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Intensity Meters: New Notes and Discoveries on the Invention of Early Modern Precision Instruments

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Abstract

The article sheds light on the invention of early modern precision instruments and their application in medicine, by analysing a neglected work by one of the Italian pupils of the physician Santorio Santori (1561–1636). This source provides vital information on Santorio's experimental sample, and on the practical use and dimensions of instruments such as thermometers, hygrometers, pulsimeters and precision scales, showing that they also had a normative purpose: regulating the environmental factors affecting human health. The article first establishes the derivative nature of the source from Santorio's teachings, and then contextualises the invention of precision instruments with regard to Santorio's published and unpublished output. In the conclusions, I argue that the new instruments were meant to address the shortcomings of the traditional diagnostic rationale and are best conceptualised as 'intensity meters' meant to assess 'the magnitude' (*magnitudo*) of a patient's illness in degrees.

Keywords

intensity – quantification – early modern precision instruments – Giovanni Martino Bonomo – Santorio Santori – Galenism – Medical School of Padua

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The Italian physician Santorio Santori (1561–1636) has recently been shown to have played a major role in the emergence of quantified medicine.[1] A contemporary and colleague of Galileo, Santorio predated Galileo's pulsilogium and thermometer, and addressed similar themes regarding the structure of matter some thirty years before his Paduan colleague did in his *Saggiatore*. Santorio's name is associated with the invention of surgical, clinical and, above all, precision instruments such as pulsimeters, thermometers, hygrometers, and various scales designed to measure the way the body maintains its balance. Among these, the most famous instrument was the weighing chair, also known as Santorio's chair (*sella Sanctorii*), an invention for which Santorio is still known today.

These devices were briefly described by Santorio in his large treatise on methodology (*Methodi vitandorum errorum omnium qui in arte medica contingunt libri XV*, Venice, 1603) and in his masterpiece *Ars de statica medicina* (Venice, 1614; hereafter *Medicina statica*) as well as in the medical commentaries on Galen (*Commentaria in Artem medicinalem Galeni*, Venice, 1612, 1630), Hippocrates (*Commentaria in primam sectionem Aphorismorum Hippocratis*, Venice, 1629), and Avicenna (*Commentaria in primam Fen primi libri Canonis Avicennae*, Venice, 1625 and 1626), which later included a series of engraving. Santorio's immediate purpose in providing engravings and descriptions of these instruments was threefold: to establish a 'prior art' and reclaim their invention, to teach his students how to integrate them into everyday practice, and to prepare his audience for the publication of a book *De instrumentis medicis non amplius visis* (literally, "Medical instruments no longer seen") in which he would have instructed the reader on how to make these instruments. According to Santorio, the new instruments complemented medical practice by

1 See Jonathan Barry and Fabrizio Bigotti, eds., *Santorio Santori and the Emergence of Quantified Medicine: Corpuscularianism, Technology and Experimentation, 1614–1790* (Cham, 2022); Fabrizio Bigotti, *Physiology of the Soul: Mind, Body and Matter in the Galenic Tradition of the Late Renaissance, 1550–1630* (Turnhout, 2019), 225–248; idem, "The Weight of the Air: Santorio's Thermometers and the Early History of Medical Quantification Reconsidered," *Journal of Early Modern Studies*, 7 (2018), 73–103; Fabrizio Bigotti and David Taylor, "The Pulsilogium of Santorio: New Light on Technology and Measurement in Early Modern Medicine," *Society and Politics*, 11 (2017), 53–113. While this article was being revised, a new book on Santorio was published, *Sanctorius Sanctorius and the Origins of Health Measurement* (Cham, 2023, first published online on 19 May of the same year), authored by Theresa Hollerbach. Despite its novelty and the claim that it is "the first systematic study to cover the full range of the physician's intellectual and practical activities," the volume does not take into consideration anything that has been written on this author in the last four years (since 2019), including new discoveries about his life, works and instruments, which, unfortunately, limits its potential contribution to the ongoing debate on Santorio.

allowing the physician to draw precise indications (*indicationes*) of a patient's internal conditions that would otherwise remain inaccessible.[2]

While Santorio's engravings are cut in such a way that one can intuitively deduce the purpose of the instrument by knowing its application, his descriptions are often enigmatic. We know that they were used to measure variables (i.e., frequency, weight, temperature and ambient humidity) that revealed the progression of a disease in the body, thus allowing the physician to prevent or delay its effects, but Santorio is never quite clear about their specific application to medical practice. We do know that he experimented on a sample of around 10,000 subjects over a period of 25 to 30 years, suggesting 1584 as the earliest date at which his experiments may have begun.[3] What we do lack, however, is information about the composition of his experimental sample in terms of age and gender. The sizes of these instruments are not revealed either. Some, like the chair, required the patient to visit Santorio at his house to undergo repeated testing; others, like the thermometer and the hygrometer, appear to have been portable and to have aided advanced medical diagnosis at the patient's bedside. Most puzzling of all is Santorio's suggestion that some of these instruments should be used together.[4] What did this mean in practice? Were they used only to measure the environment and the body's response to it, or were they also used to control the environmental factors?

Concerned about the possibility that his students might claim these inventions as their own, Santorio withheld information about the intellectual background and precise application of the new instruments, promising a more detailed account in the work *On Medical Instruments*, which he prepared but never apparently managed to publish.

A rediscovered source, previously unknown to scholars, sheds light on early modern experimental practice and proves that Santorio's fears were indeed

2 Santorio Santori, *Commentaria in primam Fen primi libri Canonis Avicennae* (Venice, 1625), *Ad lectorem*: "Hippocrates enim 2 Aphorismorum 17 vult quod *sanatio indicet morbum*: ego quoque Divini senis imitatione dico, quod et sanatio, et experimenta, *necnon etiam instrumenta, et statica ars*; quae omnia longo usu, et periclitatione adinveni, [ut] hanc medicam philosophiam reddere possint claram, et manifestam." (Italics added.) For the necessity of using instruments to access the patient's internal conditions, see ibid., coll. 22A–24B; see also Fabrizio Bigotti, "Gears of an Inner Clock: Santorio's Theory of Matter and Its Applications," in Barry and Bigotti, *Santorio Santori*, 65–102, esp. 80–91.

3 Santorio Santori to Galileo Galilei, 9 February 1615, MS Gal. P VI, T 9, National Library of Florence, Florence, cc. 239r–240v; quoted and discussed in Fabrizio Bigotti and Jonathan Barry, "Introduction," in Barry and Bigotti, *Santorio Santori*, 26–34.

4 See, for instance, Santorio Santori, *Ars de statica medicina* (Venice, 1614; hereafter *Medicina statica*), II.4, 20v–21r; *Commentaria in primam Fen primi libri Canonis Avicennae* (Venice, 1625), coll. 23[A]–24A.

justified: as a manuscript copy, his work on medical instruments circulated privately among some of his students, giving rise to the plagiarising of his inventions.

1 The Rediscovered Source in Relation to Santorio's Work

The source in question is a booklet titled *Discorso del medico Bonomo sopra il governo del vivere* (see Fig. 1), which was published in Venice by Giovanni Martino Bonomo in 1620. Giovanni Martino Bonomo (ca. 1590–1630) is a rather obscure Venetian physician. From Santorio's own account we know that he was his pupil, while some contemporary records show that he practised medicine in Asiago as a municipal doctor, and that he eventually died during the second outbreak of plague that occurred in Venice between 1630–1631.[5] The *Discorso*, a rather conventional booklet on hygiene, was the only publication of Bonomo's otherwise unremarkable career. The most relevant parts of the work can be construed as a vernacular compendium of Santorio's *Medicina statica* with three important differences.

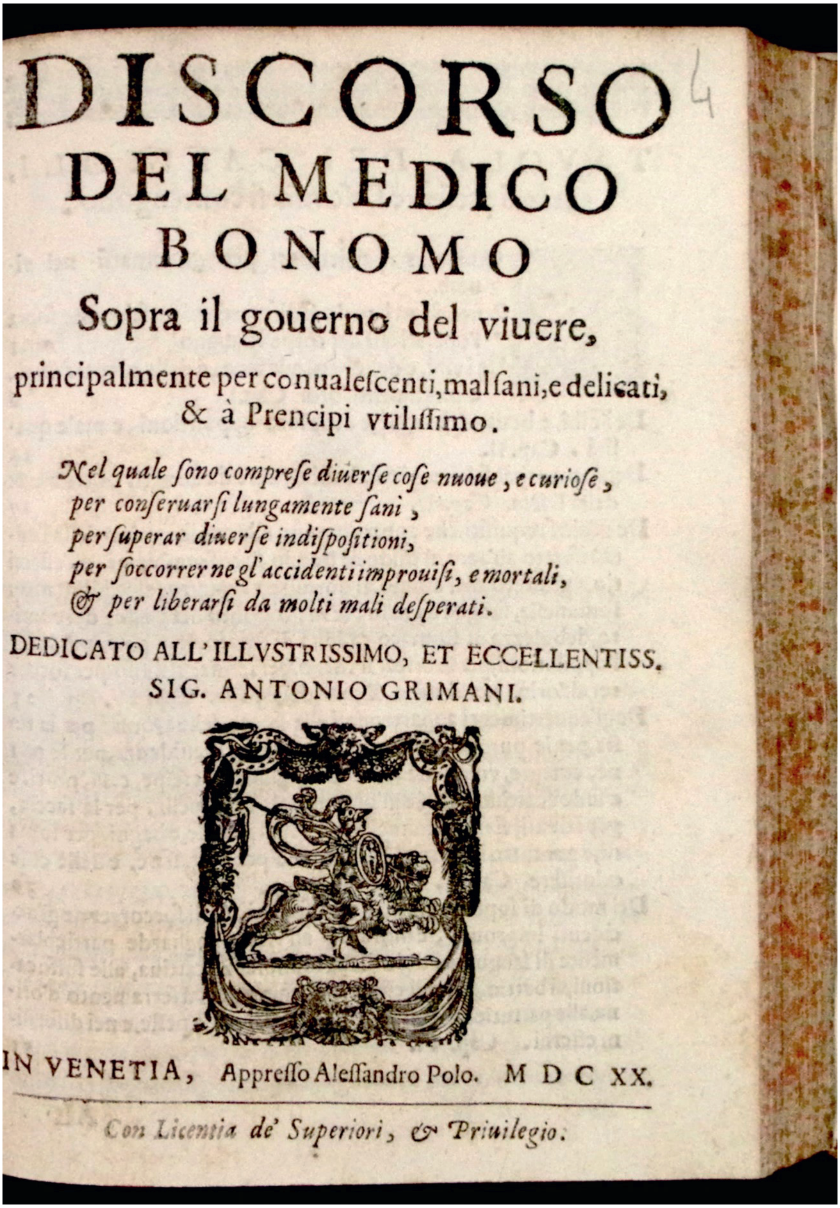
Firstly, Bonomo provides an accurate historical description of two instruments (i.e., the thermometer and the pulsilogium), and details of the application of a third (i.e., the weighing chair), which Santorio either never mentioned or only alluded to briefly in his works.

