Published in final edited form as:
J Early Mod Stud (Bucur). 2018 ; 7(1): 73–103. doi:10.5840/jems2018714.

The Weight of the Air: Santorio's Thermometers and the Early History of Medical Quantification Reconsidered

Fabrizio Bigotti
Institut für Geschichte der Medizin, Julius-Maximilians Univeristät Würzburg, Centre for Medical History, University of Exeter

Abstract

The early history of thermometry is most commonly described as the result of a continuous development rather than the product of a single brilliant mind, and yet scholars have often credited the Italian physician Santorio Santori (1561–1636) with the invention of the first thermometers. The purpose of using such instruments within the traditional context of Galenic medicine, however, has not been investigated and scholars have consistently assumed that, being subject to the influence of atmospheric pressure and environmental heat, Santorio's instruments provided unreliable measurements. The discovery that, as early as 1612, Santorio describes all vacuum-related phenomena as effects of the atmospheric pressure of the air, provides ample room for reconsidering his role in the development of precision instruments and the early history of thermometry in particular. By drawing on a variety of written and visual sources, some unpublished, in the first part of this article I argue that Santorio's appreciation of phenomena related to the weight of the air allowed him to construct the first thermometers working as sealed devices. Finally, in the second part, I consider Santorio's use of the thermometer as related to the seventeenth-century medical practice and his way to measure the temperature as based on a wide sample of individuals.

Keywords

Santorio Santori (Sanctorius); thermometer; temperature; Galen; early modern medicine; University of Padua

> We have stated this elsewhere, the efficient cause which moves those things that are believed to be moved by the vacuum is of two kinds: one resides in the container […], [t]he other lies in the air, which is always heavy, and all the things that seem to happen because of the void, are moved as such by the weight of the air.
>
> Santorio Santori, *Commentaria in Artem Medicinalem Galeni* (1612), III, col. 352 D–E

The early history of thermometry is most commonly described as the result of a continuous development rather than the product of a single brilliant mind, and yet scholars have often credited the Italian physician Santorio Santori (1561–1636) with the invention of the first thermometer.[1] There are valid reasons for this. It was indeed Santorio who first applied a

Europe PMC Funders Author Manuscripts

graded scale behind the thermoscope allowing it to measure the temperature of both the air and the body.[2] To that end, he set the parameters of the instrument, measuring the minimum and maximum temperature by exposing the glass bulb of the thermometer to the fire of a candle and then to melting snow.[3] Experimentally, Santorio understood the need to take measurements at equal intervals of time, which he did by means of his pendulum-regulated devices called *pulsilogia*.[4] Finally, the invention of the thermometer follows Santorio's programme of quantification of the physiological parameters of the human body which started approximately in the 1580s and was reflected in the invention of other similar devices (steelyard chair, pulsilogia, hygrometers).[5]

1 Santorio's Scholarship. Past and Recent Attempts

Although generally known in outline, this story lacks many significant details.[6] For one, Santorio's invention and use of the thermometer in the context of late-Renaissance Galenism remain largely uncharted. Whilst twentieth-century historians of science tended to consider Santorio's inventions as a late adaptation of Galileo's insights,[7] historians of medicine have often seen his attempts to improve Galenic medicine by means of new devices as a trick of history played at his expense and without his knowledge. In the words of Owsei Temkin:

> Sanctorius's endeavor to help Galenic medicine by the use of the thermometer might well be cited as a case of what the philosopher Hegel called "die List des Begriffes" ("the cunning of the concept") whereby a harmless-looking device effects the downfall of the subject. The measurement of heat and cold by the rise or fall of a fluid in the tube of the thermometer substituted for qualities. For Galen, hot and cold, dry and moist were meant to have objective existence. To the touch, hot and cold are quite different, whereas if measured by the thermometer they become the more or less of something else.[8]

---

[1]Raffaello Caverni, *Storia del Metodo Sperimentale in Italia*, tome I, Florence: Civelli, 1891, pp. 267–268; William Edgar Knowles Middleton, *Invention of Meteorological Instruments*, Baltimore: Johns Hopkins Press, 1969, p. 14; Mirko Drazen Grmek, *La Première Révolution Biologique. Réflexions sur la Physiologie et la Médicine du XVIIème siècle*, Paris: Payot, 1990, pp. 77–82.

[2]Santorio Santori, *Commentaria in Artem Medicinalem Galeni Libri Tres*, Venice: Giacomo Antonio Somasco, 1612, Pt III, col. 62C–E.

[3]Santorio Santori, *Commentaria in Artem Medicinalem Galeni*, Venice, Marco Antonio Brogiollo, 1630, Pt II, 762D. For Santorio's use of fixed points and its scientific contexts see Hasok Chang, *Inventing Temperature. Measurement and Scientific Progress*, New York: Oxford University Press, 2004, p. 10. Middleton, *Invention*, p. 10 traces back this way of assessing the temperature to Galileo's friend Francesco Sagredo (1571–1620), but it seems that Sagredo's experiments started at a later date with respect to those of Santorio. According to Sagredo's own statement, in fact, his experiments began at a time when he had been informed by Agostino da Mula (1561–1621) that Santorio had invented the thermometer (1610c.).

[4]Santorio Santori, *Commentaria in Primam Fen Primi Libri Canonis Avicennae*, Venice: Giacomo Sarzina, 1625, coll. 22E–24A.

[5]Fabrizio Bigotti and David Taylor, "The Pulsilogium of Santorio. New Light on Measurement and Technology in Early Modern Medicine," *Society and Politics* 11.2 (2017), pp. 59–60.

[6]An exception to this rather depressing panorama may be considered a work in Croatian by Mirko Drazen Grmek, *Santorio Santorio i Njegovi Aparati i Instrumenti*, Zagreb: Institut za Medicinska Istraživanja Jugoslavenske Akademije, 1952, which, whilst fairly accurate for some of the surgical devices, is generally not reliable for Santorio's precision instruments as not sufficiently grounded in the reading of his works. Most recently, a PhD candidate at the Max Planck Institute for the History of Science has undertaken the daunting task of reconstructing Santorio's chair, see Teresa Hollerbach, "The Weighing Chair of Sanctorius Sanctorius: A Replica," *NTM Zeitschrift für Geschichte der Wissenschaften, Technik und Medizin* 26.2 (2018), pp. 121–149, but the replica has been made not according to historical criteria and experiments with it end up providing inconclusive results.

[7]Most notably Antonio Favaro, *Amici e Corrispondenti di Galileo Galilei*, Florence: Editrice Salimbeni, 1983 (Reprint of Venice, 1894), Bk I, pp. 218–219; Modestino del Gaizo, "Le Conoscenze in Fisica di Santorio Santorio e l'Efficacia delle Scoperte di Galilei sul Movimento delle Scienze Mediche nel Secolo XVII," in *Atti della Riunione di Venezia (1909) della Società Italiana di Storia Critica delle Scienze Mediche e Naturali*, Venice: Tip. Orfanotrofio di A. Pellizzato, 1909, pp. 92–102; and more recently, yet in a more subtle way, Grmek, *La Première Révolution*, p. 76. In favour of Santorio's priority, however, Arturo Castiglioni, *La Vita e l'Opera di Santorio Santorio Capodistriano*, Bologna–Trieste: Licinio Cappelli Editore, 1920, pp. 44–46.

Most recently, however, a different picture has been sketched. If William Edgar Knowles Middleton had already stressed the existence of a medical understanding of temperature well before the early attempts of measuring it with instruments were put in place,[9] Arianna Borrelli has recently called attention to the use of the thermometer within the context of Renaissance meteorology and highlighted that Santorio's instrument represents "the operationalisation" of a pre-existing theoretical model. Borrelli, however, denies Santorio any appreciation of a concept of temperature as different from the Galenic one.[10]

Overall, the invention of the thermometer and its application to medical diagnosis rest on two different but closely intertwined paths. On the one hand, both draw from a Galenic model of intensity, which, developed throughout the medieval and early modern period, had established the criteria to evaluate a disease in terms of magnitude (*latitudo, magnitudo morbi*) and so the foundation of the concept of degree and temperature (*medicinarum gradus*, *temperamentum*, *temperies*, *temperatura*).[11] On the other, they stem from Santorio's theory of matter, which accords primacy and substantiality to the geometrical and quantitative features of elemental bodies.[12] As a consequence of this theory, Santorio anticipated the full potential of the new instrument and distanced himself from Galen's subjective appreciation of temperature, gradually replacing his standards. Thus, in considering both the medical and the experimental path of his discovery, I will start my analysis by exploring the philosophical and scientific background of Santorio's thermometers and I shall then move to describing their technical features and applications to medical diagnosis.

2 Theoretical and Technical Aspects of Santorio's Thermometers

Medieval scholars have long clarified the connection between the scholastic theories of *latitude of forms* (*latitudo formarum*) and the process of condensation and rarefaction of matter, which affects temperature and volume of substances.[13] Commentaries on the *Physics* of Aristotle were usually the place in which to discuss the different implications of this problem and especially how particular properties (*formae*) could act differently according to various degree of intensity (*intensio et remissio formarum*). In the immediate aftermath of the publication of Giovanni Battista Della Porta's *Magia Naturalis* (1560) and Heron of Alexandria's *Pneumatika* (1575), experiments related to the rarefaction of air became increasingly popular and attracted the attention of Benedetti, Drebbel, Bacon, Santorio and Galileo. As described by Arianna Borrelli, most of these were *inverted-glass experiments*[14]

---

[8]Owsei Temkin, *Galenism. Rise and Decline of a Medical Philosophy*, Ithaca–New York: Cornell University Press, 1973, p. 160.
[9]Middleton, *Invention*, pp. 3–4 which points specifically to Johan Hasler's *Logistica Medica* (1578).
[10]Arianna Borrelli, "The Weatherglass and its Observers in the Early Seventeenth Century," in Claus Zittel, Gisela Engel, Romano Nanni, Nicole C. Carafyllis (eds.), *Philosophy of Technology. Francis Bacon and His Contemporaries*, Leiden–Boston: Brill, 2008, p. 111.
[11]See Georg Harig, *Bestimmung der Intensität im medizinischen System Galens. Ein Beitrag zur theoretischen Pharmakologie, Nosologie, und Therapie in der Galenischen Medizin*, Berlin: Akademie Verlag, 1974; Edith Dudley Sylla, "Medieval Quantifications of Qualities: The Merton School," *Archive for the History of Exact Sciences* 8 (1971), pp. 9–39; Edith Dudley Sylla, "Medieval Concepts of the Latitude of Forms. The Oxford Calculators," *Archives d'histoire doctrinale et littéraire du Moyen Âge* 40 (1973), pp. 223–283.
[12]Fabrizio Bigotti, "A Previously Unknown Path to Corpuscularism in the Seventeenth Century: Santorio's Marginalia to the *Commentaria in Primam Fen Primi Libri Canonis Avicennae* (1625)," *Ambix* 64.1 (2017), pp. 1–14.
[13]Anneliese Maier, "Das Problem der *Quantitas Materiae* in der Scholastik," *Gregorianum* 27.1 (1946), pp. 89–109; Edward Grant, *Much Ado about Nothing. Theories of Space and Vacuum from the Middle Ages to the Scientific Revolution*, Cambridge: Cambridge University Press, 1981, pp. 71–74.

which consisted in taking an empty (i.e. air-filled) glass flask with a long neck, heating it up and turning it upside down to plunge the extremity of its neck into a bowl full of water. After a while, the air in the flask cools down and the water in the bowl slowly rises up the neck of the inverted glass flask insofar as the air occupies less volume than before and attracts the water inside the neck. Although some philosophers framed their observation on rarefaction and condensation as part of an increasing anti-Aristotelian strategy, this was not necessarily the case for all of them. Indeed, after Della Porta started popularizing the earliest *inverted-glass experiments*[15] these came to be regarded as an application of the Aristotelian natural philosophy by the Jesuit Francisco de Toledo (1573).[16]

Due to the lack of primary sources, it is difficult to sketch out a timeline in the gradual development from the thermoscope to the thermometer. Throughout the more than sixty years that separate Della Porta's experiments (1560) from Santorio's publication of a plate showing the thermometer (1625, Fig. 5) we only have one published source providing a complete description of the instrument. This is Giuseppe Biancani's well-known *Sphaera Mundi* (Bologna 1620), which—written in 1617—describes an instrument called *thermoscopium* whose invention is ascribed to Santorio [Fig. 1].[17]

As for manuscript sources, the only one known hitherto was Bartholomeo Telioux's *Mathematica Meravigliosa* (1611), providing a patchy and very confused description of a two-bulb thermometer which is different from Santorio's models and was meant mostly to measure the temperature of the air [Fig. 2].[18] However, in 2015 I found a third source, in a manuscript of the Marciana Library in Venice titled *Epistolarum et Disquisitionum Sacrarum libri XII* [Fig. 3] written by Ippolito Obizzi, Santorio's most famous rival and critic.[19] The manuscript's title would hardly reveal that it contains a description of an airthermoscope [Fig. 3a] written at about the same time as Biancani's account. The description is part of a letter written by Obizzi father to his son Ippolito, a Carthusian friar, on the 2nd October 1617 and is accompanied by a sketch [Fig. 3b]. Both the size and functioning of the instrument are described in detail with the overall length said to be 1 Venetian fathom (*cubiti unius*), that is 68.3 cm.[20]

The terminology is akin to that already adopted by Biancani, with Obizzi calling the instrument *vas vitreum* and *instrumentum temperamenti*, names which Santorio had already adopted for his description in 1612 and 1614 respectively.[21]

14Borrelli, "The Weatherglass and its Observers," p. 68.
15Giovanni Battista Della Porta, *Magiae Naturalis sive de Miraculis Rerum Naturalium Libri IIII*, Antwerp: Christophorus Plantinus, 1560, c. 59r as well as Giovanni Battista Della Porta, *I Tre Libri De' Spiritali*, Naples: Giovanni Giacomo Carlino, 1606, p. 77.
16Francisco de Toledo, *Commentaria Una Cum Quaestionibus in Octo Libros Aristotelis De Physica Auscultatione*, Venice: Giunti, 1573, c. 133v col. A.
17Giusppe Biancani, *De Sphaera Mundi seu Cosmographia Demonstrativa, et Facili Methodo Tradita*, Bologna: Sebastiano Bonomi, 1620, p. 111.
18Guillaume Libri, *Histoire des Sciences Mathématiques en Italie*, tome quatrième, Paris: Jules Renouard, 1841, p. 471; see also John Anthony Chaldecott, "Bartolomeo Telioux and the Early History of the Thermometer," *Annals of Science* 8.3 (1952), pp. 195–201.
19Ippolito Obizzi, *Epistolarum et Disquisitionum Sacrarum Libri XII*, Venice, Biblioteca Nazionale Marciana (BNM), Cod. Lat. III, 132 (2151), Bk VII, ff. 143v–144r.
20*Ivi*, f. 143v: "Vas vitreum *de quo sit dubium, quod* temperamenti instrumentum *noncupatur, est firme designatus, corpore nimirum orbiculari fistulam cubiti unius, et senis longitudine habens angustam*." Emphasis added.
21Santorio, *Commentaria in Artem Medicinalem* (1612), III col. 62D–E, col. 105A–B, col. 229 D–E, col. 375B; Santorio Santori, *Ars Sanctorii Sanctorii Iustinapolitani De Statica Medicina*, Venice: Niccolo Polo, 1614, II.4, cc. 20v–21r.

