James Lind, *A Treatise of the Scurvy* (Edinburgh, 1753), pp. 191–94.

contact with the air: no parallel trial was involved in this case, probably because Malpighi simply assumed that if the samples of earth contained seeds, the seeds would simply germinate. This example testifies to his knowledge of Redi's experiment.[11]

Malpighi further wished to test whether by removing the cotyledons—or, as he called them, seminal leaves—from several seeds of broad beans, beans, gourds, melon, and lupine, the plants would still grow. Of all the many seeds he planted, only one broad bean grew for a few days. He then repeated the experiment with a wider range of plants, removing the cotyledons once the vegetation had just started; also in this case plants did not fare well. Malpighi concluded that the seminal leaves are analogous to the albumen in the egg, and the earth is the uterus in the vegetation process; thus the cotyledons provide nourishment to the plantlet.[12]

In 1685, Malpighi's views on plants came under attack by the prefect of the botanic garden in Rome, Giovanni Battista Trionfetti, the author of *Observationes de ortu et vegetatione plantarum*. Trionfetti challenged several propositions by Redi on spontaneous generation and by Malpighi; in particular, Trionfetti challenged by means of a series of experiments with beans and castor beans the view that the cotyledons or seminal leaves help the growth of the plant. Trionfetti argued that the cotyledons protect the young plant and prevent the dissipation of the most active particle by the undue entrance of matter from the outside; thus, their role would be purely that of a mechanical shield, though Trionfetti was no mechanist. In order to prove his point, he filled the empty space left after the removal of the cotyledons with earth and wax, arguing that with this added precaution the plants still grew well.[13]

In the last few years of his life, Malpighi drafted an extensive autobiography or *Vita*, to be published posthumously, in which he defended himself from criticisms and attacks he had received throughout his life. This autobiography appeared in 1697, three years after Malpighi's death, thus after Homberg had performed his experiments at the Paris Académie. Among the most interesting passages in his *Vita* are those reporting a series of experi-

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[11]Marcello Malpighi, *Anatome plantarum* (London, 1675–79), in *Opera omnia*, 2 vols. (London, 1686–7), 2:69 and 71–2. Pagination varies and is not continuous: I rely on the widely available facsimile reprint by George Olms (Hildesheim, 1975).

[12]Malpighi, *Anatome*, 2:11–15.

[13]Giovanni Battista Trionfetti, *Observationes de ortu et vegetatione plantarum* (Rome, 1685), 56–7. Howard B. Adelmann, *Marcello Malpighi and the Evolution of Embryology*, 5 vols. (Ithaca: Cornell University Press, 1966), 1:439, 493–7; L.R. Angeletti and S. Marinozzi, "Giovanni Battista Triumfetti e la rinascita dell'orto medico di Roma," *Medicina nei Secoli*, 12, (2000):439–75; A. Ottaviani, "Il dibattito sulla generazione delle piante imperfette tra sei e settecento," *Medicina nei Secoli* 15, (2003):291–317; "Scuola galileiana e cartesianesimo nella polemica tra Marcello Malpighi e Giovan Battista Trionfetti," in eds. Maria Teresa Marcialis and Francesca Maria Crasta, *Descartes e l'eredità cartesiana nell'Europa seisettecentesca* (Lecce: Conte, 2002).

ments on plants that are of special interest from our perspective. While initially Malpighi had removed the cotyledons from some seeds in order to observe the effect on their growth, in 1685, following Trionfetti's challenge, he repeated the experiment with beans and lupine seeds, with the added precaution of filling the space left by the removal of the cotyledons with wax, something he continued doing in subsequent trials; no plant grew. Among twelve gourd seeds he planted, however, only one, where a portion of one cotyledon had accidentally remained attached, did grow; its size was only three inches as opposed to more than half a foot for a normal plant. Malpighi does not state whether he had planted whole unmutilated seeds to make the comparison, or whether he was just giving the reasonable size of a normal plant at that developmental stage. Immediately after this report, however, he stated that he ran two parallel trials, planting a number of mutilated chestnuts and acorns alongside unmutilated ones; the mutilated nuts did not grow whereas the whole ones did. Thus the added precaution of running parallel trials arose at a later stage, possibly as a second thought in reaction not only to Trionfetti's challenge but also to the fact that one gourd seed did germinate after all. There is an interesting parallel here with Redi's experiments on the styptic water, in which he had perceived the need to perform two parallel trials in order to weed out those cases when healing occurs naturally. Here too Malpighi needed to weed out—so to speak—those seeds that seem to be so vigorous as to germinate regardless of whether their cotyledons are removed, or those where the excision had left a portion of cotyledon attached, as well as to compare the growth of plants with and without cotyledons. His trials did not rely on a rigorous and systematic comparison between the two sets of cases, however, but rather they were based on rather loose criteria, in line with Redi's approach. In fact, Redi had given the number of animals in his trials, whereas Malpighi at times omitted even such simple details.