Secondly, the work shows engravings of two instruments (see Figs. 2 and 4) – with the possibility of a third (see Fig. 6) – which are the same as those that Santorio was to publish only in his *Commentary on Avicenna's Canon* (1625) and more especially in a second, rare edition of the same work – almost identical, except that some copies show variations in text and engravings – dated 1626 (see Figs. 3 and 5), six years after the publication of Bonomo's booklet.

Thirdly, Bonomo's booklet gives us a more complete picture of how mathematical instruments were used together to achieve precision in medical diagnosis.

The derivative nature of Bonomo's work is also established by three main elements. The first is the proximity of Bonomo's engravings to Santorio's works; the second is in the textual similarities; and the third is Santorio's statement

5 There are no studies on Bonomo. A brief foreword to the reprint of this work, undertaken by the Municipality of Asiago in Italy, collects the few biographical outlines that I have presented above; see Pietroantonio Gios, "Gio Martino Bonomo, fisico," in Giovanni Martino Bonomo, *Discorso sopra il Governo del Vivere* (Venice, 1620), facsimile reprint (Selci-Lama, 1997), ix–xv.



DISCORSO
DEL MEDICO
BONOMO
Sopra il gouerno del viuere,
principalmente per conualeſcenti, malſani, e delicati,
& à Prencipi vtiliſſimo.

Nel quale ſono compreſe diuerſe coſe nuoue, e curioſe,
per conſeruarſi lungamente ſani,
per ſuperar diuerſe indiſpoſitioni,
per ſoccorrer ne gl'accidenti improuiſi, e mortali,
& per liberarſi da molti mali deſperati.

DEDICATO ALL'ILLVSTRISSIMO, ET ECCELLENTISS.
SIG. ANTONIO GRIMANI.

IN VENETIA, Appreſſo Aleſſandro Polo. M D C XX.

Con Licentia de' Superiori, & Priuilegio.

FIGURE 1 Giovanni Martino Bonomo, *Discorso sopra il governo del vivere* (Venice, 1620), frontispiece
COURTESY OF ATENEO VENETO, VENICE

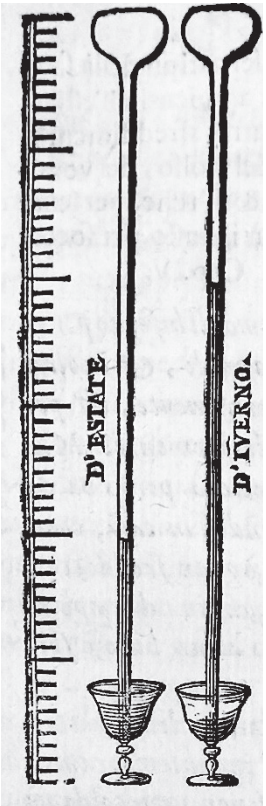


FIGURE 2
Environmental thermometer, from Giovanni Martino Bonomo, *Discorso sopra il governo del vivere* (Venice, 1620), 24
COURTESY OF THE FONDAZIONE QUERINI STAMPALIA ONLUS, VENICE

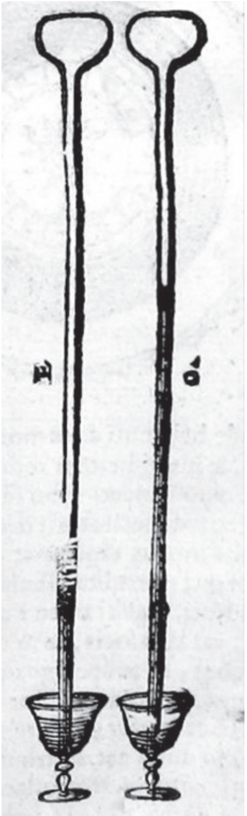


FIGURE 3
Environmental thermometer, from Santorio Santori, *Commentaria in primam Fen primi libri Canonis Avicennae* (Venice, 1626), 22
COURTESY OF THE ANCIENT LIBRARY VINCENZO PINALI, PADUA

that Bonomo's book contained teachings that the latter had received as his pupil. Let us consider each of these elements individually.

(1) *Visual proximity*. The closeness of Bonomo's and Santorio's engravings is striking, especially for the thermometer, which is an exact replica of the one Santorio was to use only in a very rare copy of the second edition of his commentary on Avicenna, dated 1626, which I was able to consult

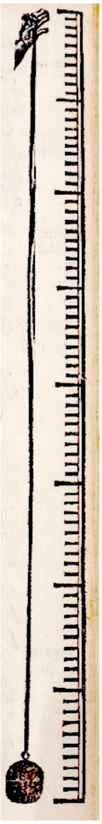


FIGURE 4
Pulsilogium type A1, from Giovanni Martino Bonomo, *Discorso sopra il governo del vivere* (Venice, 1620), 31
COURTESY OF THE FONDAZIONE QUERINI STAMPALIA ONLUS, VENICE

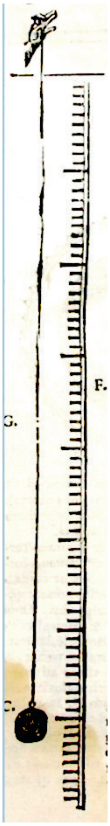
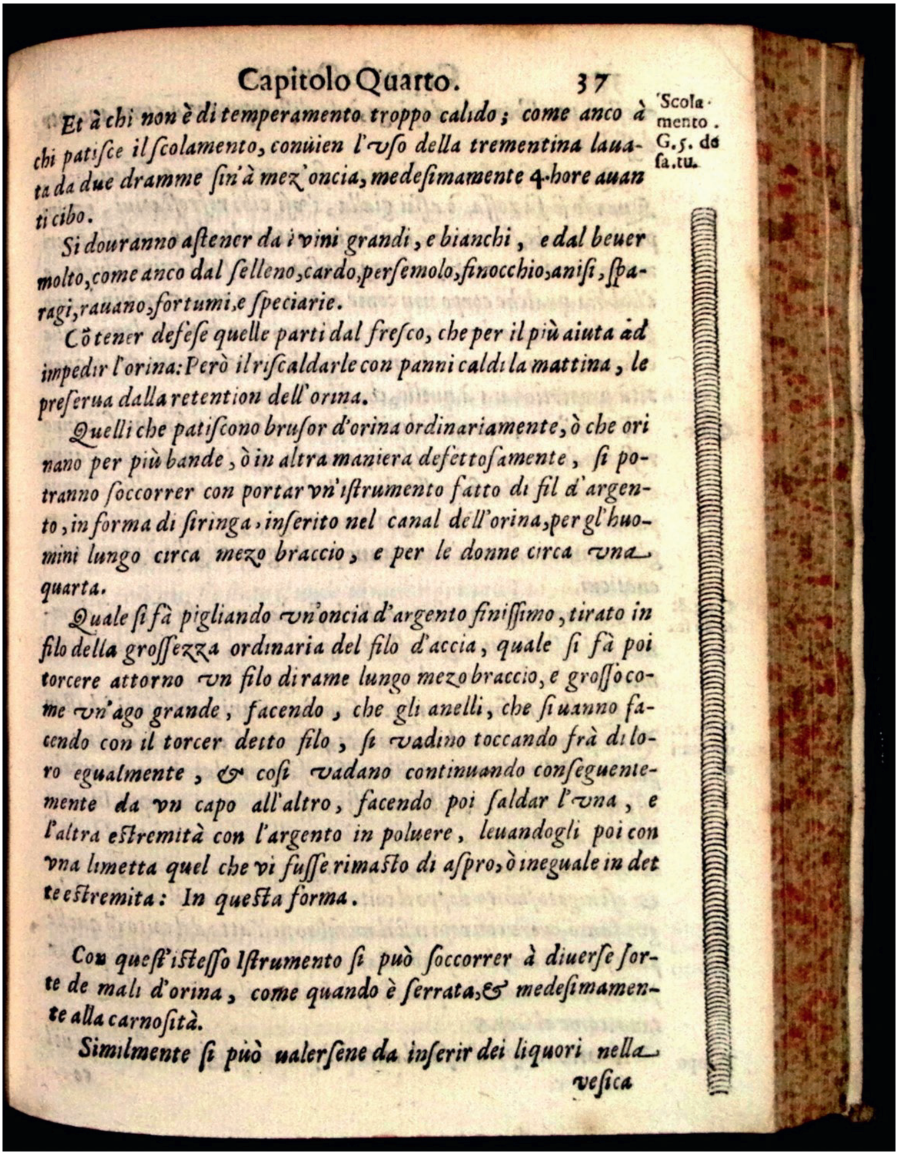