Based on both the sketch and the account Obizzi provides, there can be little doubt that the instrument he saw was presented at one of Santorio's Paduan lectures. The similarity with Biancani's and the parallel with another engraving Santorio provided for the 1626 edition of his *Commentaria in Primam Fen Primi Libri Canonis Avicennae* [Fig. 4] are striking, whilst the fact that Obizzi was associated with Santorio in the Venetian *Collegio dei medici fisici* during the period 1617–1619 provides further strength to the claim.[22] A noteworthy detail in the sketch is the caption "vacuum" used by Obizzi to describe the empty space within the glass bulb. Although the description provided correctly identifies the functioning of the instruments in the rarefaction and condensation of the air, Obizzi still maintains that the "violent ascent of water inside the glass tube is *caused by the necessity of vacuum* [*de necessitate vacui*]", that is by virtue of an attractive power.[23] Furthermore, to stress that the content of the upper glass bulb was empty (*corpus vasis vacuum*), Obizzi unrealistically sketches two holes in its lower surface so to prove that, if perforated, it could attract external air.

As it clearly appears, the models portrayed in Figs. 1, 3b–4 are unsealed, with the glass tube either disconnected from the underlying vessel [Figs. 1, 4] or kept in place simply by shape [Fig. 3b][24]. Also important is that, in the above-mentioned Fig. 4 (1626), the change in temperature is displayed by two side-by-side pictures of the same instrument.[25] Although no scale is shown, we know that the degree of temperature was measured by using a compass (*circinus*). Something that comes as a bit of puzzle is that, despite being published one year later, the plate in Fig. 4 replaced a more elaborate sketch that Santorio had provided for the first edition of his *Commentaries on Avicenna's Canon* (1625) [Fig. 5]. In the latter, we find an engraving of one instrument apparently sealed with two threads bound around the column to mark the difference in temperature. Notably, the instrument's vessel is shaped as a very long neck which wraps the glass tube [Fig. 5a]. This model, known as "cylindrical vessel" (*a vaso cilindrico*) was later adopted by the Accademia del Cimento and is shown in Lorenzo Magalotti's *Saggi di Naturali Esperienze* (1667) [Fig. 6]. The difference between Santorio's and Magalotti's thermometer is that the latter, apparently opened, was actually sealed with stucco and used to test the air pressure with different fluids [Figs. 6a–b], whilst Santorio seems to achieve the same result by curving the shape of the vessel so as to sustain the glass tube. The hypothesis that Santorio could have devised a sealed-close-loop thermometer is

[22]Details of Obizzi's life can be gathered from Santorio's account and indirect criticism of him (indirect as Santorio never mentions his name), see Santorio, *Commentaria in Primam Fen* (1625), coll. 81E–82A: "*Denique dum esset Belluni cum prospera fortuna, illam imprudenter amisit: hac venit* [*scil.* Venetiis], elegit se in archiatrum medicorum venetorum: *tamen videns se inter infimos, sprevit Coeli posituram et quae illi tam magna pollicebatur: illum penituit operam Astrologiae dedisse, et Paulo post decessit, cum totius familiae perniciem*." Emphasis added.

[23]Obizzi, *Epistularum… libri XII*, ff. 143v–144r: "[…] *igitur si aeris in fistula, corporeque vasis inclusi partes a calore externo attenuante fuerint, idem aer dilatabitur, et quod sequens est, maiorem occupabit locum, cui aqua facile cedet, cum natura deorsum tendat. Hac autem facta hypothesi, aerem scilicet calore dilatari per partium attenuationem, frigoreque densari, minoremque tunc locum occupare: dubii solutio per se patet: nam quomodocumque calor aeri incluso communicatus fuerit, sive ambientis ratione, sive vi aquae, in ampullae contentae, sive corporis vasis calido adhibito, pro caloris ratione aer attenuabitur, qui tunc maiorem occupabit locum, cui aqua cedens necessario descendet: contra quocumque modo frigus ipsi aeri impertitum fuerit, sive ambientis ope, sive applicatione frigoris corpori vasis, sive infrigidatione aquae ipsius ampullae, aer condensabitur, quem minorem in locum restringi opus erit, quo tempore* de necessitate vacui *aqua violenter ascendet*." Emphasis added.

[24]On this Middleton, *Invention*, p. 13; Grmek, *La Première Révolution*, pp. 81–82; Giuseppe Ongaro, *Santorio Santorio: La Medicina Statica*, Florence: Giunti, 2000, p. 28; Borrelli, "The Weatherglass and its Observers," p. 67.

[25]Santorio Santori, *Commentaria in Primam Fen Primi Libri Canonis Avicennae*, Venice: Giacomo Sarzina, 1626. As I pointed out in Bigotti–Taylor, "The Pulsilogium of Santorio," pp. 62, 91–93, this edition is extremely rare and only few of the surviving copies present variations that are significant in terms of text and engravings. The engraving shown in Fig. 4 is taken from the copy kept in the Ancient Library "Vincenzo Pinali" of Padua, Shelf-mark STM. DUCC.VI.F.-2.(FA), col. 22.

reinforced by the existence of another type of instrument also engraved in the *Commentaries on Avicenna's Canon*, where the vessel is arranged in the form of a pyramid reaching almost the limit of the upper glass bulb [Fig. 7].

Further differences between these instruments and others devised by Santorio (probably at an earlier stage) are revealed by the shape of the vessel, which in the earliest model was similar to that one portrayed by Obizzi [Figs. 9b, 12]. Modern replicas of seventeenth-century thermometers, i.e. that in the Museum of Science in Florence, tend to keep the glass tube in place by means of a cork [Fig. 8], a precaution certainly not needed in Figs. 5,7 due to the shape of the vessel.

3 Problems

A series of historical, technical, and theoretical problems arise if we assume that one or more of Santorio's instruments worked as sealed instruments. To begin with, we know from Santorio's own account that the images provided for the *Commentaries on Avicenna's Canon* were crudely drawn to prevent other scholars from claiming Santorio's inventions as their own, and thus are not entirely reliable.[26] Another difficulty lies in the fact that, although developed across a relatively long period of time, Santorio's instruments are often presented without any references to their conceptual evolution but only as different applications of the same principle. Furthermore, Santorio purposely limits his descriptions to the purely medical applications of his instruments, devoting very little or no attention to the details of their construction, deferring such an explanation to a book titled *De Instrumentis Medicis Non Amplius Visis*, which ultimately was never published. Finally, the almost complete absence of manuscript sources makes the reconstruction of a theoretical background even more complex.

The lack of direct references leaves only two approaches as practicable: one is to look at Santorio's texts to find some directions about his ideas on natural philosophy; the other consists in reconstructing the instrument. In this article I can only address the former task, reserving the latter for a later stage of my research.

4 Santorio on the Weight of the Air

As historians of technology have shown, early thermometers were nonsealed air thermometers, due to the lack of appreciation of the influence of atmospheric pressure, which was experimentally proved by Evangelista Torricelli in 1643. Working as baro-thermometers, these instruments could only provide very imprecise measurement, mixing together parameters such as atmospheric pressure and temperature. So far this has been assumed to apply also to Santorio's instruments. Using thermometers to obtain measurements of the temperature of the body and the air—let alone the heat of the sun and the moon[27]—Santorio soon realised that these instruments could be read differently

[26]Santorio, *Commentaria in Primam Fen* (1625), *Ad Lectorem*: "*In his vero commentariis apposui solum illorum instrumentorum icones ruditer, et extempore expressas, quae huic physiologiae respondent: quia audio discipulos meos in varias terrarum partes dispersos, quos summa caritate, et gratuita benevolentia docui, horum multorum sibi inventionem attribuere, quorum inhumanitas silentio certe non erat obvolvenda.*"
[27]*Ivi*, coll. 76B–78A; 346C–347.

according to the type used and the time of exposure to the source of heat.[28] For these kinds of measurements alone, however, he did not need to develop sealed thermometers. Such a precaution would only be needed by someone who had realised that the dynamic movements of fluids (viz. air and water) inside the thermometer is caused not by "an attractive power of the vacuum," as in Obizzi's explanation, but by a difference in their specific density and, above all, by the pressure exerted on water by the external air. Historians of science have usually attributed the latter discovery to Torricelli, but I shall argue that there is enough evidence to trace it back to Santorio.

To address the question of how Santorio came to identify the weight of the air we ought to consider more closely his natural philosophy and the functioning of the thermometer, especially Santorio's understanding of rarity and density in relation to the formation of the void.

Santorio explicitly relates the functioning of the thermometer to the rarefaction and condensation of the air within the glass tube, which once heated comes to occupy greater space.[29] In keeping with a theory he had elaborated in his *Methodus Vitandorum Errorum Omnium qui in Arte Medica Contingunt Libri XV* (Venice 1603), rarefaction and condensation of matter are related to the motion of certain corpuscles (*particulae minimae*) whose number, at equal volume, differentiates the relative rarity and density of a substance.[30] Most notably, Santorio links rarefaction and condensation to the existence of void, insofar as heat triggers a kinetic movement (*motus aliquod velocissimus*) which rarefies the substance and increases the number of empty spaces (*meatus*) between its particles.[31] From this standpoint also the name attributed by Santorio's followers to the thermometer might help to shed some lights on its early applications: the so-called *Hydrolabium Sanctorii* (Santorio's water-catcher) was also used to test the existence of the vacuum.[32] Santorio's theory of void, however, rests on different grounds than that of his contemporaries.

Throughout the sixteenth and much of the seventeenth century the common appreciation of the vacuum, amongst physicians and philosophers who were willing to admit its existence, was related to the abhorrence of nature for empty spaces (the so-called *horror vacui*) and regarded as a kind of attraction exerted by the vacuum towards the surrounding parts.[33] Galileo himself accepted the concept of "the attractive power of the vacuum" and never linked its existence to the atmospheric weight of the air.[34] As early as 1603, however, Santorio had already denied the concept of "attractive power:" insofar as it is a non-thing—

[28] *Ivi*, col. 77A: "[…] *varii enim gradus fiunt pro ut varia sunt instrumenta, et variae sunt pulsationes*."

[29] *Ivi*, coll. 24A, 76C.

[30] Santorio Santori, *Methodi Vitandorum Errorum Omnium qui in Arte Medica Contingunt Libri XV*, Venice: Francesco Bariletto, Bk VIII, ch. 8, for a short introduction to Santorio's theory of matter see also Bigotti, "A Previously Unknown Path to Corpuscularism," pp. 8–10.

[31] Santorio, *Methodi… Libri XV*, Bk VIII, ch. 8, ff. 158rD–158vA; Santorio, *Commentaria in Artem Medicinalem* (1612), Pt III, col. 37A–B: "*[T]ransmutationes omnes fieri supposita dispositione materiae, quae disponitur prius a raritate introducta a motu velocissimo, illumque motum provenire a motore, qui est actus et qui est substantia, quod Antiqui non cognoverunt*."

[32] Caspar Bartholin, *Vindiciae Anatomicae Claro Viro Casparo Hoffmano Opposite*, Copenhagen: Melchior Marzan, 1648, p. 9; Giovanni Alfonso Borelli, *De Motu Animalium*, Pars II, Leiden: Peter van der Aa, Cornelis Boutesreyn, Johan de Vivie, Daniel Ema Gaesbeeck, 1685, pp. 262–263.

[33] For the theoretical background of the experiments on void in the sixteenth century see Charles B. Schmitt, "Experimental Evidence for and against a Void: The Sixteenth-Century Arguments," *Isis* 58.3 (1967), pp. 352–366.