In June 1685, Malpighi repeated similar experiments with beans, but this time he let the root germinate for one or two days before removing the cotyledons; whilst those plants that were left intact germinated, those mutilated on the second and third day soon died. Performing similar experiments with lupines, Malpighi noticed a significant difference in the growth of the stalk and leaves between mutilated and intact seeds. Additional variations of the experimental procedures occurred with gourds. This time Malpighi delayed the mutilation process of the twelve plants until they had sprouted, and he noticed that only two grew but the difference in size compared to plants that had grown from whole seeds was in the ratio of one to five. In 1687, he performed additional experiments with gourd seeds by removing only one cotyledon, showing that their growth was hampered. He proceeded relentlessly to experiment with the castor bean (*catapucia major*), arguing that the portions Trionfetti had removed were not the true seminal leaves. Malpighi provided an extensive diary and a series of plates detailing its growth. Although at times one would like to know more details about Malpighi's trials, his *Vita* shows a systematic attempt to vary the conditions of the experiment, by removing the cotyledons at different stages of the plant's growth, for example, or removing only one cotyledon instead of two.[14]

Malpighi's experiments on plants and Redi's experiments on generation and styptic water are useful reminders that seventeenth-century sophisticated experimentation went well beyond the physico-mathematical disciplines and included medicine and surgery, anatomy and the study of generation, and plants as well; a careful examination of the *Anatome plantarum*, for example, reveals an extensive set of elaborate experiments still awaiting careful investigation.

Concluding reflections

It is time for some final reflections on the role of parallel trials in the seventeenth century. From what we have seen, all four experiments discussed above were problematic or involved controversies. Florin Périer could not climb the Puy-de-Dôme several times in a day; Redi was engaged in a controversy with Kircher on spontaneous generation and needed to protect himself from the charge that the pieces of meat and fish he had selected may have been unsuitable for generating maggots and flies; Denis was a prominent physician, yet initial experiments on his water carried out in Tuscany disproved his claims or proved inconclusive; lastly, Malpighi turned to a parallel trial only as a second thought when challenged by Trionfetti. Of course, uncertainty, difficulty, and controversy in performing experiments were widespread, yet it seems that the specific problems associated with nature's variability and disputes about the experiments discussed above played an important role in the development of the methods discussed in this paper.

The four cases I presented come from widely different disciplines but they share common traits at various levels, or at least so they seem to us. Here a cautionary note may be in order about control experiments, namely experiments involving parallel trials with a comparison between a tampered case and one in which nature runs its normal course and which involve a careful, often quantitative and relatively complex analysis of data and ideally double-blind trials: such experiments have become so pervasive and important in our culture that twenty-first-century readers may be prone or particularly sensitive to "seeing" them in different circumstances and times. One may legitimately

[14]Marcello Malpighi, *Vita*, in *Opera posthuma* (London, 1697), pp. 63–4. On Malpighi's *Vita* see Domenico Bertoloni Meli, "The Posthumous Dispute between Borelli and Malpighi," in *Marcello Malpighi, Anatomist and Physician*, ed. Domenico Bertoloni Meli, (Florence: Olschki, 1997), pp. 247–75, (pp. 263–75); Adelmann, *Embryology*, pp. 437–8 did not analyze the change in Malpighi's experimental procedures; see pp. 496–97. Marcello Malpighi, *Correspondence*, 5 vols. (Ithaca: Cornell University Press, 1975), ed. by Howard B. Adelmann, 3:1120–21; Cestoni to Malpighi, Livorno, 17 January 1686; 3:1267, Malpighi to Henrici, 13 May 1687.