FIGURE 5
Pulsilogium type A1, from Santorio Santori, *Commentaria in primam Fen primi libri Canonis Avicennae* (Venice, 1626), 22
COURTESY OF THE ANCIENT LIBRARY VINCENZO PINALI, PADUA

in Padua.[6] This second edition also presents some textual variants with regard to the description of the pulsilogium. It is important to highlight that Santorio, fearing that someone else might claim his invention as his own, withheld information about the exact nature of his thermometer. It was, as Bonomo shows and explains, an environmental thermometer in which the different water levels correspond to the difference between the average summer (*d'estate*) and winter (*d'inverno*) temperatures, as

6 Only a handful copies of the 1626 edition contain visual and textual variants with respect to the 1625 edition. The copy I am referring to is kept at the Vincenzo Pinali Ancient Library in Padua, Shelf-mark STM.DUCC.VI.F.-2.(FA): *Commentaria in primam Fen primi libri Canonis Avicennae* (Venice, 1626), coll. 21D–22. Variants from the 1625 editions are shown in Bigotti and Taylor, "Pulsilogium of Santorio," Appendix I, 91–93. Another copy that I recently discovered is kept at the Biblioteca Nazionale Braidense in Milan, Shelf-mark NBA. 14. 02448. It belonged to the physician Werner Rolfinck (1599–1673), who obtained his doctorate in Padua with Adriaan van der Spiegel in 1625.



Capitolo Quarto. 37

Et à chi non è di temperamento troppo calido; come anco à chi patisce il scolamento, conuien l'vso della trementina lauata da due dramme sin'à mez'oncia, medesimamente 4. hore auanti cibo.

Scolamento. G.5. de sa.tu.

Si douranno astener da i vini grandi, e bianchi, e dal beuer molto, come anco dal selleno, cardo, persemolo, finocchio, anisi, sparagi, rauano, sortumi, e speciarie.

Cõtener defese quelle parti dal fresco, che per il più aiuta ad impedir l'orina: Però il riscaldarle con panni caldi la mattina, le preserua dalla retention dell'orina.

Quelli che patiscono brusor d'orina ordinariamente, ò che orinano per più bande, ò in altra maniera defettosamente, si potranno soccorrer con portar vn'istrumento fatto di fil d'argento, in forma di siringa, inserito nel canal dell'orina, per gl'huomini lungo circa mezo braccio, e per le donne circa vna quarta.

Quale si fà pigliando vn'oncia d'argento finissimo, tirato in filo della grossezza ordinaria del filo d'accia, quale si fà poi torcere attorno vn filo di rame lungo mezo braccio, e grosso come vn'ago grande, facendo, che gli anelli, che si uanno facendo con il torcer detto filo, si vadino toccando frà di loro egualmente, & così vadano continuando conseguentemente da vn capo all'altro, facendo poi saldar l'vna, e l'altra estremità con l'argento in poluere, leuandogli poi con vna limetta quel che vi fusse rimasto di aspro, ò ineguale in dette estremità: In questa forma.

Con quest'istesso Istrumento si può soccorrer à diuerse sorte de mali d'orina, come quando è serrata, & medesimamente alla carnosità.

Similmente si può ualersene da inserir dei liquori nella

vesica

FIGURE 6 Bonomo's [Santorio's?] instrument to alleviate difficulties in urinating, from Giovanni Martino Bonomo, *Discorso sopra il governo del vivere* (Venice, 1620), 37
COURTESY OF ATENEO VENETO, VENICE

measured by the graduated bar next to the instrument (see Fig. 2). For a variety of reasons that I shall discuss below, both the inscriptions and the graduated bar were removed in the 1626 engraving. This appears to have been a somewhat last-minute decision, for the engraver could only remove part of the inscriptions, as evidenced by the fact that the captions' final letters, *e* and *o*, were left in exactly the same place as in Bonomo's engraving (see Fig. 3). One reason for this was that the original copper plate in Bonomo's work had its captions in Italian, while Santorio's original was written in Latin and probably bore no captions at all. Another reason was to harmonize this engraving with the one displayed in the previous edition of the same text (Venice, 1625), which provided no information about the significance of the different water levels. It is noteworthy that the graded bar was also removed for the same reason. Along with the engraving of the pulsilogium, the thermometer engraving is one of the most important pieces of evidence supporting the idea that both Santorio and Bonomo drew from the same source.

(2) *Textual proximity*. Textual evidence is another key element for establishing the derivative nature of Bonomo's work, with several passages simply translating or paraphrasing Santorio's Latin prose into Italian, as in the examples shown in Table 1:

TABLE 1 Textual parallels between Bonomo's and Santorio's works

Bonomo 1620, 24–25	**Santorio 1612, III, 62D–E**
Con l'istesso Istrumento al modo medesimo si può venir in cognitione della differenza del caldo da una stanza all'altra. Così anco del temperamento diverso di una persona dall'altra. Et in un'istessa persona di una parte dall'altra. Similmente d'una parte malsana, come calda, et infiammata, quanto eccede in calore. Et l'istessa persona in tempo di febre, ò d'altro male calido tanto eccede di calore dal tempo, che si ritrova senza febre, e per consequenza di quanti gradi de rinfrescamento haverà di bisogno.	[…] ego quoda[m] instr[ument]o vitreo soleo dimetiri temperatura[m] frigida[m], et calidam aeris, o[mn]ium regionum, o[mn]ium locorum, et o[mn]ium partium corporis, et adeo exacte, ut qualibet hora diei possimus gradus, et ultimas mansiones caliditatis, et frigiditatis circino dimetiri; (For similar statements, in the same text, see also III, 105 A–B; 229 D–E; 375 B.)

TABLE 1 Textual parallels between Bonomo's and Santorio's works (*cont.*)

	Santorio 1612, III, 376 B–C
Il che solevano dir gl'antichi, che se l'havessero potuto sapere, si sarebbono stimati Esculapii.	[...] quamvis fatear cum Galeno [...] si ego scirem illud quantum agendum, talem me putarem, qualem fuisse ferunt Aesculapium.
Bonomo 1620, 20–21	**Santorio to Galileo, 9 February 1615**[a]
[Hip. Lib. De flatibus] E per questo la medicina non consiste in altro, che in aggiongere o sminuire.	L'opera e ridotta in afforismi, i quali nascono da due principi certissimi. Il primo [è] la diffinition della medicina, proposta da Hippocrate nel libro *De flatibus* dove dice: *Medicina est additio, et ablatio, additio eorum quae deficiunt, et ablatio eorum quae excedunt*: diffinition degna di un tanto vecchio; et da questa nasce il primo afforismo, che è prova di molti altri.
Bonomo 1620, 25	**Santorio 1614, II.4, 20v–21r**
Così anche l'humidità, e siccità dell'aere si conoscerà con l'allume di feccia in polvere esposto all'aria.	Quanta sit aeris ponderositas, colligitur primo ex maiori, vel minori gravitate aluminis faecum prius exiccati in sole, et deinde aeri nocturno expositi.
Bonomo 1620, 30	**Santorio 1625, 21E–22A**
E se si abbrevia il filo, la balla fà la battuta frequente, tanto se si move fortemente, quanto se si move piano, perche quanto manco spatio và occupando, tanto manco violentemente si và movendo;	At notandum quod pila plumbea per maiorem, vel minorem vim impulsa non mutat raritatem seu frequentiam: quia impellendo quantum amittitur de spacio, tantum remittitur de violentia.

a National Library of Florence, MS Gal. P VI, T 9, c. 239. A similar passage is found in Santorio Santori, *Commentaria in primam sectionem Aphorismorum Hippocratis* (Venice, 1629), 71.

(3) *Santorio's own statement*. A final element comes from Santorio's 1625 correspondence with a former Paduan student, Senatore Settala (ca. 1590–1636), concerning Bonomo's booklet. At the request of his former pupil, Santorio had sent him a copy of Bonomo's booklet and promised to send him, at a reduced cost, a copy of the *Commentaria in primam Fen primi libri Canonis Avicennae*, which had just been published in Venice. In his reply – which unfortunately has not survived, Senatore must have noted that Bonomo's book contained descriptions of many of Santorio's precision instruments. This explains why, in his next letter of 22 November 1625, Santorio makes it clear that "Bonhomo's [sic] book contains many things of mine which I taught him as my pupil."[7] The tone of this exchange suggests that Santorio was not angry with Bonomo and probably saw the latter's work – in which Bonomo never directly claimed to have himself invented the instruments depicted therein – as a good, albeit indirect, way of selling his inventions to general practitioners. Indeed, the same neutral tone towards Bonomo can be found in another letter, undated but certainly written between 22 November and 20 December, in which Santorio informs Senatore that "it seems that Bonhomo [and his family] have settled in Venice."[8] From the exchange that follows, we can glean some more information about the "Bonomo affair." Since Bonomo's descriptions and illustrations closely reflected the teachings that Senatore had received in Padua from Santorio himself, he must have wondered about the usefulness of acquiring Santorio's expensive *Commentaria*, for they might not have contained anything new in comparison to what was already in Bonomo. In his letter of 20 December 1625, Santorio therefore reassured his pupil that the effort would be worthwhile: "I can promise you," he writes to Senatore, "that the doctrine of these books of mine will contain only new things, since I will

7 Santorio Santori to Senatore Settala, Venice, 22 November 1625, Milan State Archive (hereafter: ASM), Autografi 218 c. 1r: "Le ma[n]do il lib[ro] de valvulis il qual costa £ 4 et ancho il libro del S[ignor] Bonhomo. Il mio libro del Avicen[n]a che è di più di 100 fogli mi par troppo machina p[er] mandar g[li] il portalettere; ma se mi ordinerà ò che lo dia al S[ignor] Zuane de Lore[n]zi ò p[er] il corriero ò per altri, haverò gran gusto à presentargine uno, che certo è curioso, et ha più di 40 figure di miei instrume[n]ti inve[n]tanti, et legendolo, lei ne caverà fruto grandiss[im]o. Quello del S[ignor] Bonhomo co[n]tien molte cose mie have[n]doglile insegnato come mio scholaro[.]"