[34] Galileo Galilei to Giovanni Battista Baliani (Florence, 6 August 1630) in Galileo Galilei, *Le Opere di Galileo Galilei*, Edizione Nazionale, Florence: Barbera, 1890–1909, vol. XIV, pp. 127–130, for a discussion of it see Middleton, *Invention*, p. 5.

he defended—the vacuum cannot exert any positive actions, an idea which is linked to Santorio's denial of occult qualities. The action of vacuum must instead be described as a kind of "reception" (*susceptio*) which follows the rarefaction caused either by pain or by heat. In both cases, once rarefied, the parts are rendered *weak* and so *receptive* of whatever material surrounds them.[35] In the third part of the *Commentaria in Artem Medicinalem Galeni* (Venice 1612) this very idea is argued for again and clarified whilst its general explanation is linked to a "weight" exerted by the air on all natural phenomena:

> Second doubt: in [this] text Galen claims that the internal parts emptied by means of a previous evacuation also attract humours, which by the use of repellent drugs, recede to the greater veins; and yet it does not seem that the emptied and void spaces have any attractive power. Being nothing, in fact, the vacuum does not possess any attractive action. Thus, how can we defend Galen when he claims that void spaces attract? We address this doubt by saying that is certainly true that the vacuum qua vacuum does not have any positive action; we have denied, however, that in the vessels where the vacuum is created there is no attractive power. We have stated this elsewhere: the efficient cause which moves those things that are believed to be moved by the vacuum is of two kinds: one resides in the container (for instance when the stomach is void because of excessive fasting, in which case, as Galen says in the passage already quoted, the stomach is filled by bad humours); in this case, however, the attractive virtue does not come from the vacuum, but from the natural desire for the plenitude, which each tunic of the stomach is provided with. All the vessels and the belly of animals avoid as much as they can any sediment as a form of disease, for the reason that, what is against nature, is most dangerous. The other cause lies in the air, which is always heavy, and all the things that seem to happen because of the void, are moved as such by the weight of the air […].[36]

There are two aspects that are particularly noteworthy in this passage. The first is Santorio's apparent use of a double explanation to account for the effects of the vacuum as occurring within and without the body. As for the latter, Santorio will later declare that pain is a phenomenon equally attributable to the rarefaction caused by heat and thus subject to the same cause.[37] The second, is that Santorio is clearly anticipating here a debate that historians of science usually locate at around 1630, with Galileo's reply to Giovanni Battista Baliani;[38] a debate which clearly does not rely on Galileo's investigations.[39] Also important

---

35 Santorio, *Commentaria in Primam Fen* (1625), col. 732D.

36 Santorio, *Commentaria in Artem Medicinalem* (1612), III, 352A–B, D–E: "*2 dubitatio: dicit Galenus in textu exinanita loca interna per evacuationem praecedentem attrahere quoque humores, qui repellentium virtute retrocedunt ad venas maiores: at non videtur, quae loca exhinanita, et vacua habeant vim attrahendi: vacuum enim cum nihil sit, nullas habet actiones attrahendi: quomodo igitur poterit defendi Galenum dum dicit, loca vacua attrahere?* […] *Respondemus nos ad dubium, esse verissimum vacuum ut vacuum non habere positivas operationes: negamus tamen quae in vasis, in quibus est vacuitas non est virtus attrahendi. Hinc diximus alibi, causa efficientem, quae movet ea, quae creduntur a vacuo moveri, esse duum generum, alia esse in parte continente, sicuti dum ventriculus est vacuus ob nimiam inedia, qua occasione ex Galeno loco citato impletur malis ichoribus: virtus sane attrahendi non provenit a vacuitate, sed a naturali desiderio plenitudinis, quae est insertum tunicis ventriculi, vasa enim omnia, et ventres viventium evitant quantum possunt subsidentiam tamquam morbum, eo quid praeter naturam perniciosissimum; aliam vero causa esse in aere, qui semper gravitat, et omnia quae videntur ratione vacui contingere, ab aere gravitante, ut tali moventur: sed de his fusius egimus 10 et 13 methodi nostrae.*"

37 Santorio, *Commentaria in Primam Fen* (1625), col. 679C–D and, again, col. 733C.

38 See n. 34.

39 Possible sources were Aristotle's *De Caelo*, IV.4, 311b, 6–11 as well as Archimedes *On Floating Bodies* and Heron's *Pneumatika*.

is that Santorio offers a very broad generalisation of his assumption about the void to encompass any kind of empty spaces (*vasa in quibus est vacuitas*), including those within the human body. We find a confirmation of this in the *Ars de Statica Medicina* (Venice 1614), where this insight is adopted to justify variations of weight that occur in the human body as a result of changes in external air:

> The external air which passes through the arteries into the body, may render the body heavier or lighter; lighter, if it be subtle and warm; and heavier, when thick and moist.[40]

The application to human physiology of what might well have been a passing remark is revealing of Santorio's systematic approach to natural philosophy. Indeed, Santorio's remarks are not isolated and seems to be part of a greater project for experimentation on the environmental influences on the human body, particularly on the relation between void, rarefaction and weight of the air. For instance, the above-mentioned aphorism is followed by two more which describe in some details instruments and methods to quantify the weight of the air and its influence on human bodies, to which I shall return. As for the connection between weight and rarefaction, an important glimpse is offered in the second part of the *Commentaries on Galen's Ars Medica*.

Confronted with the classical problem of explaining why, when water is pre-heated, it freezes more rapidly (*cur aqua calefacta citius congelatur*), Santorio resorts to his celebrated statical experiments and proves the connection between rarefaction and weight quantitatively:

> As for my part, I believe that cold water which was pre-heated has been rendered tenuous and less resistant to external cold. The victory of the active power, in fact, is very rapid if the passive one offers little resistance. The fact that water which has been boiled is more tenuous is revealed by the fact that it is easily penetrated, and that it weighs less.[41]

Since the conditions of this experiment are not clarified it is difficult to draw any firm conclusions about its results. The experiment is clearly pointing at the reduced weight as related to a change in water's specific density, in which case, however, the container used for experimentation must have been sealed before and after being weighed.[42] According to Santorio, the parts of water not only are rendered "tenuous" by heat—and thus more easily penetrable by cold—but, as a consequence of this, they weigh less. It is interesting to note that, on at least two occasions (on 20 and 21 June 1657), the members of the Accademia del Cimento performed a similar experiment, which confirmed a change in the specific gravity of water after boiling.[43]

---

[40]Santorio, *Ars… De Statica Medicina*, II.3, c. 20v: "*Aer externus per arterias in profundum corporis penetrans potest reddere corpus levius, et gravius, levius si tenuis et calidus: gravis, si crassus et humidus sit*." English translation by J. Quincy.

[41]Santorio, *Commentaria in Artem Medicinalem* (1612), II, coll. 589D–E: "*Ego autem puto, aquam frigidam antea calefactam fuisse redditam tenuem, et minus resistentem, et oppugnantem externo frigore: citissima enim est agentis victoria, si patiens parum resistat: quod vero aqua cocta sit tenuior, patet ex citissima penetratione, et ex leviori pondere*."

[42]This assumption is consistent with sixteenth-century practice to seal containers with hot water and then freezing them to test the existence of the void, see Schmitt, "Experimental Evidence," pp. 357–359.

[43]William Edgar Knowles Middleton, *The Experimenters. A Study of the Accademia del Cimento*, Baltimore: Johns Hopkins University Press, 1971, p. 360.

With another set of experiments, we get closer to Santorio's conception of the weight of the air and the need of its measurement for medical purposes. These consist in a series of hydrostatic measurements aimed at testing the quality of water and the percentage of air contained within foodstuffs to detect their medical properties: the first is discussed in the *Medical Statics* and the second in the *Commentaries on Avicenna's Canon*. With the first experiment Santorio evaluates the quality of water and its being healthier for the body by comparing the weight of the same object in water and air, by means of a hydrostatic balance. Depending on the density of the medium, the difference in weight reveals the different quality of the water.[44] Same approach, but reverse method, is used to test the quality of foodstuffs, particularly the percentage of air within them; the lighter the object—the medium being the same—the greater the quantity of air contained within it and so its increased suitability for people in need of airy food.[45]

Mentioned, but not described in detail, these experiments are akin to those Galileo had undertaken in his youth, especially in *La Bilancetta* (1586). However, such experiments had been popular in medicine since late antiquity[46] and Santorio never acknowledges any debt to Galileo but refers only to Archimedes. The Venetian physician directs these experiences to measure "not only the quantity of the air in each mixed body but also its weight [*aeris pondus quod in mixtis invenitur intelligere*]" and they ultimately convinced him that "not only air, but also water are heavy within their own place."[47]

From what has been argued hitherto, Santorio's appreciation of the weight of the air seems to be linked to his theory of rarity and density as changes occurring in the very structure and quantity of a material substance. As such, it comes as no surprise that his way to measure the phenomenon mix together the concept of humidity and weight (*maior et minor aeris ponderositas*). Indeed, humidity and dryness are understood as changes in the relative density of the air particles, and are accordingly measured with hygrometers. Those using absorption materials, weighted before and after their exposure to ambient air, were amongst the first to be used by Santorio:

> What the weight of the air is, may be collected from several types of salt dried first in the warm sun, and then exposed to the open air of the night. Secondly, from the greater increase of cold as to our sense of it, than what is discernible in the instrument that measures the temperaments [*intrumentum temperamentorum*]. To us, in fact, it is air's moisture, that is to say its weight, which sharpens the sensation of cold;[48] thirdly, from the greater or lesser warping of thin boards, especially if

---

[44]Santorio, *Ars… De Statica Medicina*, II.5, c. 21r.

[45]Santorio, *Commentaria in Primam Fen* (1625), col. 200C–D.

[46]Samuel Sambursky, *The Physical World of Late Antiquity*, Princeton: Princeton University Press, 1962, p. 81.

[47]Santorio, *Commentaria in Primam Fen* (1625), col. 153A–C: "*Per simile experimentum facile dignoscimus, quae sint illa alimenta, quae magis vel minus aerem participant, et an corpora viventia plus minusve de elemento aeris amiserint, et quibus alimentis animal, quod amisisset aliquam huius elementi portionem, posset alimentis aeris reparari, et ad salubriorem statum revocari: qua lance vero perpendatur metalla et aliam mixta in aere prius, et deinde in aqua in lib[ro] de instrumentis medicis agemus. Postremo* non solum aer, sed etiam aqua in propria sphaera gravitat, *quod patebit ex vase ligneo vacuo, quod supernatat, quod si acqua impleatur statim ad imum descendat, quo accidit:* quia aqua in proprio loco gravitat. *Ne dicant id evenire ob vasis figuram, quia in quacumque figura semper vas, si plenum sit, fundum petet,* ergo mixta per aerem non erunt leviora," emphasis added, and again 156E: "*nec dicant hoc summe leve esse aerem quod probatum est superius aerem gravitare*."

[48]Quincy's translation of Santorio's aphorism makes no sense of this passage.

they be of pear-tree. Fourthly, from the contractions of lute-strings and hemp-cord.[49]

Commenting on this as well as on the previous aphorism of the *Medical Statics*, the English physician and apothecary John Quincy (d. 1722) launched himself into a detailed explanation of the influence exerted by atmospheric pressure on the body, but he did not fail to note that most of Santorio's experiments bear relation only to the moisture and dryness of the air rather than to its weight, a phenomenon which—Quincy remarks—was largely unknown in Santorio's time.[50] Although Santorio was clearly wrong in attributing to humidity the cause of the weight of the air, humidity is actually one of the parameters affecting atmospheric pressure and experiments in this direction were later performed in the Accademia del Cimento as late as 17 September 1657.[51] It may also be useful to remind ourselves that in early modern physics air and water are mutually convertible elements and that the process of distillation by means of which the former was believed to be extracted from the latter results in a constant quantitative proportion, a phenomenon which Santorio relates to the different volume of air and water *minima*[52] and to their material structure, that is, once again, to their relative rarity and density.[53]

"Subtle" and "light," "thick" and "coarse" were therefore the standard expressions by means of which the weight of the air was appreciated in the early seventeenth century and which represent the conceptual landmarks for both Torricelli's and the Accademia del Cimento experiments on atmospheric pressure. It may therefore be relevant to compare Santorio's quotes as discussed hitherto with a passage from Torricelli's letter to Matteo Ricci (11 June 1644), describing the cause of why the vacuum occurs:

> I have already hinted to you that some sort of philosophical experiment was being done concerning the vacuum, not simply to produce the vacuum, but to make an instrument which might show the changes of the air, now heavier and coarser, now lighter and more subtle. Many have said that there cannot be a vacuum; others that it occurs, but with the repugnance of nature, and with difficulty. I really do not remember that anyone has said that it may occur with no difficulty, and with no resistance of nature. I reasoned thus: if I found a very obvious cause of this resistance that is felt in trying to produce vacuum, it would seem vain to attribute the resistance to the vacuum itself, as it would clearly derive from the other cause. On the contrary, by making some very easy calculations, I find that the cause I adopted ought by itself to produce greater resistance than it does when we attempt to make the vacuum. I say this because some philosopher, seeing that he could not

[49]Santorio, *Ars… De Statica Medicina*, II.4, cc. 20v–21r: "*Quanta sit aeris ponderositas, colligitur primo ex maiori, vel minori gravitate aluminis faecum prius exiccati in sole, et deinde aeri nocturno expositi. Secundo ex eo quia sentiamus maius frigus, quam quod observetur in instrumento temperamentorum: aeri enim humiditas, seu ponderositas nobis est lima frigiditatis. Tertio ex maiori, vel minori incurvatione tabulae subtilissimae praecipue ex piro. Quarto ex contractio cordarum testudinum, vel ex cannabe*." My translation. Same argument about the identy of humidity and weight is developed in Santorio, *Commentaria in Prima Fen* (1625), col. 144B–C.

[50]John Quincy, *Medicina Statica: being the Aphorisms of Sanctorius*, London: W. Newton, 1712, p. 77.

[51]Middleton, *The Experimenters*, p. 372.

[52]Santorio, *Commentaria in Primam Fen* (1625), col. 169A. Santorio's understanding of the difference in density in fluids is displayed in many aphorisms of his statics (Santorio, *Ars… De Statica Medicina*, I.72, cc. 17r–v; III.22, c. 36r) and is extensively used elsewhere and notably when he discusses the transformation of elements and expounds that their *minima* are different in terms of volume, see Santorio, *Commentaria in Primam Fen* (1625), col. 169A.

[53]Santorio, *Commentaria in Primam Fen* (1625), coll. 150C, 158C.