question whether seventeenth-century practitioners as well saw a common methodological thread among the cases discussed here. My answer to this question is cautiously affirmative overall, especially for the strong connections that can be established among cases two, three, and four. Malpighi certainly knew Redi's work on the generation of insects, Redi probably knew Pascal's report. This falls short of explicit statements acknowledging matters to do with method, but the circulation of texts makes it plausible that seventeenth-century practitioners may have seen a thread uniting the different cases.

It may be useful to recapitulate some of the main similarities and differences among the four cases. The central idea in all of them is to compare two simultaneous trials, one of which seeks to represent as closely as possible nature's normal course, or at least nature's course in average day-to-day circumstances, whereas the other involves the modification of a variable in order to ascertain its role. The criterion of simultaneity is quite stringent and is meant to remove potential effects due to a time lag between the two trials that could alter the result. Simultaneity was crucial to the Puy-de Dôme experiment because of the imponderable variability of the height of the column of mercury, but Redi's and Malpighi's experiments too may have been affected by differences in weather or season of the year, for example. Malpighi's investigation involved the comparison between a natural process on the one hand, such as the growth of a plant from a seed planted in the earth, with a tampered one on the other, such as the lack of growth of plants in which both cotyledons have been removed, or the inhibited growth of plants in which only one cotyledon has been removed. Redi's experiments on generation show a similar pattern in that they involve the comparison between a natural process, such as the behavior of chunks of meat placed in the open air in an open container, with a tampered one, where flies are prevented from getting close to the meat either by sealing the container with paper or covering it with pieces of cloth. The case of the Puy-de-Dôme experiment is slightly different in that both trials involved the same measurement at different altitudes—one of which was highly unusual—and relied on experimental apparatus. The one at the foot of the mountain was intended to serve as a benchmark for the height of the column of mercury during the day, whereas the one brought to the top and checked at different places during the trip was meant to ascertain the role of altitude, thus isolating it as a variable—although a few years later Linus, Boyle, and the Cimento academicians would have questioned how effective this isolation was in relation of temperature. The case of styptic water too presents some differences, because strictly speaking for most of the trials Redi did not let nature run its course in that he bandaged the wound in both cases. Wetting the bandages in some instances with water from a well rendered the trials more symmetrical, because all bandages were wet in some way. At the same time, water from an unspecified well, as opposed to water from one of the many springs with special and peculiar mineral waters to be found in Tuscany, looked as neutral a way to wet the bandage as one may ever find. Only in the final trial did Redi let nature run its course by refraining from bandaging at all the last six capons.

There is also a noteworthy interplay between the two parallel trials: on the one hand, the "benchmark" trial was intended to be as close as possible to nature's normal course and therefore to measure or ascertain the differences introduced in the modified trial. On the other hand, reciprocally, the modified trial unraveled some features of the benchmark one. For example, in the mid-seventeenth century the explanation of the Torricellian experiment was contested and the Puy-de-Dôme trial helped solidify consensus on the view that the column of mercury measured the weight of the ocean of air above us, since at a greater altitude the column of mercury was lower. Similarly, the trial in which fine cloths prevented flies from gaining access to putrefying meat shed light on the process of generation of insects and cast doubts on spontaneous generation. The trial with styptic water highlighted that simple arterial wounds can heal with appropriate bandages and water or occasionally even on their own. Finally, the trials in which one or both cotyledons were removed and replaced with wax or earth highlighted that their role was not simply to protect the growing plantlet, but also to provide nourishment to it.

Of course, mine is an exceedingly partial survey and a limited analysis of this rich field. Nonetheless, I hope that these initial observations on parallel trials may serve as a useful starting point for further investigations and reflections on seventeenth-century experimentation in and around the Cimento Academy, crossing the boundaries between the physico-mathematical and medico-anatomical disciplines; despite a current bias in favor of the former, I believe that the latter were equally significant in this regard.