8 Santorio Santori to Senatore Settala, Venice (?), unknown date, but before 20 December 1625, ASM, Autografi 218, cc. 1r–v: "Inviai a V[ostra] S[ignoria] ancho il libro del Bonhomo […]. Quanto [poi] alla citatione del Sig[no]r Bonhomo […] fu scritto nelle ultime lettere à V[ostra] S[ignoria] m[ol]to Ill[ust]re che no[n] occorera altro p[er] il Bonhomo che par che si sijno acomodati qui in Venetia […]."

never stoop to write things that others have written fully (*pienamente*)."[9] At this point, Senatore must have felt encouraged by Santorio's words, because he paid for the books, which were sent to him in Milan two days after Christmas, on 27 December 1625.[10] From Santorio's exchange, we thus find further confirmation that the most important part of Bonomo's work is simply an embodiment of Santorio's teachings.

2 The Rediscovered Source in Relation to Santorio's Book "On Medical Instruments"

Derivative though his booklet was, Bonomo only reluctantly acknowledged his debt. Santorio's name appears only once, in a brief marginal note on p. 19, when discussing the importance of statical experiments in maintaining health. In the absence of any other reference, the reader is led to believe – as in the Dedicatory letter to Antonio Grimani – that the instruments were in fact Bonomo's.[11] The fact, however, that there was no direct false claim of credit for the inventions means that the "Bonomo affair" is very different from the one that, in 1608, led Galileo to denounce the physician Baldassarre Capra (1580–1626) to the *Riformatori* of Venice for appropriating the applications of the proportional compass.[12]

Santorio's attitude towards his former pupil was therefore one of forbearance and noble self-restraint: after all, he had nothing to fear since the instruments had already been described in previous works and were known to everyone in Venice, and beyond, as Santorio's inventions. In fact, while teaching in Padua (1611–1624), Santorio performed public experiments with

9 Santorio Santori to Senatore Settala, Venice, 20 December 1625, ASM, Autografi 218, c. 1r: "Io le prometto che la dottrina di questi miei libri co[n]tien solo cose nove che io non mi abbasseria mai à scriver quello che han[n]o scritto gli altri piename[n]te, et mi sarà grato che lei lo lega tutto, et riferir al Ecc[ellentissi]mo S[ignor] suo padre à bocca, accioche dal tedio della lettura no[n] si offenda."

10 Santorio Santori to Senatore Settala, Venice, 27 December 1625 ("Con due libri ligati insieme"), ASM, Autografi 218.

11 Bonomo, *Discorso sopra il governo del vivere* (1620), "Al Sig. Antonio Grimani": "[…] senza posa, e senza spesa, mi sono industriato di produrre alcun parto con l'ingegno, e tale che dovesse riuscir giovevole al secolo presente, et al futuro, nel che spero non essermi affaticato indarno mediante quelle vigilie, e sudori, che hò speso in comporre il presente Libro, concernente la salute e conservation dei corpi umani."

12 For the controversy between Galileo and Capra, see Mario Biagioli, "Replicating Mathematical Inventions: Galileo's Compass, Its Instructions, Its Students," *Perspectives on Science*, 30 (2022), 437–462.

his inventions, while sketches of them were made by his students and spread throughout Europe.[13] Drawings of Santorio's thermometers are found in both manuscript and printed sources of the time, such as those by Ippolito Obizzi (manuscript 1617), Giuseppe Biancani (written ca. 1617, published 1620), Joseph Salomon Delmedigo (written ca. 1621, published 1629), often without crediting Santorio for their invention who found this emulation a bit persecutory.[14] While the majority of these authors relied on Santorio's own oral accounts or those of his pupils and could therefore provide only rough approximations of the actual instruments, Bonomo, by contrast, seems to have had access to the original manuscript or at least to a series of lecture notes. As we have seen, this source must have been a written one, otherwise the wording and engravings would not be so close.

Other elements independently support this hypothesis. For example, we know that Santorio began writing his *Commentary on Avicenna* in 1623, so we can rule out the possibility that Bonomo drew from this text.[15] The only possible remaining explanation is that the source in question was a manuscript that Santorio kept for his personal use, possibly the very text of *De instrumentis medicis*, that Santorio had begun to write in 1610[16] and which, according to his later account in 1626, contained several engravings on the construction and use of the new instruments.[17]

13 For Santorio's experiments, see Santorio Santori, *Commentaria in artem medicinalem Galeni* (Venice, 1612), Pars III, col. 105A–B. For the circulation of their drawings, see Paul Müntzer to Michael Döring, Wittenberg, 8 December 1622, in Daniel Sennert, *Opera in sex tomos divisa* (Lyon, 1666), "Epistulae medicinales," Centuria I, Epistula XLVIII, 1161(b): "Narrarunt et mihi aliquot ex meis auditoribus ex Italia reduces, aliquid de Instrumentis istis Sanctorii, *et delineata, ni fallor, alicubi habeo*, sed talia non videntur, ut tantus vir istis famam captare debeat. Molitur idem iam editionem Commentarii in aliquam partem Avicennae: iis pleraque sua instrumenta inserturum aiunt." (Italics added.)

14 Biancani, in fact, is the only exception. For a comparison between these descriptions and prototypes, see Bigotti, "Weight of the Air," 78–92. For Santorio's statement, see Santorio Santori to Senatore Settala, Venice, 27 December 1625, ASM Autografi 218, c. 1: "et però io hò una tal emulatione che si puo dir esser convertita in persecutione." For Delmedigo, see Jacob Adler, "J.S. Delmedigo and the Liquid-in-Glass Thermometer," *Annals of Science*, 54 (1997), 293–299.

15 Bigotti and Barry, "Introduction," 24.

16 For the dating of *De instrumentis medicis*, see Santorio, *Commentaria in primam Fen* (1625), "Ad lectorem": "Ego tamen posthac icones omnes magis elaboratas in lucem promam. lmmo iam 15 annis elapsi sunt, ex quo coeperam instrumentorum figuras elaboratissimas praeparare, et in publicam utilitatem proferre: sed ab incaepto opere destiti: quia tunc inopinate fui accersitus ab Excellentissimis Moderatoribus Gymnasij Patavini ad Theoricae ordinariae interpretationem."

17 Santorio, *Commentaria in primam Fen* (1626), Padua, Ancient Library Vincenzo Pinali, Shelf-mark STM.DUCC.VI.F.-2.(FA), 21D: "quod [scil. Pulsilogium] imprimi non curavimus:

The relationship between the engravings of instruments contained in the *Commentary on Avicenna* – and the promised book *On Medical Instruments* – warrants further investigation as it sheds light on Santorio's reluctance to reveal the purpose and functioning of his instruments.

As Mario Biagioli has shown, this circumspection reflects the early modern system of privileges and patents, where intellectual property was covered by the concession of printing privileges and the priority of an invention was attributed on the basis of a 'prior art' against any subsequent possible application. This meant that inventors and instrument makers had to secure their market by showing the reader that the instrument had practical applications without revealing too much about how the instruments could be reproduced.[18]

Santorio adeptly employed this marketing approach early in his career, carefully selecting individuals with whom he shared his "secrets" (*arcani*) or sold his instruments.[19] One example is in the earliest reference to the pulsilogium, mentioned in 1602 by the physician Eustachio Rudio (1548–1612) as an invention by Santorio.[20] This was followed a year later by Santorio's own account which described the possibilities of the new instrument for medical practice, without going into details about its design or functioning.[21] Several contemporary accounts also independently document Santorio's disinclination to share the knowledge of his invention, especially so for the mathematical instruments. Colleagues such as the Polish physician Paul Croquer (*Paulus Croquerus*, fl. 1616–1643) or the Dutch surgeon Jacob Block (ca. 1601–1666) had the opportunity to learn how to use an instrument for paracentesis (*acus sanctorii*) and to

quia, nisi ageretur de eius constructione, quod per multas figuras fieret, lectores non intelligerent: ideo de illo esse agendum remisimus in librum *De instrumentis medicis*, quem, Deo dante, imprimemus."