Europe PMC Funders Author Manuscripts

> escape confessing that the gravity of the air is the cause of the resistance that is felt in producing a vacuum, would not say that he conceded the operation of the weight of the air, but would persist in his assertion that Nature also helps by her repugnance to the vacuum. We live submerged at the bottom of an ocean of elementary air, which is known by incontestable experiments to have weight, and so much weight, that the heaviest part near the surface of the earth weighs about one four-hundredth as much as water.[54]

As similar as they might seem, Santorio's and Torricelli's considerations rest on different grounds. Santorio realised that the air exerts a certain influence on objects and sought ways to quantify it. In both his theoretical assumption and experimental outcomes, Santorio consistently defends that the difference in density between the container and the surrounding medium (i.e. air/water) is the cause of all vacuum-related phenomena. In this sense, his experiments seem to have reached a degree of sophistication and generalisation which allow us to use the term "pressure" when referring to his concept of "the weight of the air" and they justify Boyle's appreciation for Santorio's endeavours in this direction.[55] In contrasts with Torricelli's undertaking, however, Santorio had only an indirect interest in undertaking a full-scale investigation into the phenomenon, which is thus grasped in its general outlines but rarely used as an elaborated procedure of medical analysis. Torricelli's experiments were in fact motivated by the very practical concern that water pumps could not raise water over two meters of height. It is also relevant that the instrument used by Torricelli for his experiments was an unsealed thermometer, filled with mercury rather than water, to reduce the space needed to perform the demonstration and in order to easily calculate the weight of the air.

There are no records that Santorio actually used the thermometer for these experiments. The occasions when he mentions the thermometer in connection with the weight of the air he does so in order to gain an objective measure of the temperature of the air in respect to the human sensation of it.[56] It is clear therefore that he thought the instrument could not measure differences in atmospheric pressure but only in temperature. In any case, taking the period 1608–1611 as the likely interval of time where Santorio first adopted the thermoscope to his measurements of the human body, the instruments described in 1614 must still have been early prototypes of the kind described by Obizzi and Biancani, and so experimentation with them should have been at a very early stage. On the other hand, if we take for granted Santorio's theory of void as caused by the difference in density between the container and the medium, then the only possible explanation left for the functioning of his thermometers was to admit that a certain quantity of water remained inside the tube because of the pressure exerted by external air on water in the underlying vessel.

[54]Middleton, *Invention*, p. 11.

[55]Robert Boyle, *Medicina Hydrostatica, or, Hydrostaticks, Applyed to the Materia Medica*, London: Sam Smith, 1690, p. 1; Michael Hunter, *Boyle. Between God and Science*, New Haven: Yale University Press, 2009, p. 211.

[56]See n. 49.

5 Further Evidences

Such a realisation must have occurred as a consequence of his comparative measurements on the weight of the air by means of hygrometers and thermometers. These experiments should have revealed that thermometers were affected by the same phenomenon he had periodically observed in the human body, although the effect on the instruments was not enough to allow him to use these instruments to precisely measure such a variation. In any case, Santorio's appreciation of the weight of the air and its relation to the vacuum was sophisticated enough to permit him to invent devices [Figs. 5, 7] working as sealed thermometers, if not to measure the weight of the air at least to prevent the interfering of yet another parameter when checking for his medical experiments. An important evidence of this comes from the testimony of the Jewish physician and mathematician Joseph Salomon Delmedigo (1591–1655), who studied with Galileo possibly graduating in Padua with Santorio in 1613.[57] Delmedigo's work *Ma' yan Ganim* (*A Fountain of Gardens*, Amsterdam 1629) contains the first description (1621c.) of two air-sealed thermometers containing alchool, the former of which is Santorio's air thermometer. Both the account and the engraving Delmedigo provides [Fig. 9a] are consistent with Santorio's ones [Fig. 9b], particularly the fact that the instruments features a scale, to track with precision the ascent and descent of water:

> And if you want to know the hotness of the air and the relation between [its hotness from] one day to another, prepare for yourself one of these two instruments. Let them be sealed in the place where the tube enters the vessel [i.e. the bulb] so that the air may not enter and the strong water (i.e., eau-de-vie or the like) may not escape. Behold, in the one [instrument], if you place your hand on top, it will heat the air and it [the air] will seek more space and the water will descend. Likewise it will happen that when the air is hot, it [the water] will descend a great deal, and when it [the air] is cold, it [the water] will rise. You should make signs on the tube so that you may know the increase or difference between one day and another. [58]

Regardless of the use of alcohol or distilled liquor—in itself important, insofar as it enhances the visibility of phenomena of dilatation and contraction inside the tube—the fact that the thermometer is sealed in order not to make air enter in it is another hint that the use of sealed thermometers was common in Padua around the 1620s. Also relevant is that one of the very few faithful replicas of Santorio's thermometer described in Fig. 5, currently in the Science Museum of London, has rightly been recreated as a sealed instrument [Fig. 10], according to the details featured by the 1625 engraving.

As advanced as these ideas might have been for the period, concerns about the weight of the air had little or no import when applied to medical practice and could be relayed orally to students. This simple consideration may well account for why, in the 1626 edition of his *Commentaries on Avicenna's Canon*, Santorio thought to replace a rather advanced design of his thermometer with a simpler and more rudimental version. In the end, an open and

[57]Jakob Adler, "J. S. Delmedigo and the Liquid-in-Glass Thermometer," *Annals of Science* 54 (1997), pp. 293–294; Isaac Barzilay, *Yoseph Shlomo Delmedigo (Yashar of Candia): His Life, Works and Times*, Leiden: Brill, 1974, pp. 28, 48.
[58]Adler, "J. S. Delmedigo" p. 294.

unsealed device [Fig. 4] was best to show the functioning of an instrument which was designed mostly for its applications to diagnosis.

6 Medical Uses of the Thermometer

The last point leads us naturally to reflect on the application of Santorio's thermometer to medical diagnosis.

Obizzi and Biancani's accounts prove that Santorio's thermometer quite soon gained popularity, inside and outside medical practice. In 1633 the Bohemian musician, physician and philosopher Johan Caspar Horn donated a copy of the *Hydrolabium Sanctorii* to the *Natio Germanica* of the University of Padua for medical use,[59] whilst Santorio's texts and devices kept being copied and studied by generations of medical students, as is proved by the series of notes in the Marmi Collection in the Wellcome Library of London, which contains extracts of Santorio's works with sketches of some instruments.[60] Outside the medical fields not everyone was able to appreciate the importance of the new invention: Giovanni Nardi (1585–1654), for instance, described Santorio as "evil" because he invented the thermometer, which had started being used to discredit traditional opinions about the temperature of the fire in the inner part of the earth.[61]

Despite its widespread adoption, problems arise as to how the instrument was used by Santorio and his followers. Arianna Borrelli has recently claimed that, despite Santorio having used the thermometer in a modern way—not as an object *per se*, but for the quantitative readings it was able to provide—his concept of "temperature" was different from the modern one, being simply an extension of the classic Galenic–Aristotelian concept of the perfect mixture (*aequale ad pondus*).[62] Besides not being substantiated by any actual references, this statement fails to do justice to Santorio's appreciation of temperature and to his statistical procedures. Santorio was in fact well aware that the thermometer broke with Galen's diagnostic procedure and he stated this clearly. Under the graded scale of his thermometer all the traditional "species of heat" proper to Galen and Avicenna (i.e. *celestial*, *elemental* and *natural* heat, *accidental* and *essential* temperament) collapse,[63] with the essential temperament declared useless for measurement by Santorio as early as 1603.[64] However, as a medical instrument, and above all as the operationalisation of Galenic–Aristotelian natural philosophy, Borrelli is right when she claims that Santorio's thermometer makes sense only against the framework provided by traditional medicine. To understand this point it is important to dwell upon the concept of temperature.

[59]Padua, Archivio Antico dell'Università di Padova [AAUP], *Acta Nationis Germanicae Artistarum*, Ms 472, p. 343, quoted and trascribed in Lucia Rossetti (ed.), *Acta Nationis Germanicae Artistarum (1616–1636)*, Padua: Antenore, 1967, p. 342.

[60]Wellcome Library, London, MS 3455, ca. 1680.

[61]Giovanni Nardi, *De Igne Subterraneo*, Florence: Massa e Landis, 1641, p. 62: "*negant verum tepere viscera terrae, sed aequali frigoris gradu ubique semperque pollere affirmant: non si mordeat Syrius Canis, aut saeviat bruma, non si superficie tenus, vel intimius illas scruteris. Quapropter novae credulitatis in comfirmationem, mutuantur organa vitrea, malo homine a Sanctorio Sanctorio olim fabrefacta, ut temperamenta distingueret*."

[62]Borrelli, "The Weatherglass and its Observers," p. 111: "Santorio's 'temperature' was not the modern one. For Santorio, the reference point for measuring the temperature of a body was the 'temperate state' of that same body, i.e. the state in which hot and cold balanced each other exactly. Thus, in Aristotelian–Galenic terms, a healthy human body, a healthy animal and a temperate climate would all have had the same Aristotelian–Galenic 'temperature': a temperate one."

[63]Santorio, *Commentaria in Primam Fen* (1625), coll. 158–159, 216–218.

[64]Santorio, *Methodi… Libri XV*, Bk IV, chap. 1–2, specifically f. 81v, coll. A–B.

In ancient medicine, and particularly for Galen, the concept of temperature (*temperies*, *temperatura*, *temperamentum*) depends upon the equilibrium (*aequabilitas*) of opposite qualities (hot–cold). Being a dynamic process, equilibrium is not reached by mixing drugs that simply fit into one or another of these opposites but must be considered according to the specific virtue of each drug (δύναμις, *potentia*, *virtus*) which is classified in four degrees of intensity.[65] To reach a perfect balance, therefore, a physician must be able to calculate the degree of intensity of each substance as well as the final temperature of each mixture. When transferred to the human body, the concept of *aequabilitas* turns into the rapport between balance/imbalance of individual temperatures.[66] Being progressive, the imbalance was calculated as a linear distance from a perfect state and therefore accounted for in terms of latitude (*latitudo*). Three latitudes were contemplated in all, *latitude of health*, *latitude of neutrality* and *latitude of disease*, each provided with its own range of action (which in medieval medicine was expressed in degrees) and varying from one individual to another.[67] Given that this is the very theoretical background out of which the concept of intensity and magnitude evolved, it comes as no surprise that throughout the Middle Ages the medical doctrine of latitude and degree overlapped and was improved by the so-called theory of "latitude of forms" (*latitudo formarum*)[68] which borrowed from medicine the concept of temporal range and applied it to the analysis of elements and natural mixtures. Besides developing new theoretical models to calculate the intensification of qualities, the new approach defined also some of the visual aides to represent it.[69] The earliest amongst such forms was the comparison of triangles, but sometimes also segments of different length were used, a practice that we find still in place during the Renaissance, when Alessandro Piccolomini (1508–1579) adopts it to visualise different intensities [Fig. 11].[70]

When measuring the temperature with the thermometer by using a compass to track changes in the water level, Santorio clearly had this practice in mind: he was quantifying a phenomenon in terms of its linear distance from the natural state (*quantitas recessus*); the later substitution of these segments with degrees was only to improve the resolution of such a measurement. It makes perfect sense, therefore, that all Santorio's instruments represent an operationalisation of the Galenic concept of intensity:

> Galen […] teaches us how we can measure the quantity and strength of hot and cold in intemperate mixtures. He states that the quantity or the strength of the intemperate mixture will be as much as its distance from the natural state [*quantus est recessus a statu naturali*] […]. I make use of four instruments by means of which I ascertain the quantity of this distance [*de quantitate recessus*]. […] The

[65]Galen, *De Temperamentis*, K I, 560, 13–561, 13; *De Simplicium Medicamentorum Temperantis ac Facultatibus*, K XI, 571, 13–572, 6.

[66]On *aequalitas* and Galen's model of equalization see Joel Kaye, *History of Balance, 1250–1325. The Emergence of a New Model of Equilibrium and its Impact on Thought*, Cambridge: Cambridge University Press, 2014, pp. 128–240.

[67]Santorio, *Commentaria in Artem Medicinalem* (1612), Pt I, col. 105A–C; 140D–141A; Santorio, *Commentaria in Primam Fen*, col. 200A–C; Timo Jutisvuo, *Scholastic Tradition and Humanist Innovation: The Concept of "Neutrum" in Renaissance Medicine*, Helsinki: Academia Scientiarum Fennica, 1999, p. 115.

[68]Sylla, "Medieval Concepts of the Latitude of Forms," pp. 226–228.

[69]Ian Maclean, "Diagrams in the Defence of Galen: Medical Uses of Tables, Squares, Dichotomies, Wheels, and Latitudes, 1480–1574," in Sachiko Kusukawa, Ian Maclean (eds.), *Transmitting Knowledge. Words, Images and Instruments in Early Modern Europe*, Oxford: Oxford University Press, 2006, pp. 135–164.

[70]Alessandro Piccolomini, *Della Filosofia Naturale di M. Alessandro Piccolomini*, Venice: Francesco De' Franceschi, 1585, Pt II, Bk II, p. 30.

Europe PMC Funders Author Manuscripts

> fourth instrument, which is wonderfully advantageous, is a sort of glass ampulla, with which we can measure [*metiri*] not only the temperament of the air, but also of any part of the body, and how much is for every day the distance from the natural state [*recessus a statu naturali*].[71]

7 From Individual Complexions to the Statistical Comparison of Individuals

In these very words we find that the purpose and application of the thermometer is to make comparisons across different measurements. Santorio however modified the traditional understanding of temperature in crucial respects: he considered the concept of temperature as universal and shared by many individuals and he invented instruments able to calculate and define the latitude of each complexion. Santorio specifies the criteria for such a comparison: the temperature must be taken in healthy men and then compared to that of the sick ones.[72] Although in normal conditions the temperature is approximately the same, each individual varies across a range of degrees either in good or bad health. It is therefore important to exactly set the point of equilibrium between opposite qualities, and, to do so, Santorio has to set the limits of the instrument by successively applying snow and the fire of a candle to the upper glass bulb of the instrument in order to define its maximum range, which is then divided in degrees to allow greater precision.[73] The middle point between the upper and lower limits is what Galen called the *aequale ad pondus*, or mathematical medium, and it makes perfect sense that Santorio followed almost exactly the same procedures that had already been adopted by Galen to find it.[74] This mathematical medium, however, can only be used to circumscribe 'a point around which:' individual complexions, in fact, span across a region of degrees insofar as each of them realises an *aequale ad iustitiam*, that is to say a specific equilibrium proper to each individual.[75] A series of repeated measurements was therefore required to test the *latitudo sanitatis* in terms of range of degrees, after which the instrument could be used for statistical comparison, especially in those cases in which the physician had not had the chance to appreciate the prior conditions of his patients:

> In what way shall a physician called by his patients ascertain their natural state, if he has not seen them before? As far as I am concerned, if I have no previous knowledge of the patient's condition, I am led to understand how much the distance

[71]Santorio, *Commentaria in Artem Medicinalem* (1612), Pt III, coll. 374B–375B: "[*T*] *ertio* [*Galenus*] *nos docet, quomodo dimetiri possimus quantitatem, et vehementiam caliditatis, vel frigiditatis intemperaturarum; dicitque tantam fore intemperiei quantitatem, seu vehementiam, quantus est recessus a statu naturali* […] *. Qui vult distincte in omni morbo pernoscere quantitatem recessus, debet summa industria conditiones partium affectaur, et aegrotantium perpendere.* […] *Nos utimur quattuor instrumentis, quibus reddimur certi de quantitate recessus; quorum primum est pulsilogium a nobis inventum, quo quotidie quantum quis recedat ab optimo suo statu cognoscimus; secundum, idem cognoscimus per motum pilae plumbeae pensilis filo, qua quisque filo commota, et magis, vel minus elongata observare poterit naturalem pulsus motionem, et recessum a naturali; verum nos mira industria ex pulsilogio dimetimur motus, et quies arteriae, collationemque facere possumus cum pulsibus praeteritorum dierum; tertium instrumentum est quo per staticas observationes varios recessus a statu naturali penetramus. Hic tunc non est locus, ut de staticae artis arcanis aliquid dicamus, quia vel brevi in lucem quadringentos aphorismos de staticis experimentis promemus; quartum, quae mirifice quoque iuvat, est quoddam vas vitreum, quo possumus metiri non solum aeris, sed cuiuslibet partis corporis temperaturam, et quantum quotidie fiat recessus a statu naturali* […]."

[72]See above n. 64.

[73]Santorio, *Commentaria in Artem Medicinalem* (1630), Pt II, col. 762D.

[74]Galen, *De Temperamentis*, K I, 560, 13–561, 13.

[75]Santorio, *Commentaria in Primam Fen* (1625), coll.186E–187A, 193B.

> [from the natural state] and the dose of the remedy can be by using the four instruments I mentioned before [i.e. 2 types of pulsilogia, the thermometer, and the steelyard chair or *statera medica*]; along with Galen [*De methodo medendi* I.1], however, I shall declare that it is impossible that the exact and specific quantity will be penetrated by the physician, and so rightly Galen states that: "if I knew that exact quantity of action, I would consider myself like what people say Asclepius was." [76]

The final remark is in striking opposition to what Santorio usually states in relation to his instruments as providing "absolute certainty"; however, the conjectural nature of knowledge is referred here not to the instrument itself but to the measuring procedure which, if not followed through daily assessments, could provide only an estimate of the patient's condition.

The use of the thermometer soon raised a series of theoretical and practical concerns which the standard Galenic rationale was no longer able to address. Indeed, when inquired into by means of the thermometer, different individual complexions become samples within a statistical comparison and thus can no longer be considered as being of a specifically individual nature, as argued by Galen and Avicenna. In short, they became the 'more or less' within range of degrees. As highlighted before, the thermometer collapses all the differences between the traditional species of heat, which are now comprehended in a new and dynamic concept of temperature. Once he had reached this point, Santorio no longer needs to rely on Galen and can therefore denounce his methods as misleading when applied to medical diagnosis:

> Furthermore, both Avicenna and Galen [*De temperamentis* Bk II] claim in this passage that our sense of touch is the judge of all [species] of heat: if the species of heat were different, the touch would not be the right judge of them. Indeed, with reference to the passage just quoted [*De temperamentis* Bk II] where he assigns to the touch the judgment about the equality of heat in children and young men, Galen urges us to touch many and different objects, that is to say water at first not too hot and temperate, then the very limbs [of the body] yet according to this rule, which consists in comparing the weak to the weak, the stocky to the stocky, the fat to the fat and not the unexercised people to those at rest or those fasting to those who are full. This way of measuring the degree of heat is certainly misleading. As for our part, we resort to the glass instruments shown in folio 219 [Fig. 12] which surely cannot mislead us. By means of these instruments we have tested whether heat is the same in children and young men. The experiment consists in placing the hand of a child and then of a young man on the glass bulb of the instrument for an equal interval of time; from this we understood that the water descent was the same in both ages which means an equality of heat.[77]

[76]Santorio, *Commentaria in Artem Medicinalem* (1612), Pt III, col. 376 B–C: "[…] *sed quomodo medicus vocatus ab aegrotis, poterit scire eorum statum naturalem, cum tempore sanitatis illos non viderit?* […] *Ego vero si antea non fuerit mihi notus aeger, usu quatuor instrumentorum propositorum paulo supra manuducor ad cognoscendum quantus possit esse recessus, et quanta remediorum dosis: quamvis fatear cum Galeno I* [*Methodo medendi*] *ad Glauconem in principio, esse impossibile, ut illud ultimum, et specificum quantum a medico penetretur, merito ibi dicit; si ego scirem illud quantum agendum, talem me putarem, qualem fuisse ferunt Aesculapium.*"

The quote shows exactly Santorio's method as outlined in his *Method to Avoid All Errors* (Venice 1603). The diagnostic and physiological principles of Galenic medicine are assumed as true and then tested against anatomical dissections or the results provided by the new instruments. The impossibility of verifying an assumption, however, does not lead Santorio to the rejection of the entire practice because such an approach would destroy the very grounds of medicine, and indeed of any scientific approach; it leads to the revision of specific and always partial implications of that practice. In general, the major premise of Santorio's medico–philosophical enquiries is always the Hippocratic–Galenic model of balance, which is then supplemented with particular analytic tools able to convert theoretical premises into quantitative parameters that are then tested experimentally. In the case of the thermometer, for instance, the pre-operational model is represented by the Galenic concept of temperature as an *aequalitas ad iustitiam*, that is to say the relative equilibrium in the composition of opposite qualities in each individual. And yet this concept is either too general or too vague to allow the physician to draw precise conclusions (*indicationes*) about the exact nature of individual complexions. Thus, when confronted with the puzzle of finding an exact indication of the quantity of remedy to give to each patient in response to their particular disease, without the possibility to resort to the thermometer to address such a need, Santorio openly declares his concerns:

> As for the problem of how much someone has to act [in respect of a disease], contemporary physicians rightly argue that such quantity must be inferred from the action of what indicates [*actio indicantis*], yet this is precisely the point where we struggle, that is how to find out those signs that are able to reveal whether the action of what indicates is either extreme or minimal. Indeed, simply knowing the quantity by deducing it from the action of what indicates is something very common to know and from which one cannot draw any consequence. Therefore we claim that the question of how much one has to operate, that is to say the action of what indicates, is inferred above all from the temperature […].[78]

Once again we are taken back to the concept of intensity of a disease. Not only the thermometer but also instruments such as the pulsilogium, the hygrometer and the various scales Santorio invented are meant as answers to the Galenic need to ascribe a magnitude to each disease. In this sense, they do not aim to 'replace' the Galenic paradigm with a new mathematical one, but to 'make visible' the fundamental forces of the Aristotelian universe and to underpin their existence with the certainty now granted by technology and mathematical analysis. As a consequence, the movement of tension and relaxation in the primary qualities of each body is revealed by the motions of dilatation and compression of

[77] *Ivi*, col. 357B–D: "*Praeterea Avicennas hic, et Galenus 2 de Temp*[*eramentis*] *vult tactum nostrum esse iudicem omnium calidorum: si calores essent diversae specie tactus non esset rectus iudex: imo Galenus 2 de temp[eramentis] citato deferens hoc iudicium de aequalitate caloris puerorum, et iuvenum ad tactum admonet esse tangenda plura, et diversa obiecta, aquam videlicet primo remisse, et temperate calidam: deinde ipsa membra: sed hac lege, ut graciles conferantur gracilibus, quadrati quadratis, crassi crassis, et non exercitati requietis, et ieiuni saturis, qui modus dimetiendi caloris gradus cert est fallax: nos vero confugimus ad instrumenta vitrea proposita folio 219. Quae certe non fallent nos: in dictis enim instrumentis periculum fecimus, an revera caliditas puerorum, et iuvenum sit aequalis, quod fit admota manu pueri, et deinde iuvenis globulo vitreo in aequali temporis spacio: inde cognovimus, aequalem esse in utraque aetate aquae descensum, quod significat aequalitatem caloris*."

[78] Santorio, *Methodi… Libri XV*, Bk III ch. 4, f. 64r B–C: "*De quanto agendum sit, nostrates optime dicunt, quantum desumi ab actione indicantis, nos vero hic laboramus, ut inveniamus illa signa, quae nos docere possunt, an actio indicantis sit maxima, vel parva; quoniam scire quantum desumi ab actione indicantis, est communissima, et generica scire, a quibus nulla inferri potest consequentia; quare dicimus nos quantum agendum, vel actionem indicantis desumi praecaeteris a temperatura* […]."

the air included in the thermometer; the humidity and dryness of the air, by the tension and relations of cords of tortoise; the daily exchange of food, drink and excrements by means of which the body reaches its balance, by monitoring the change of weight at each meal; the faster or slower movement of the arteries by the constant motion of the pendulum. As said elsewhere, Santorio succeeded in adopting and systematically applying the notion of "magnitude" (*magnitudo*) to the Galenic concept of equilibrium by converting the rapports of proportion/disproportion of bodily fluids and temperaments into linear segments of various length (*recessus*) departing from, or approaching to a mid-point representing the equilibrium (*aequabilitas*). The greater the distance from this point was, the greater the disease in terms of gravity. In this way he could then treat disease and healthiness as different regions over a scale of degrees.[79] From this standpoint it is clear that, if the concept of latitude (*latitudo*) as the physical extension of a quality (*extensio*) fails, then the measurement itself loses its meaning and the instrument becomes a useless toy, as it was for Galileo and many others prior to him. At the same time, however, such an approach marked a radical departure from the practice of subjective appreciation of temperaments and bodily disposition which was still dominant in any aspect of medical practice in the seventeenth century. The new approach was rooted in two assumptions that Santorio had set out since the very beginning of his medical investigations (1603): that the most fundamental properties in nature are quantitative, being "figure," "number" and "position" (*situs*, *figura*, *numerus*), and that individuals differ from each other not in terms of essence, but as mere spatial and temporal instantiations of universal properties (*per hinc et nunc*) which all the individuals share and can therefore be quantified and measured.[80]

On these grounds rests Santorio's entire programme for quantification in medicine, which clearly underpins the invention of his instruments, as well as his medical and natural philosophical applications. Had Santorio lived long enough to complete his book *On Medical Instruments*, we would not only have better appreciated the details of his method but also the extent of his contribution to seventeenth-century science. Yet some glimpses of this commitment do remain to testify to his involvement in the making of experimental philosophy, a philosophy which Santorio felt was mature enough not to reject tradition, but to assimilate it in order to address old problems with new ideas and instruments.

Acknowledgements

I am grateful to Jonathan Barry and the anonymous referees of *JEMS* for their useful comments and criticisms on the early drafts of this article. My gratitude also goes to Filip Buyse and Jacob Adler who provided precious suggestions on how to strengthen my original findings with additional readings. Finally, I would like to thank Grigore Vida and Rosy Crocitta for their kind assistance in proofreading the pre-print of this paper.

Works Cited

Adler, Jakob. J. S. Delmedigo and the Liquid-in-Glass Thermometer. Annals of Science. 1997; 54:293–294.

Barzilay, Isaac. Yoseph Shlomo Delmedigo (Yashar of Candia): His Life, Works and Times. Leiden: Brill; 1974.

[79]Bigotti–Taylor, "The Pulsilogium of Santorio," p. 66.

[80]Santorio, *Methodi… Libri XV*, Bk VIII, ch. 8, Bk XI, ch 5, ff. 175vD–176rA, Bk XII ch. 2, f. 184rA; Santorio, *Commentaria in Artem Medicinalem* (1612), Pt III, coll. 10E–11D; Santorio, *Commentaria in Primam Fen* (1625), col. 30D.

Europe PMC Funders Author Manuscripts

Bartholin, Caspar. Vindiciae Anatomicae Claro Viro Casparo Hoffmano Opposite. Copenhagen: Melchior Marzan; 1648.

Biancani, Giusppe. De Sphaera Mundi seu Cosmographia Demonstrativa, et Facili Methodo Tradita. Bologna: Sebastiano Bonomi; 1620.

Bigotti, Fabrizio. A Previously Unknown Path to Corpuscularism in the Seventeenth Century: Santorio's Marginalia to the *Commentaria in Primam Fen Primi Libri Canonis Avicennae* (1625). Ambix. 2017; 64(1):1–14. [PubMed: 28532319]

Bigotti, Fabrizio; Taylor, David. The Pulsilogium of Santorio. New Light on Technology and Measurement in Early Modern Medicine. Society and Politics. 2017; 11(2):55–114.

Borelli, Giovanni Alfonso. De Motu Animalium Pars II. Leiden: Peter van der Aa, Cornelis Boutesreyn, Johan de Vivie, Daniel Ema Gaesbeeck; 1685.

Borrelli, Arianna. The Weatherglass and its Observers in the Early Seventeenth CenturyPhilosophy of Technology. Francis Bacon and His Contemporaries. Zittel, Claus; Engel, Gisela; Nanni, Romano; Carafyllis, Nicole C, editors. Leiden–Boston: Brill; 2008. 67–130.

Boyle, Robert. Medicina Hydrostatica, or, Hydrostaticks, Applyed to the Materia Medica. London: Sam Smith; 1690.