18 Mario Biagioli, "From Print to Patents: Living on Instruments in Early Modern Europe," *History of Science*, 44 (2006), 139–186, esp. 155. Venice was the first state to introduce legislation about patents (1474) and inventions were patented for public utility, but disclosure of them to the public was deemed unnecessary to maintain the monopoly. The few surviving patents from the period show that drawings were rarely used to submit privilege requests; see Roberto Breveglieri, *Inventori stranieri a Venezia* (1474–1788): *Importazione di tecnologia e circolazione di tecnici, artigiani, inventori. Repertorio* (Venice, 1995), 20–49 and Sabrina Minuzzi, *Sul filo dei segreti. Farmacopea, libri e pratiche terapeutiche a Venezia in età moderna* (Milan, 2016), 26–30.

19 For the word *arcani* applied to Santorio's inventions and particularly to *Medicina statica*, see Santorio Santori to Galileo Galilei, Venice, 9 February 1615, MS Gal. P VI, T 9, c. 239–240: "Ma io non tediero piu V[ostra] S [ignoria] Ecc[ellentissi]ma, perche lei col suo mirabile ingegno, et con l'esperienza che fara in detta mia fatica, scoprira gl'arcani suoi."

20 Eustachio Rudio, *De pulsibus libri duo* (Venice and Frankfurt, 1602), II.1, 23v.

21 Santorio Santori, *Methodi vitandorum errorum omnium*, "De pulsilogi usu," V.7, 190rD–109vB.

purchase it.[22] Others, such as Balthasar Timaeus von Güldenklee (1599–1667), a German student interested in the mathematical instruments, were apparently not so lucky. Admitted to Santorio's house in Venice, Güldenklee recounts his frustration at being shown medical, surgical and mathematical instruments without being informed of their use "except those that [Santorio] mentioned in his *Commentaria in primam Fen primi libri Canonis Avicennae*."[23]

This selective strategy of disclosure was intended to create anticipation among colleagues, who did indeed begin to discuss possible applications of the new technology and to build replicas of Santorio's instruments for themselves.[24] The case of Isaac Beeckman (1588–1637) is emblematic; such was the eagerness with which he anticipated Santorio's forthcoming publication that he asked his influential friend Marin Mersenne (1588–1648) to let him know as soon as the book *On Medical Instruments* was published.[25] A document in a vernacular language, such as Bonomo's, complement this picture by testifying to the success of the strategy in fostering the emergence of a market for the new instruments, even among everyday practitioners and curious readers.

Thus, in order to establish 'prior art,' to protect his claims from ungrateful students and to satisfy the growing demands of his admirers, Santorio included the engravings of his inventions in the *Commentary on Avicenna's Canon*, while postponing the provision of details of their construction and use to appear instead in the book *On Medical Instruments*.[26] This book was certainly ready for publication in 1629, as he refers to it and to the chapters dedicated to the

22 On Paul Croquer (*Croquerus*), see Johan Shenk, *Observationes medicae rariores* (Frankfurt, 1665), lib. III, obser. IV, 453(a); on Jacob Block, see Paul Barbette, *Chirurgie nae de hedendaeghsche Practijck* (Amsterdam, 1662), 51 and, for more details, Michael Adam Gusovius, *Observationum domesticarum specimen offerens novum Paracenteos instrumentum* (Königsberg, 1723), 7.

23 Balthasar Timaeus von Güldenklee to Johan Stadius, Colberg, 6 September 1627, in idem, *Epistolae et consilia. Accessit et Hortolini Timaeani topographia metrica et inscriptiones* (Leipzig, 1677), lib. VI, epist. IV, p. 848(b): "Instrumenta quidem sua medica seu chirurgica non minus ac mathematica Venetiis monstravit Sanctorius, *sed monstravit, non communicavit praeter illa quorum in commentariis suis super primam Fen libri l Canonis Avicennae meminit*." Italics added.

24 I have shown above a few instances of the early efforts at replicating Santorio's thermometers. For replicas of Santorio's pulsilogium, see Bigotti and Taylor, "Pulsilogium of Santorio," 58–60. For a contextualisation of Santorio's strategy, see Minuzzi, *Sul filo dei segreti*, 26–30; Biagioli, "From Prints to Patents," 153.

25 Isaac Beeckman to Marin Mersenne, Dordrecht, 7 October 1631, in Cornelis de Waard, ed., *Journal tenu par I. Beeckman de 1604 à 1634*, 4 vols. (The Hague, 1953), 4: 207: "Si ibi Galileo Galilei *Cosmographia* aut Sanctorio Sanctorij *Instrumenta medica* innotuerunt, fac me quam primum, si vacat, certiorem."

26 For the content of *De instrumentis medicis*, see n. 18.

void as being completed.[27] The title also deserves attention. *De instrumentis medicis non amplius visis* reflected both Santorio's theoretical assumptions and his strategic aims. As he explains, in fact, the new mathematical instruments addressed an ancient desideratum of medical practice, that of measuring the magnitude or intensity of a disease (*quantum morborum*, *magnitudo morbi*). As such, they could be understood either as reinventions of instruments used in the past but whose knowledge had disappeared, or as modern innovations that complemented and perfected ancient teachings.[28] An indication of this can be found in an early designation that Santorio used to refer to his much anticipated publication: *De instrumentis noviter a me inventis*, which literally translates as "Instruments that I have reinvented."[29] However, the title was also intended to prevent and neutralise the scepticism of an audience that was rightly suspicious of the possibility of applying mathematical instruments to medical practice, which at that time was entirely based on the interpretation of symptoms and the qualitative assessment of bodily fluids.

Reinforced by the discovery of the new source, these considerations suggest that the promised book, *On Medical Instruments*, did in fact exist prior to 1620, if only as a draft provided with illustrations. The way in which Santorio himself interpolated the descriptions of his instruments into the relevant parts of his various commentaries, especially that on Avicenna (1625–1626), can be taken as final evidence of this. As they seem to appear out of the blue, Santorio is repeatedly compelled to apologise for his rhapsodic writing, promising to provide the construction and use of the new devices in the forthcoming book. Most importantly, the quotations referring to these instruments always use the same or very similar wording in all the works, lending credibility to the hypothesis that Santorio himself copied the relevant passages from his manuscript work and placed them in different contexts.

27 See especially Santorio, *Commentaria in primam sectionem* (1629), 51, where he speaks about the book as completed.

28 Santorio contextualises his discoveries as new inventions with respect to the ancient ones, but he generally follows the line of Guido Panciroli's book *Rerum memorabilium, iam olim deperditarum* (Venice, 1612) where new discoveries are seen, in fact, as *desiderata* of an ancient science then lost; see Santorio, *Commentaria in primam Fen* (1625), col. 7A–C. Similarly, instruments such as the thermometer, are seen as adaptations of ancient instruments, of Heron of Alexandria in particular, and Santorio openly links his medical statics to the re-invention of ancient but lost medical practices; see Santorio, *Commentaria in primam sectionem* (1629), Dedicatory letter to Francesco Maria II Della Rovere, which begins with the following words: "Staticam medicinam tot seculis sepultam, e tenebris in lucem, et hominum prospectum longo usu et pereclitatione arcessimus."

29 Santorio, *Methodi vitandorum errorum omnium*, I.31, fol. 26vD.

3 Content and Relevance of the Rediscovered Source for Early Modern Technology

In the absence of the original manuscript, Bonomo's account is the closest and most important source for reconstructing the exact purpose and use of Santorio's instruments in medicine. Bonomo's *Discorso* is articulated into six chapters and begins with a *proemium* (pp. 1–5) where he argues for the importance of innate heat and insensible perspiration for the preservation of health. He also presents a theory of perception that basically stems from Santorio's interpretation of Galen's anatomy of the nerves.[30] Chapters I and II provide some common-sense advice on the preparation of aliments and dietary prescription, while Chapters V and VI deal with women's diseases and the way to treat extreme illnesses or sudden accidents. The central chapters (III–IV), which constitute the most important part of the work, embed descriptions and engravings of Santorio's instruments and experiments for quantification in medicine, including an instrument to alleviate difficulties in urinating (see Fig. 6).

While the description of some instruments, such as the hygrometer, contains nothing more than what Santorio had already disclosed in 1614, the account of the statical experiments provides new material on their context and purpose. This is discussed in Chapter III, "On the quantity of food and drink to be observed, and on diet" (*Della quantità del mangiare, et del bevere da doversi osservare, et della dieta*), which begins with the assertion that self-assessment and custom are not sufficient to determine with accuracy the quantity of food to be administered, since such parameters are only conjectural. He goes on to explain that, for those whose health and longevity must be assured – such as princes and nobles –, absolute precision in measuring the quantity of food is required.[31] The same precision is needed for people with fragile constitutions and for those who want to know the means of ensuring their own longevity. This aspect throws light on the sample of Santorio's experiments; experiments which – as I will argue in the conclusions – are indeed of painstaking precision and would have gone beyond the purpose of a simple diagnosis. Santorio himself would later stress the need to hide the mechanism of his instruments from view "because of the nobles" (*propter proceres*), who might have found the mechanisms unpleasant to look at, and "because of laymen" (*propter indoctos*) to whom "anything new seems strange."[32] However, Bonomo puts this brief

30 Bonomo, *Discorso*, 5; cf. Santorio, *Commentaria in primam Fen* (1625), col. 788.

31 Bonomo, *Discorso*, 18.

32 Santorio, *Commentaria in Primam Fen* (1625), col. 558A.

remark into context and shows us that, apart from Santorio himself and his assistant Girolamo Tebaldi da Oderzo (1575–1641), the subjects of his experiments were more often than not members of the nobility.