Castiglioni, Arturo. La Vita e l'Opera di Santorio Santorio Capodistriano. Bologna–Trieste: Licinio Cappelli Editore; 1920.

Caverni, Raffaello. Storia del Metodo Sperimentale in Italia. Firenze: Civelli; 1891. tomo I

Chaldecott JA. Bartolomeo Telioux and the Early History of the Thermometer. Annals of Science. 1952; 8(3):195–201.

Favaro, Antonio. Amici e Corrispondenti di Galileo Galilei. Venice: Tipografia Ferrari; 1894.

del Gaizo, Modestino. Le Conoscenze in Fisica di Santorio Santorio e l'Efficacia delle Scoperte di Galilei sul Movimento delle Scienze Mediche nel Secolo XVIIAtti della Riunione di Venezia (1909) della Società Italiana di Storia Critica delle Scienze Mediche e Naturali. Venice: Tip. Orfanotrofio di A. Pellizzato; 1909. 92–102.

Galilei, Galileo. Le Opere di Galileo Galilei. Edizione Nazionale. Florence: Barbera; 1890–1909.

Grant, Edward. Much Ado about Nothing. Theories of Space and Vacuum from the Middle Ages to the Scientific Revolution. Cambridge: Cambridge University Press; 1981.

Grmek, Mirko Drazen. Santorio Santorio i Njegovi Aparati i Instrumenti. Zagreb: Institut za Medicinska Istraživanja Jugoslavenske Akademije; 1952.

Grmek, Mirko Drazen. La Première Révolution. Biologique Réflexions sur la Physiologie et la Médicine du XVIIème siècle. Paris: Payot; 1990.

Harig, Georg. Bestimmung der Intensität im medizinischen System Galens. Ein Beitrag zur theoretischen Pharmakologie, Nosologie, und Therapie in der Galenischen Medizin. Berlin: Akademie Verlag; 1974.

Hollerbach, Teresa. The Weighing Chair of Sanctorius Sanctorius: A Replica. NTM Zeitschrift für Geschichte der Wissenschaften, Technik und Medizin. 2018; 26(2):121–149.

Hunter, Michael. Boyle. Between God and Science. New Haven: Yale University Press; 2009.

Jutisvuo, Timo. Scholastic Tradition and Humanist Innovation: The Concept of "Neutrum" in Renaissance Medicine. Helsinki: Academia Scientiarum Fennica; 1999.

Kaye, Joel. A History of Balance, 1250–1325. The Emergence of a New Model of Equilibrium and its Impact on Thought. Cambridge: Cambridge University Press; 2014.

Libri, Guillaume. Histoire des Sciences Mathématiques en Italie. tome quatrième, Paris: Jules Renouard; 1841.

Maclean, Ian. Diagrams in the Defence of Galen: Medical Uses of Tables, Squares, Dichotomies, Wheels, and Latitudes, 1480–1574Transmitting Knowledge. Words, Images and Instruments in Early Modern Europe. Kusukawa, Sachiko; Maclean, Ian, editors. Oxford: Oxford University Press; 2006. 135–164.

Maier, Anneliese. Das Problem der *Quantitas Materiae* in der Scholastik. Gregorianum. 1946; 27(1): 89–109.

Knowles Middleton, William Edgar. Invention of Meteorological Instruments. Baltimore: Johns Hopkins Press; 1969.

Knowles Middleton, William Edgar. The Experimenters. A Study of the Accademia del Cimento. Baltimore: Johns Hopkins University Press; 1971.

Nardi, Giovanni. De Igne Subterraneo. Florence: Massa e Landis; 1641.

Ongaro, Giuseppe. Santorio Santorio: La Medicina Statica. Florence: Giunti; 2000.

Piccolomini, Alessandro. Della Filosofia Naturale di M. Alessandro Piccolomini. Venice: Francesco De' Franceschi; 1585.

Della Porta, Giovanni Battista. Magiae Naturalis sive de Miraculis Rerum Naturalium Libri IIII. Antwerp: Christophorus Plantinus; 1560.

Della Porta, Giovanni Battista. I Tre Libri De' Spiritali. Naples: Giovanni Giacomo Carlino; 1606.

Quincy, John. Medicina Statica: being the Aphorisms of Sanctorius. London: W. Newton; 1712.

Rossetti, Lucia, editor. Acta Nationis Germanicae Artistarum (1616–1636). Padua: Antenore; 1967.

Sambursky, Samuel. The Physical World of Late Antiquity. Princeton: Princeton University Press; 1962.

Santori, Santorio. Methodi Vitandorum Errorum Omnium qui in Arte Medica Contingunt Libri XV. Venice: Bariletto; 1603.

Santori, Santorio. Commentaria in Artem Medicinalem Galeni Libri Tres. Venice: Giacomo Antonio Somasco; 1612.

Santori, Santorio. Ars Sanctorii Sanctorii De Statica Medicina Aphorismorum Sectionibus Septem Comprehensa. Venice: Niccolò Polo; 1614.

Santori, Santorio. Commentaria in Primam Fen Primi Libri Canonis Avicennae. Venice: Giacomo Sarzina; 1625.

Santori, Santorio. Commentaria in Primam Fen Primi Libri Canonis Avicennae. Venice: Giacomo Sarzina; 1626.

Santori, Santorio. Commentaria in Artem Medicinalem Galeni. Venice: Marco Antonio Brogiollo; 1630.

Schmitt, Charles B. Experimental Evidence for and against a Void: The Sixteenth-Century Arguments. Isis. 1967; 58(3):352–366.

Sylla, Edith Dudley. Medieval Quantifications of Qualities: The Merton School. Archive for the History of Exact Sciences. 1971; 8:9–39.

Sylla, Edith Dudley. Medieval Concepts of the Latitude of Forms. The Oxford Calculators. Archives d'histoire doctrinale et littéraire du Moyen Âge. 1973; 40:223–283.

Temkin, Owsei. Galenism. Rise and Decline of a Medical Philosophy. Ithaca–New York: Cornell University Press; 1973.

de Toledo, Francisco. Commentaria Una Cum Quaestionibus in Octo Libros Aristotelis De Physica Auscultatione. Venice: Giunti; 1573.

Europe PMC Funders Author Manuscripts

Figure 1.
Biancani (1617)

Europe PMC Funders Author Manuscripts

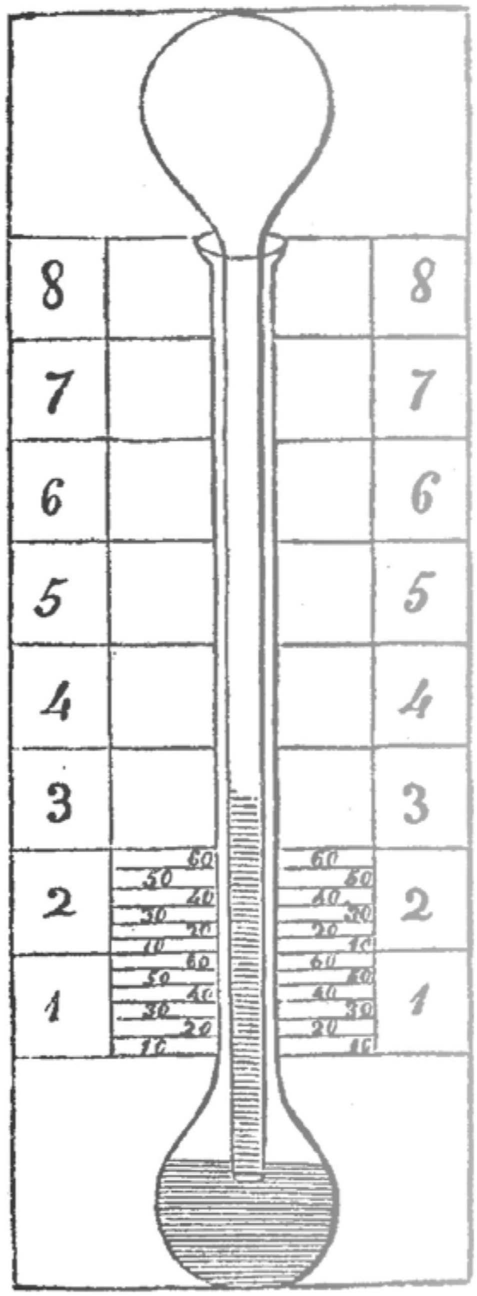
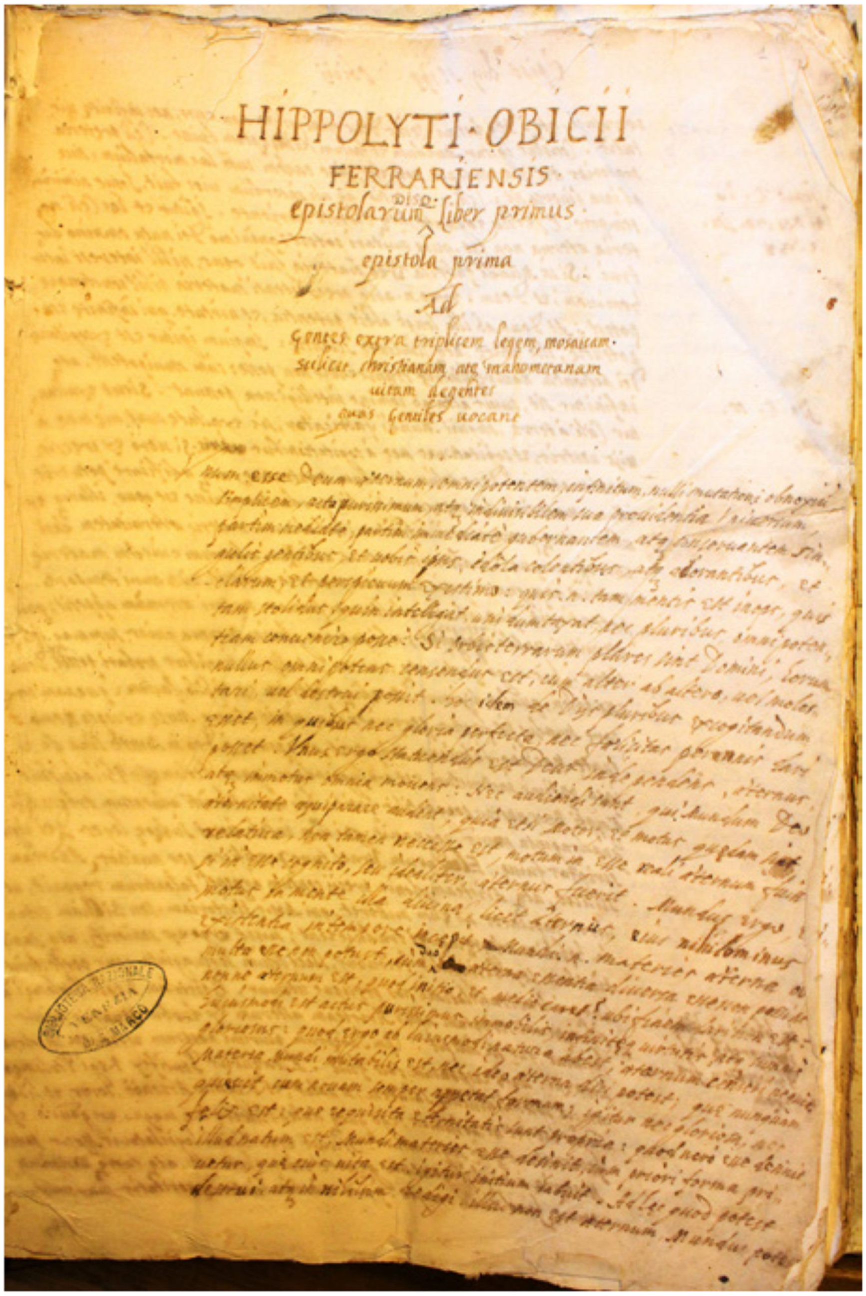


Figure 2.
Telioux (1611)


HIPPOLYTI·OBICII
FERRARIENSIS
epistolarum liber primus
epistola prima
Ad
Gentes extra triplicem legem, mosaicam
scilicet christianam atque mahometanam
uitam degentes
quas Gentiles uocant

Epist. hy. Hipp. obicii

Hippolytus obicius
Filio suo Hipp.to Monacho Cartus.
S. D.

6

corpus vasis vacuum
fistula
plenum
Ampula plena
aqua

Vas vitreum de quo fit dubium, quod temperamenti instrumentum nominatur, est forme designate, corpore nimirum orbiculari fistulam cubiti unius, et semis longitudine habens angustam. Vasis corpore sursum appenso, rostroque deorsum manente, et in ampullam aque plenam iniecto tridui spacio aqua per rostrum ipsum usque ad quendam terminum ascendit, ibique manet, donec ambientis fiat mutatio: ipso enim ambiente frigidiori facto tollitur aqua, calidiori deprimitur: atque pro eiusdem ambientis mutatione, que licet exigua, quinimo minima: in ipsius fistule aqua fit motus, vel ascendendo pro frigoris, vel descendendo pro caloris ratione.

Adhec corpore Vasis sursum manente aliqua arte calefacto, aqua in fistula contenta deprimitur, si ampulle aqua calefiat, pari ratione prime fistule aqua descendit, que aqua in ampulla contenta quanto calidior, tanto aqua in fistula collecta descendit: quinimo fistula evacuari aqua non poterit, nisi ampulle aqua quasi ferveat: qua arte, nec secus, tota e fistula hauritur aqua.

Si eiusdem Vasis corpus sursum appensum arte frigefiat, seu eidem frigida applicentur, fistule aqua ascendit, hoc idem accidit, si ampulle aqua consueto frigidior evaserit.

Queris tu fili modo, quenam sit ratio, cur aque in fistula retenteque motus predicti contingant. Ad huiusmodi quesitum breviter respondeo totius negotii rationem in aere intra fistulam, Vasisque corpus retento atque ab aqua incluso, consistere. Cum pars ignea, inquit Averroes, aeris extincta fuerit, aer frigefiet, et sic condensabitur, tuncque minorem occupabit locum, et attrahet aquam de necessitate vacui.