The means of obtaining a precise diagnosis – Bonomo contends – is to weigh oneself every day, or at least some time, on an empty stomach, in perfect health, and then to note how much one has gained or lost during the period of indisposition, in order to determine what one should eat and drink. Repeated weighing also makes it possible to predict when a person will fall ill, whether due to replenishment (*pienezza*) or to a lack of the necessary nutrients (*mancamento della necessaria nutrizione*).[33] Medicine, then, is nothing more than the addition of what is lacking and the subtraction of what is excessive, the balance between the two being ensured by the evacuation of a regular quantity of insensible perspiration. This sentence is the same one used by Santorio in his letter to Galileo of 9 February 1615, but is never quoted in *Medicina statica*, which again suggests that Bonomo had access to Santorio's lecture notes or manuscript. The correct amount of food and drink to be taken every day for a healthy adult man of 200 pounds (about 60 kg) is 8 pounds (*8 libre alla sottile* = about 2.4 kg, one Venetian *libra alla sottile* being equal to 301.23g), while a little of this is retained in the body by those who are growing, such as children, those who are getting fat, and those who are convalescing.[34] Together with Santorio's statement that old age must be regarded as a long-lasting disease, these details restrict the age of the experimental sample used by Santorio, which must have been very close to that later indicated by the French physician Denis Dodart (1634–1707) for his statical experiments: begun in 1668, they involved men between the ages of 25 and 45 years.[35]

Bonomo states that, of the 8 pounds, 3 pounds (about 903g) are excreted in urine, half a pound (about 150g) in faeces, and the rest in the form of sweat (about 5 pounds, that is approximately 1.5 kg). The amount to be ingested is in a ratio of 1/3 to 2/3 between food and drink. In his 1614 edition of *Medicina statica*, Santorio gives the same figures in pounds, of course, but omits to specify

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33 Bonomo, *Discorso*, 19.

34 All weight units in this paper are given in accordance with historical accounts of the Venetian system, as provided in Ugo Tucci, "La metrologia storica. Qualche premessa metodologica," in *Papers and Proceedings of the Department of Historical Research of the Institute of Historical and Social Research of Croatian Academy of Sciences and Arts*, 7 (1974), 305–318.

35 Santorio Santori, *Ars de statica medicina* (Venice, 1634), sect. I, aphor. 83, p. 12v. Denis Dodart, *Medicina statica Gallica*, in Pierre Nouguez, ed., *Sanctorii Sanctorii de statica medicina aphorismorum sectionibus septem distinctorum explanatio physico-medica*, 2 vols. (Paris, 1725), II: 215.

the detail *alla sottile* ('subtle pounds') and does not give precise proportions as to the amount of food and drink to be taken.

For those who find weighing themselves awkward, Bonomo recommends at the end of Chapter III that the statical trials can be performed by weighing themselves over a bench, with a stone the same weight as their healthy selves as a counterbalance.

Though this is something that Santorio had never mentioned, it is worth considering, as one of the ways in which he may have begun his self-experiments. Considering that his experiments began around 1584–1589, and that this period coincides, at least in part, with his travels in Eastern Europe as a military physician (1588–1592/3), Santorio's earliest experiments must have been very rudimentary and aimed simply at establishing that a healthy organism has the capacity to restore its internal conditions by returning to the same weight every day.[36] Bonomo also makes it clear that the aim of the statical experiments was to help maintain the same weight over time in order to remain healthy. This was an aspect that Santorio had repeatedly hinted at, but which was never so clearly stated in *Medicina statica*, and it leads us to an important conclusion.

Santorio's instruments were not only measuring devices, but were also 'normative devices,' meant to manipulate bodily weight and the environment so as to maintain a person's weight within the same healthy parameters. This was particularly the case with the thermometer, which Bonomo discusses in Chapter IV of his *Discorso* "On the other requirements, which belong to the conservation of health with regard to air, heat, cold and the environment" (*De gli altri requisiti, che appartengono alla conservation della sanità, rispetto all'aere, al caldo al freddo, e cose ambienti* …). It is worth quoting Bonomo's account in full, as it contains important information not only on the technical features of the thermometer, but also on its normative application:

> And since our life consists of the temperament of the first four qualities, the more we keep ourselves in this temperament, the longer we will last in life, taking care not to suffer from excessive heat or cold, dressing, warming ourselves, going out of the house, and being more or less active according to the weather, as the air changes. This will be known and can be accurately predicted if a large glass ball is kept in the chamber, suspended in the air, with a glass straw attached to the lower end, about two arms long, with both ends, that of the concavity of the ball and that of the glass straw, forming a continuum, and so closed throughout that air can

36 Bigotti and Barry, "Introduction," 9.

enter only through the opposite lower mouth of the glass straw. Water or clear ink will be drawn in through this mouth, filling about half the glass straw, taking care to heat the glass ball well first, and then immediately placing the lower mouth of the barrel in a glass or jar filled with water or ink. In this way, as the glass cools by itself, the water or ink will rise into the glass straw for some space in this way, with the degrees noted alongside [see Fig. 2 above]. And so, over time, when the outside air cools more or less in the winter and the air inside the glass condenses, the air inside the glass will change in the same way as the outside air, cooling and condensing inside the glass. And so it will go down more, and it will necessarily happen that the ink or the water that has gone into the glass straw will go up by as many degrees, so that no void is created. And the same will happen in more or less degrees, according to the fact that more or less of the internal air will condense from the cold and rise. And so, on the contrary, if in summer the outside air is more or less heated, and consequently expands the inside air, the latter, having been similarly changed by the outside air, will heat up and expand in the glass, and consequently it will decrease in degrees, and it will be necessary for the ink or water entering the hole to decrease in degrees in order to give more space to the air inside the glass. And this in more or less degrees, depending on whether more or less of said air inside the glass expands and contracts due to heat. This is how you can tell the difference in heat from one room to another. In the same way, you will learn how temperament differs from one person to another. And in the same person one will be able to know the difference between one part of the body and another. Likewise, one will be able to know the difference between one unhealthy part and another, as in the case of being hot and inflamed, that is, how much one exceeds in heat. And you will be able to know the changes of the same person in the time of fever or another hot disease, how much he exceeds in heat compared to the time when he has no fever, and consequently how many degrees of coolness he will need. And the ancients used to say that if they could have known this, they would have considered themselves Aesculapians. Hence, such an observation is a matter of great admiration.[37]

37 Bonomo, *Discorso*, 23–25: "Et perche la nostra vita consiste nel te[m]peramento delle quattro prime qualità, però qua[n]to più ci conserveremo in tal temperamento, tanto più dureremo in vita, con procurar di non patir caldo, nè freddo immoderato, con vestirsi, scaldarsi, uscir di casa, far essercitio più, ò meno, secondo il tempo, che si và

Although – as we have seen – this account of the thermometer postdates that of Biancani, and that of Obizzi which I discovered in Venice, Bonomo's is much more precise than either of these. It gives us a glimpse into the uses of the thermometer in medical practice, as developed in Padua by Santorio from 1611 onwards.[38] The type described by Bonomo is still open and therefore subject to the influence of atmospheric pressure, although it seems that Santorio later developed closed-loop thermometers.[39] The liquid in the glass straw is said to be water or clear ink, the use of the latter (green ink or a similar substance) being recommended by Santorio to make the effects of heat and cold

mutando l'aere, il che si conoscerà, e prevederà minutamente; se si terrà in camera sospesa in aria una balla di vetro grande, c'habbia attaccata alla parte inferiore una cannella di vetro longa due braccia incirca con la concavità continuata della balla, e della canna, et talmente chiusa per tutto, che non vi possa entrar aria, se non per la bocca inferiore contraposta della canna, per la qual bocca si farà entrar dell'acqua, overo dell'inchiostro chiaro, che empia circa la metà della canna, scaldando prima bene la balla di vetro, e poi subito facendo star le [sic] bocca inferiore della canna in un bicchiero, ò vaso pieno di acqua, ò d'inchiostro, che cosi raffreddandosi da per sè il vetro, l'acqua, ò inchiostro ascenderà nella canna per qualche spatio in questa forma insieme con i gradi notati appresso. Et così col progresso del tempo secondo che l'aere estrinseco si andarà più, ò manco raffreddando per l'inverno, e per consequenza conde[n]sando così l'aria interna del vetro, alterata all'istesso modo dell'aria esterna, verrà a raffreddarsi, e a condensarsi nel vetro, e per consequenza verrà ad ascender più, dove che ne seguirà per necessità, che l'inchiostro, ò acqua entrata nella canna vada salendo in assai gradi, acciò non segue luogo vacuo, e così in più, ò manco gradi, secondo che più, ò manco l'aria interna si và condensando dal freddo, e ascendendo. Et così all'incontro secondo che l'aria esterna s'anderà più, ò manco riscaldando per l'estate, e per consequenza dilatando, così l'aria interna, alterata all'istesso modo dall'aria esterna, verrà a riscaldarsi, e a dilatarsi nel vetro, e per consequenza a descendere, dove che ne seguirà per necessità, che l'inchiostro, ò acqua, entrata nella canna vada descendendo a manco gradi, per cedere maggior luogo all'aere interno del vetro, più, ò manco gradi, secondo che più, ò manco detto aere interno si và dilatando dal caldo, e descendendo. Con l'istesso Istrumento [sic] al modo medesimo si può venir in cognitione della differenza del caldo da una stanza all'altra. Così anco del te[m]peramento diverso di una persona dall'altra. Et in un'istessa persona di una parte dall'altra. Similmente d'una parte malsana, come calda, et infiammata, quanto eccede in calore. Et l'istessa persona in tempo di febre, ò d'altro male calido quanto eccede di calore dal tempo, che si ritrova senza febre, e per consequenza di quanti gradi de rinfrescamento haverà di bisogno. Il che solevano dir gl'antichi, che se l'havessero potuto sapere, si sarebbono stimati Esclusapii. Però tal osservatione è cosa di grand ammiratione."

38 See Ippolito Obizzi, *Epistolarum et disquisitionum sacrarum libri XII*, Biblioteca Nazionale Marciana (BNM), Venice, Cod. Lat. III, 132 (2151), bk VII, fols. 143v–144r, discussed in Bigotti, "Weight of the Air," 79–80.

39 See Bigotti, "Weight of the Air."

on the water level in the thermometer more visible.[40] The use of a graduated scale to measure the temperature is also confirmed. Most important, however, is Bonomo's revelation that the water levels in the engraving refer to the temperature of the summer and winter seasons, which sheds light on Santorio's 1626 engraving as well as on a similar print in the 1625 edition of the *Commentary on Avicenna's Canon*, where the different water levels are marked on the straw by using ribbons (see Fig. 7).

FIGURE 7
Santorio's closed-loop thermometer with ribbons marking the difference in the median temperature between summer and winter seasons. From Santorio Santori, *Commentaria in primam Fen primi libri Canonis Avicennae* (Venice, 1625), col. 30

40 Santorio, *Commentaria in primam Fen* (1625), col. 306: "[…] ut aqua vero nobis clarior appareat, viridis efficiatur."

Another very valuable piece of information provided by Bonomo is the overall dimensions of the instrument, which seems to have been quite large, about two Venetian fathoms tall (*due braccia incirca*), which corresponds to about 136 cm in modern standard measurements.[41] The length is twice that given by Obizzi in 1617, which refers to one Venetian fathom (*cubiti unius*), or about 68.3 cm. Such a discrepancy is easily explained by the fact that Santorio created thermometers of different sizes and shapes, the smaller ones probably intended to be portable and used at the bedside. The bulkiest, such as those described by Bonomo, were designed to measure changes in room temperature or body temperature by using a hand, as shown in Fig. 8. An experiment of this type, which disproved Galen's statement that children and adults have different bodily temperatures, was described by Santorio in 1625. The experiment consisted of an adult and a child touching the upper bulb of a thermometer for an equal amount of time to see if they had the same temperature, which they did.[42]

By far the most important information that Bonomo gives us, however, is that relating to the use of the thermometer, which is complemented by that of the hygrometer. The thermometer not only measures the temperature of a room or a part of the human body, it also tells doctors how to intervene in order to restore the correct temperature in both. This account also explains the purpose of instruments such as the humidifier, which was used to cool down an overheated room, and which Santorio first described in 1612 and then engraved in 1625.[43] A copy of the *Commentary on Avicenna's Canon* in the British Library, with Santorio's handwritten marginal notes, shows the changes and additions the Venetian physician wished to make for a future edition of his work.[44] One of these, on col. 406C–D, shows that Santorio intended to integrate part of his earlier description of the humidifier into the main body of the text (see Fig. 9). The intent was to prove Galen wrong in his belief that a physician could not modify the air and thereby control the environmental factors affecting health.

41 I take the term *braccio* to refer to the Venetian *braccio da lana*, which was the most common measure in use at the time. If, instead, we assume that the fathoms refer to the *braccio da seta* (= 63.8 cm), as in the case of the pulsilogium, then the linear dimension of the instrument is about ten centimetres shorter (= 127.6 cm).

42 Santorio, *Commentaria in primam Fen* (1625), col. 357B–D.

43 For the original description, see Santorio, *Commentaria in Artem medicinalem*, III, col. 59C–D.

44 Copy Shelf-mark: Sloane 542H11, British Library London, transcribed and discussed in 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 (2017), 29–42.

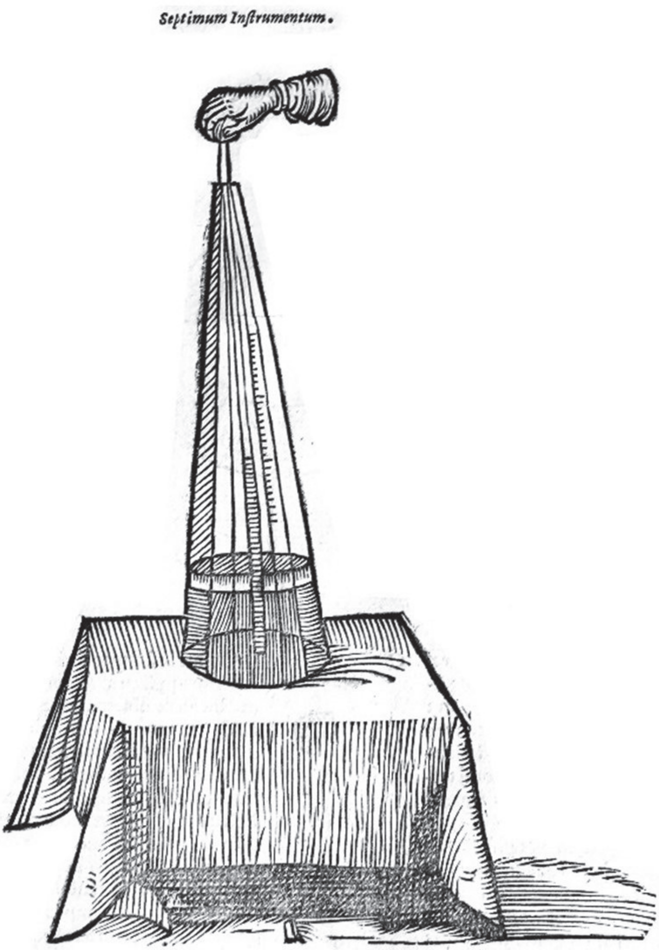

FIGURE 8 Santorio's hand thermometer, from Santorio Santori, *Commentaria in primam Fen primi libri Canonis Avicennae* (Venice, 1625), coll. 311–312

In short, Bonomo's account shows that Santorio's instruments were intended not only to measure the environmental factors that could interfere with the body's normal homeostatic activity but also to control them.

We may observe a similarly normative approach in Bonomo's description of the pulsilogium, which is the first of its kind; unlike the thermometer, neither Santorio nor any of his disciples had ever described the instrument's operation in detail before 1625. Bonomo's description is clearer than the one Santorio himself would later provide, but for the rest, it is essentially the same, except for the dimensions of the silk wire, which is said to be about half a Venetian fathom (*un filo di seta di mezzo braccio circa*). If we take the fathom

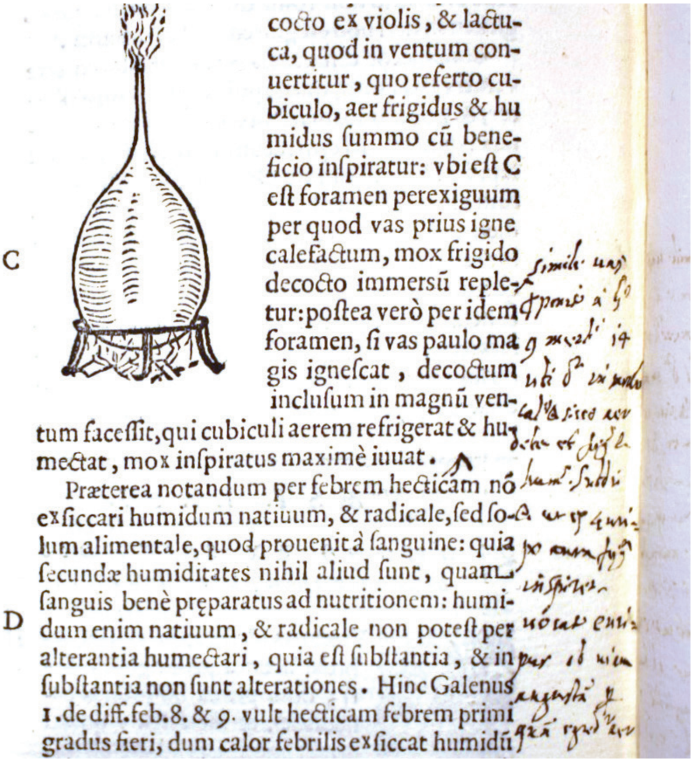
coćto ex violis, & lactu-
ca, quod in ventum con-
uertitur, quo referto cu-
biculo, aer frigidus & hu
midus ſummo cũ bene-
ficio inſpiratur: vbi eſt C
eſt foramen perexiguum
per quod vas prius igne
C calefactum, mox frigido
decocto immerſũ reple-
tur: poſtea verò per idem
foramen, ſi vas paulo ma
gis igneſcat, decoctum
incluſum in magnũ ven-
tum faceſſit, qui cubiculi aerem refrigerat & hu-
mectat, mox inſpiratus maximè iuuat.
Præterea notandum per febrem hecticam nõ
exſiccari humidum natiuum, & radicale, ſed ſo-
lum alimentale, quod prouenit à ſanguine: quia
ſecundæ humiditates nihil aliud ſunt, quam
ſanguis benè pręparatus ad nutritionem: humi-
D dum enim natiuum, & radicale non poteſt per
alterantia humectari, quia eſt ſubſtantia, & in
ſubſtantia non ſunt alterationes. Hinc Galenus
1. de diff. feb. 8. & 9. vult hecticam febrem primi
gradus fieri, dum calor febrilis exſiccat humidũ

FIGURE 9 Marginal added by Santorio in a copy of the 1625 edition of the *Commentaria in primam Fen primi libri Canonis Avicennae* (British Library, London, shelf-mark: Sloane 542H11), in which he engraved the air humidifier (col. 406) integrating an earlier description of the same device given in 1612 (III, 59C–D)
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as a Venetian silk fathom, i.e., 63.8 cm, the total length of the wire is 31.9 cm. Bonomo is clearly referring to the very first prototype developed by Santorio (type A1 in the Bigotti–Taylor classification), which is different and considerably shorter than the one David Taylor and I have calculated for our replica of the pulsilogium (type A2 = 64.3 cm).[45] Again, this early prototype may refer to a short and portable version of the bedside instrument, similar to the one developed by Marek Marci in 1639.[46] In fact, Santorio himself was to reveal in

45 Bigotti and Taylor, "Pulsilogium of Santorio," 82–83.
46 See Jan Marek Marci, *De proportione motuum* (Prague, 1639), as discussed and analysed in Bigotti and Taylor, "Pulsilogium of Santorio," 66–67.