4. Cal. 39.

Nos vero sic dicimus. contrariorum eadem est disciplina. igitur si aeris in fistula, corporeque Vasis inclusi partes à calore externo attenuate fuerint idem aer dilatabitur, et quod sequens est, maiorem occupabit locum, cui aqua facile cedet, cum natura deorsum tendat.

hac autem facta hypothesi, aerem scilicet calore dilatari per partium attenuationem, frigoreque densari, minoremque tunc locum occupare: dubii solutio per se patet: nam quomodocumque calor aeri incluso communicatus fuerit, sive ambientis ratione, sive vi aque calide in

ampulle

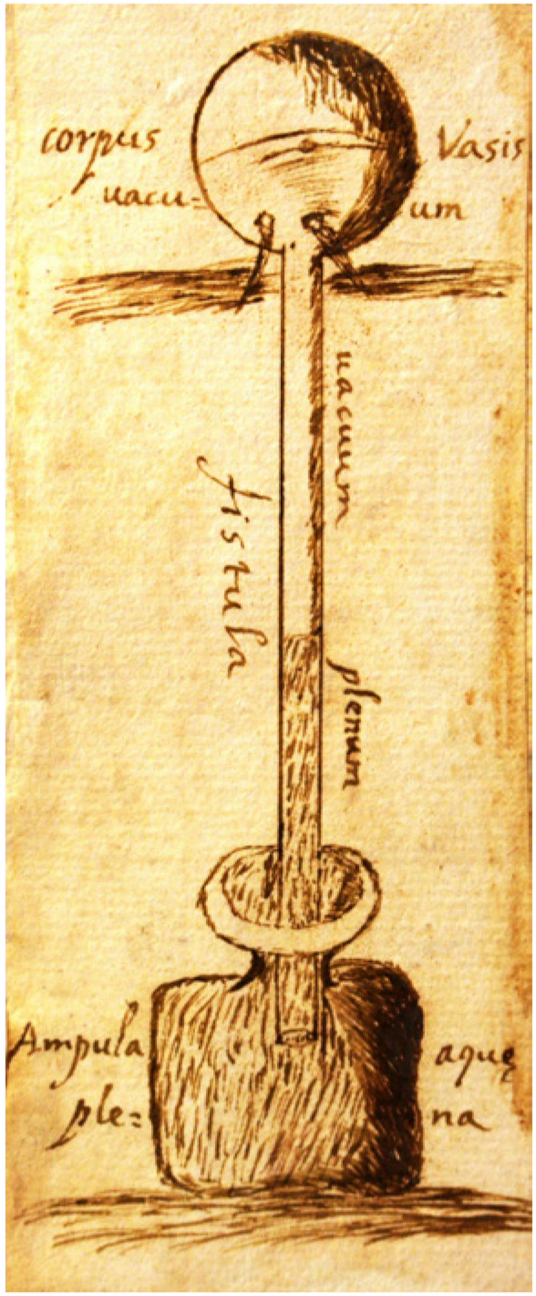
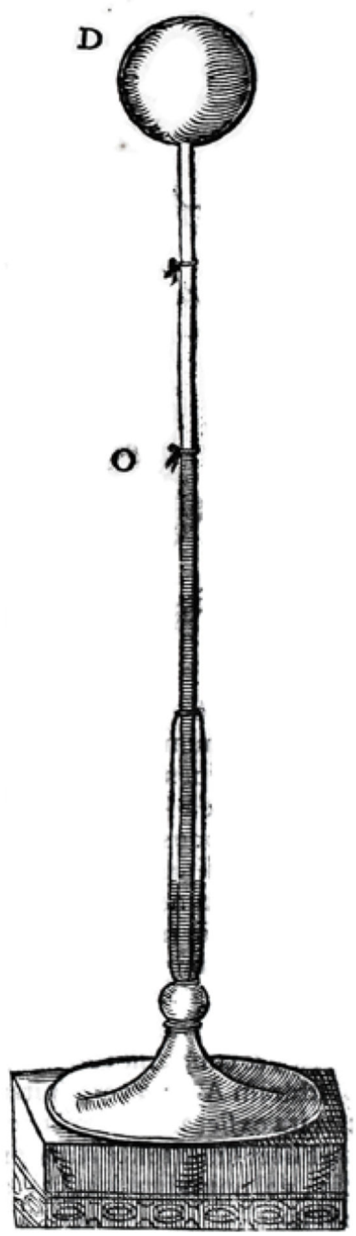


Figure 3.
Obizzi’s Manuscript, Frontispiece
a. Obizzi's Manuscript, Detail
b. Obizzi (1617)

Figure 4.
Santorio (1626)

Europe PMC Funders Author Manuscripts

Figura Secunda.



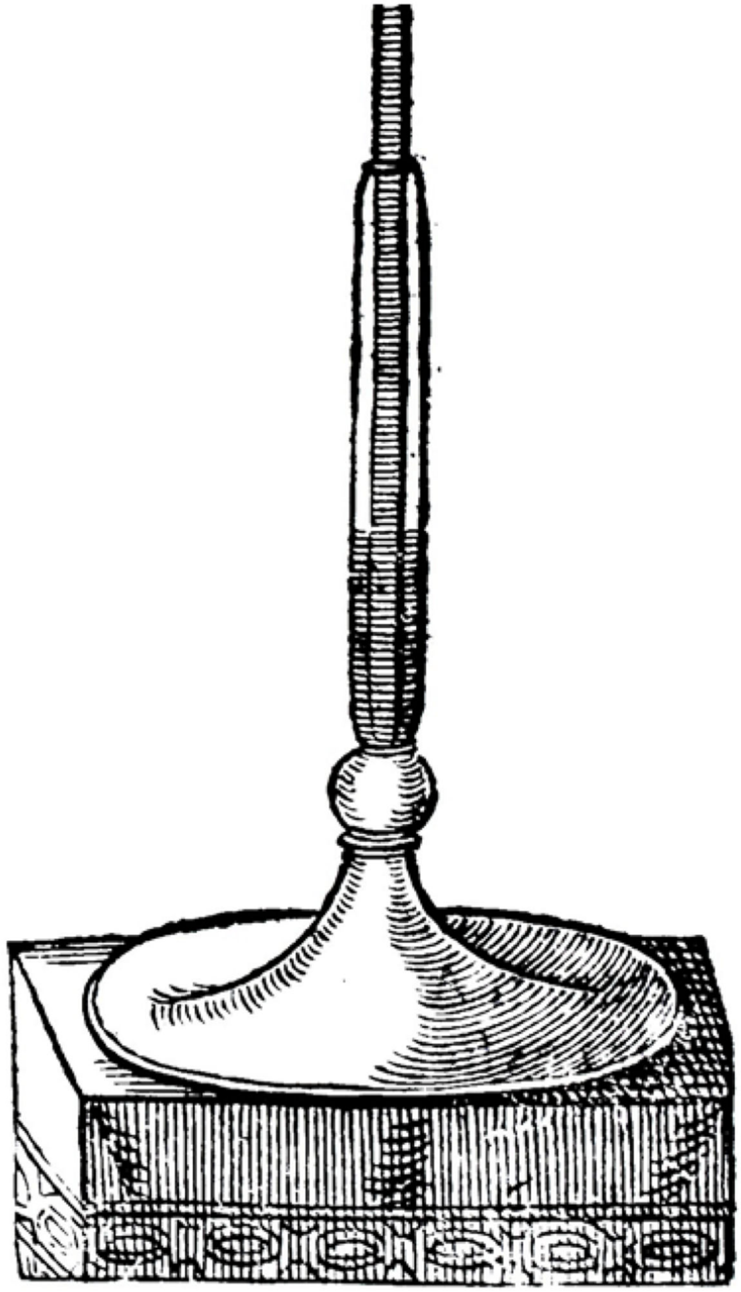
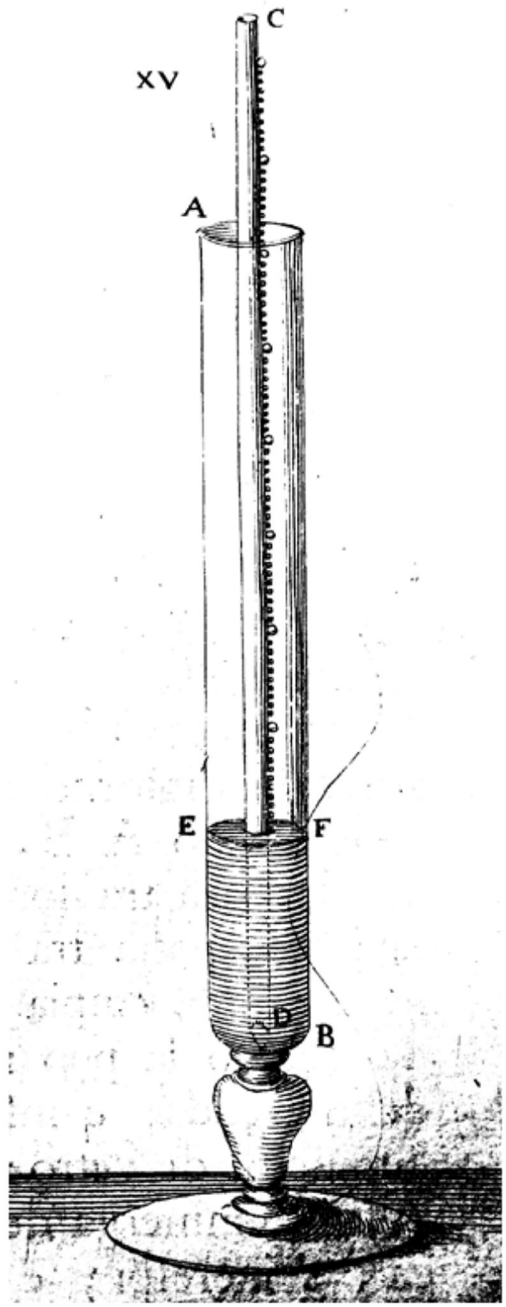
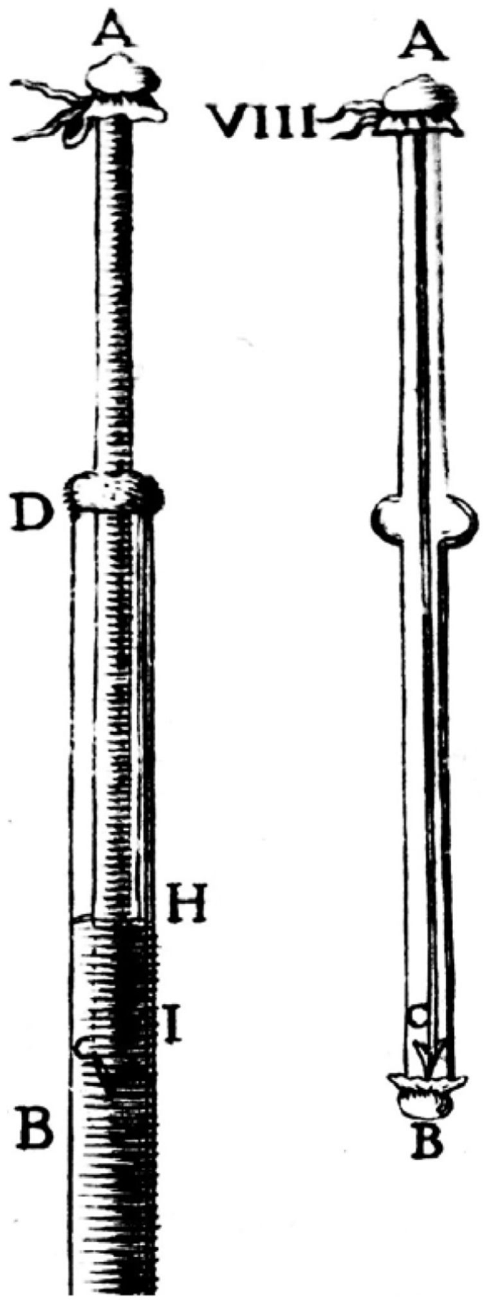


Figure 5.
Santorio’s hand-thermometer A (1625)
a. Detail



Europe PMC Funders Author Manuscripts



Europe PMC Funders Author Manuscripts

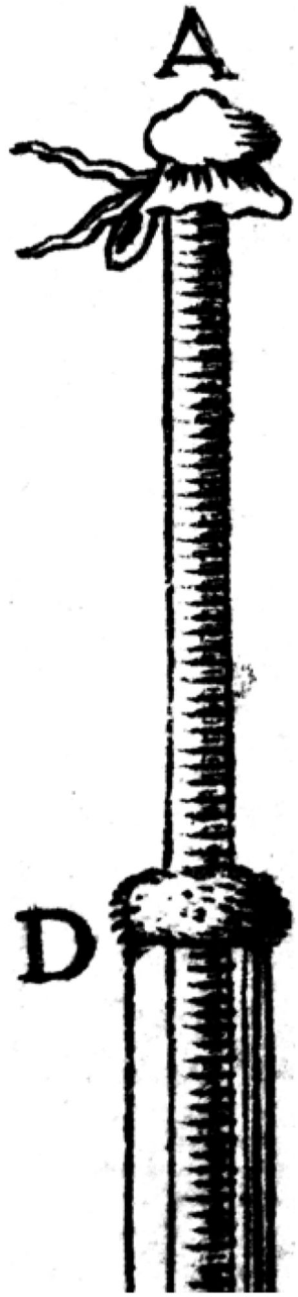


Figure 6.
Accademia del Cimento (1667)
a. Sealing Methods (1667)
b. Detail

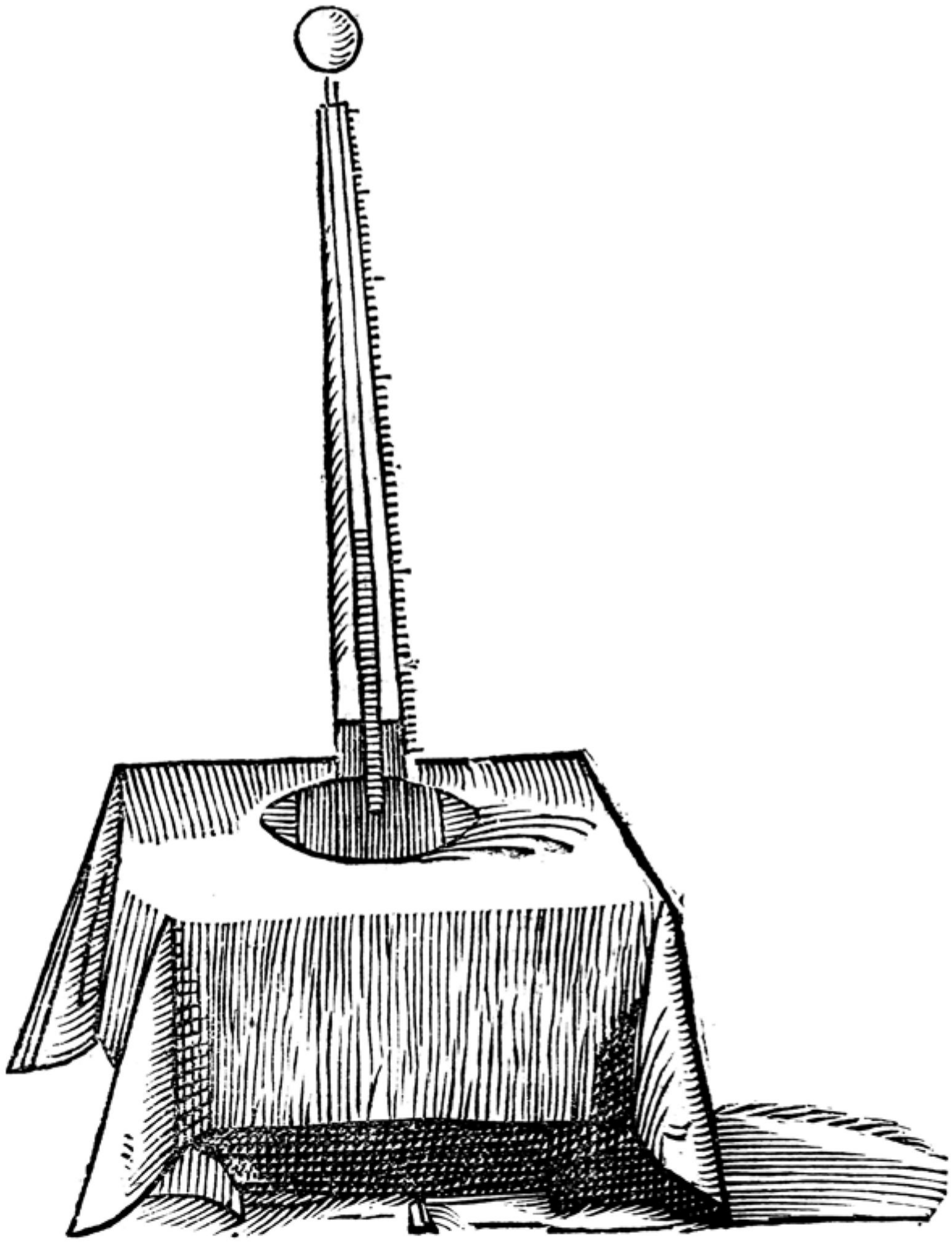
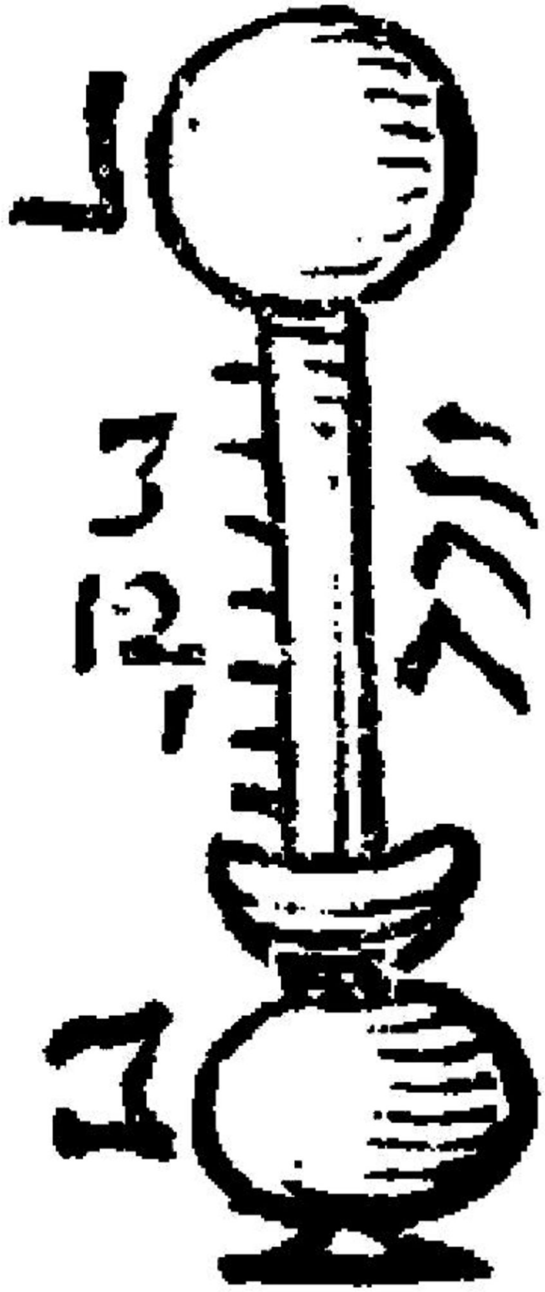


Figure 7.
Santorio Hand Thermometer B (1625)

Europe PMC Funders Author Manuscripts

Figure 8.
The so-called Galileo’s Thermoscope. Museo Galileo, Florence

Europe PMC Funders Author Manuscripts



Europe PMC Funders Author Manuscripts

Figure 9.

a. Delmedigo's engraving of a sealed thermometer with marks (1621–1629), from Adler (1997)

b. Santorio's engraving of a mouth thermometer (1625)

Figure 10.
Replica of Santorio's thermometer. Science Museum of London, 1970

Europe PMC Funders Author Manuscripts

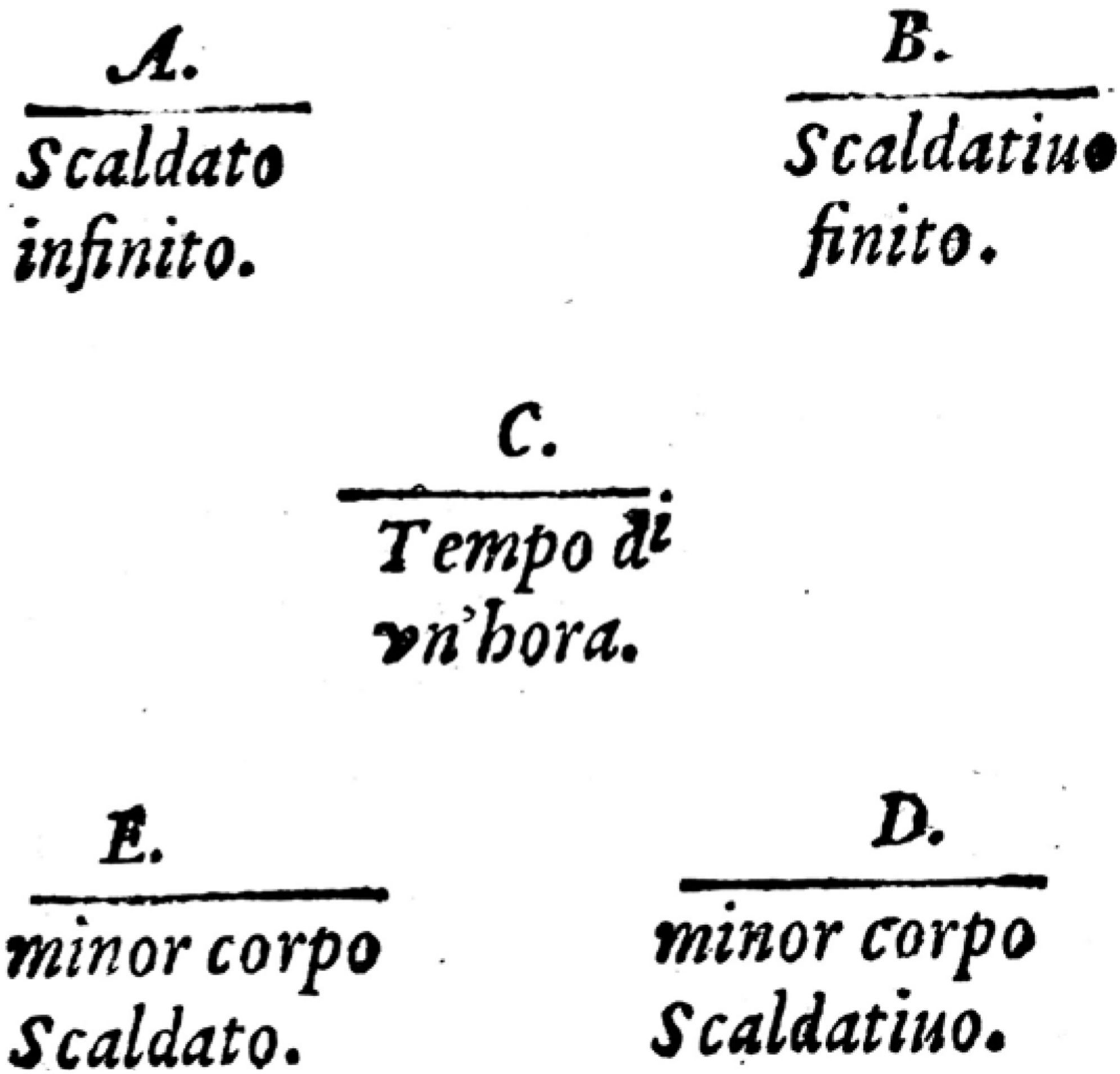


Figure 11.
Piccolomini's representation of intensity and time (1585)

Europe PMC Funders Author Manuscripts

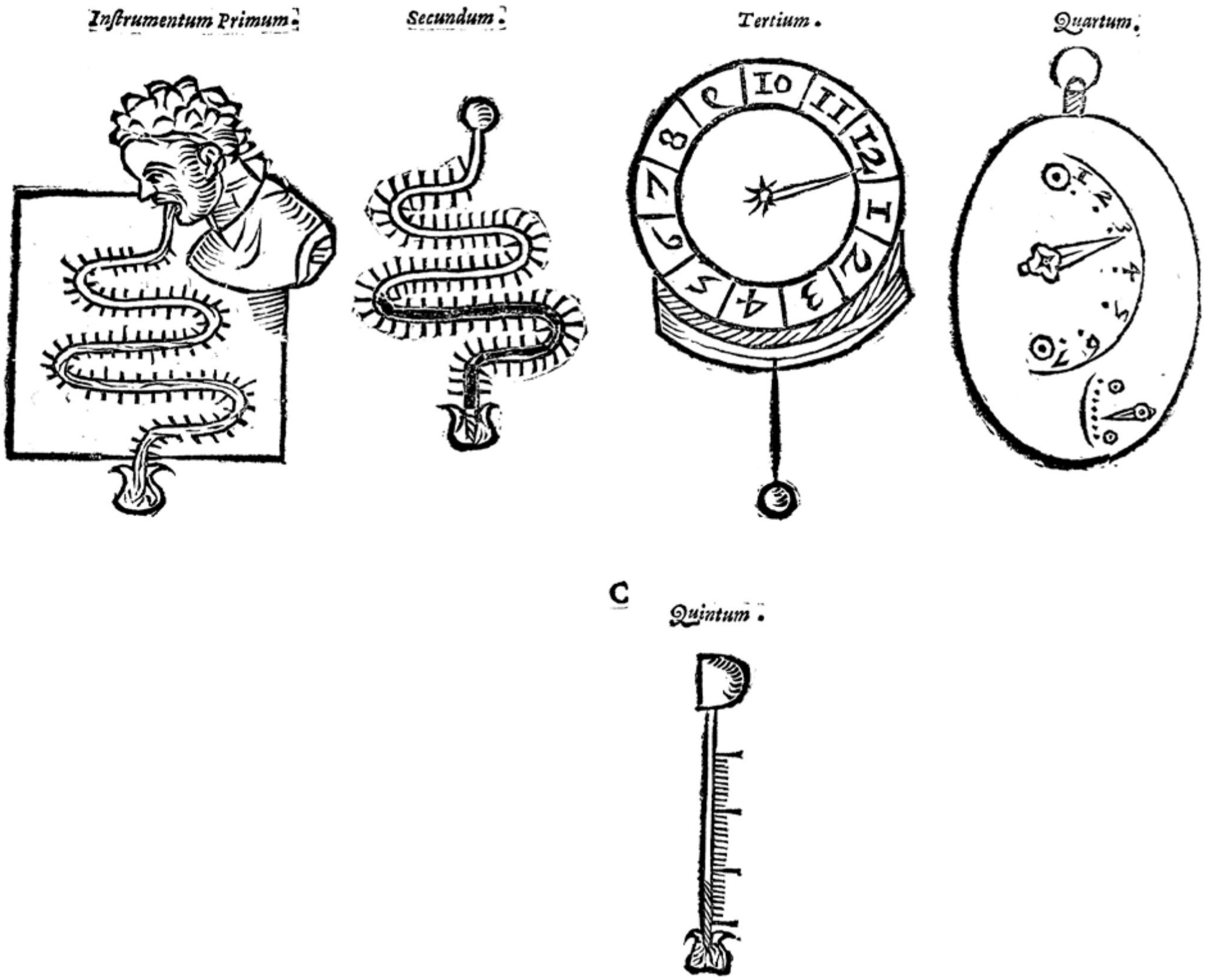


Figure 12.
Santorio’s thermometers and pulsilogia (1625)