1612 that he did indeed use the instruments on patients with whom he was unfamiliar:

> 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 <from the natural state> and the dose of the remedy can be by using the four instruments I mentioned before (i.e., pulsilogium, thermometer, hygrometer and weighing chair).[47]

This quotation is brief but historically invaluable, for it is the first description of the application of early modern precision instruments at the bedside. The instruments were taken to patients to determine whether they were healthy or sick in relation to a predetermined parameter, which allowed the instruments to measure the severity of the patient's condition. This parameter had previously been measured on healthy men so that the instruments could reveal, by difference, how unequal/unbalanced a person's constitution actually was. One example, given a detailed description by Bonomo, concerns the use of the pulsilogium:

> One of the most important things to know, if one continues in a state of perfect health, is to observe the liveliness (*gagliardezza*), and particularly the alteration of one's natural pulse, all the more so in time of illness to know the difference. The habit of the natural pulse is to make its beat slowly and in time in the likeness of the beat of the musician, some more and some less often, according to nature and temperament. Therefore, in order for one to know minutely his natural pulse, as well as every minimum variation of it in greater or lesser frequency, take a silk thread of about half an arm's length, and attach a lead ball to one end of it. While

47 Santorio, *Commentaria in Artem medicinalem Galeni* (1612), 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 [i.e., pulsilogium, thermometer, hygrometer, medical statics] 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." This is quoted and discussed in Bigotti, "Weight of the Air," 96–97.

you are moving the ball, holding the thread suspended with your hand, you will imitate the manner of the pulse, because if you lengthen the thread, the ball will beat late; and if the string is shortened, the ball will make a frequent beat, both if it moves strongly and if it moves slowly, because the less space it occupies, the less violently it moves. And so, by lengthening or shortening the string, the ball in motion will make a slower or faster beat, until it is reduced to a motion equal to our pulse. Thus, if we wish to measure the beat of our pulse, which we find ourselves to have when we are in perfect health and temperament, we will gradually lengthen or shorten the aforesaid string, while <still> keeping the ball in motion and <at the same time> touching the wrist. And thus, if we find that the ball strikes earlier than the beat of the pulse, we will gradually lengthen the string until the ball and pulse strikes are brought together. If, on the other hand, the ball strikes later than the stroke of the pulse, the thread is gradually shortened until the stroke of the ball matches the stroke of the pulse. At the moment when the centre and end of the perpendicular motion of the ball matches that of the pulse, a mark or knot will be made at the upper end of the thread, and in this or a similar way we observe the degree to which this measurement corresponds. And so, if our temperament changes with the passage of time, as in the case of a greater degree of heat, we will find, after observing the said measurement, that the beat of the pulse will be made faster than the beat of the ball suspended at the mark of the degree previously observed, for which reason we will know that, in order to return to the natural and usual temperature, our government (*il governo*) must consist in the use of refreshing foods, in quietness of body and mind, and in rest.[48]

48 Bonomo, *Discorso*, 30–32: “Una delle cose importanti per saper, se si continua nello stato di perfetta sanità sarà di osservar la gagliardezza, e particolarmente l’alteratione del suo proprio polso naturale, tanto più per saper in tempo di malattia conoscer la differenza. Il solito del polso naturale è di batter la sua battuta lentamente, e a tempo a similitudine della battuta de i musici, in chi più, e in chi manco spesso, secondo le nature, e temperamenti. Per conoscer adunque minutamente cosi il suo polso naturale, come anco ogni minima mutatione di esso in maggior, o minor frequenza, si pigli un filo di seta di mezzo braccio in circa, e se gli attacchi à una parte una balla di piombo, e cosi mentre si anderà movendo detta balla, con tener suspeso il detto filo con la mano, si verrà à imitare il moto del polso, perche se si prolonga il filo, la balla fà la battuta tarda; e se si abbrevia il filo, la balla fà la battuta frequente, tanto se si move fortemente, quanto se si move piano, perche quanto manco spatio và occupando, tanto manco violentemente si và movendo; e cosi con andar allongando, ò abbreviando detto filo, la balla stando in moto verrà à far la

The last two sentences give us a fuller sense of how precision instruments were used in tandem. They were meant to track changes in body temperature, pulse or weight as co-dependent factors. For example, irregular weight loss could be caused not only by irregularities in diet but also by excessive perspiration, which in turn could be due to environmental causes, such as changes in room temperature or humidity, or internal changes, such as fever or accelerated pulse due to immoderate exercise or rest. Equally, an accelerated pulse could be explained by irregularities in diet or as a response to changes in environmental factors. These had already been shown by Galen to be co-dependent factors (*sex res non naturales*), and early modern physicians were trained to take them into account jointly in order to give an indication of the patient's condition. As described by Bonomo, the instruments supplement the traditional rationale underlying humoral pathology by turning these factors into co-dependent *variables* that could be measured.

As previously in the case of the weighing chair, Bonomo explains that there are alternative and simpler ways of measuring the pulse if one finds it strange (*strano*) to use the pulsilogium, the most common alternative method being to count the numbers between one beat and the next as quickly as possible.[49] Most importantly, however, his account shows that faster and slower pulses can be represented on the pulsilogium as segments of different lengths, which

battuta più tarda, ò più presta, fin che si ridurrà ad un moto uguale al nostro polso. Si che volendo misurare la battuta del nostro polso, che ci ritroviamo havere, mentre siamo in perfetta sanità, e di perfetto temperamento, s'anderà à poco à poco allongando, ò abbreviando il detto filo con tener in moto la balla, e con tenersi toccato il polso, e cosi se ritroveremo, che la balla batta più presto della battuta del polso, s'anderà allongando il filo à poco a poco fin che le battute della balla e del polso si vengano ad agguagliare. Parimente se al contrario la balla batte più tardi della battuta del polso, s'anderà abbreviando il filo à poco à poco, fin che la battuta della balla si confronterà à tempo con la battuta del nostro polso, e all'hora si farà un segno, ò nodo in quella estremità del filo superiore, che si sarà *abbattuta* [= '*a battuta*,' i.e., to go in time with the pulse] esser il centro, e termine del moto perpendiculare della balla; con osservare à che grado vien ad arrivar la misura in questa, ò simil forma. Et cosi se in progresso di tempo s'anderà mutando il nostro temperamento, come in calidità maggiore, osservata detta misura, ritroveremo, che la battuta del polso sarà fatta più presta della battuta della balla suspesa al segno del grado osservato di prima, per la qual causa sapremo, che per ridursi alla temperatura naturale, e consueta doverà il governo nostro consister in usar cibi refrescativi, con la quiete del corpo, e dell'animo, e con il riposo." (Italics added.)

49 Ibid., 31: "Et à chi pare tal'istrumento strano, può più facilmente osservar con la mente, quanti numeri si può raccontare più presto, che sia possibile trà una battuta, e l'altra del polso naturale, che cosi quanto più il polso sarà frequente, tanto manco numeri si potrano raccontare."

brings me to final point of this paper, the theory underpinning the beginnings of medical quantitative experimentation.

4 Visualising and Measuring Intensity in Sixteenth-Century Medicine

This innovative medical experimentation relied in fact on the idea that natural phenomena were subject to variations in intensity which, as extending in time and space, could be represented as a latitude (*latitudo*).[50] In Galenic medicine, health and disease have a spectrum of intensity that can be measured in terms of segment lengths (*latitudo sanitatis, neutralitatis, morbi*).[51] The greater the distance from the point of equilibrium/health, the worse the condition of the patient. Visual applications of this concept in the sixteenth century can be seen in the work of Alessandro Piccolomini (1508–1578) *Della filosofia naturale* (Venice 1585) and, most importantly, Benedetto Vittori da Faenza (1481–1561), whose *Theorica latitudinum* (Florence 1551) epitomised almost three centuries of philosophical debate on intensity and its implications in medicine.[52]

Vittori visualises the latitude of health and disease through a series of diagrams representing intensity as a pyramid. As Vittori makes clear, the pyramid is made up of two right-angled triangles with a common cathetus that coincides with the line of perfect health, the so-called *sanitas punctualis*, i.e., the highest possible degree of intensity and health in one's constitution. Any deviation from this point represents a fall (*lapsus*) from the perfect state, which can fall either towards the hot or the cold spectrum (*constitutio lapsa per calidum seu figidum*). The greater the distance from the centre, the greater the decline in health (see Fig. 10).

50 Bonomo uses the expression "latitudine della quantità" (*Discorso*, 21) with reference to the statical experiments. This is similar to Santorio's "latitudo ponderis" (*Medicina statica*, I. 43, 14r) but is even closer to Galileo's expression in his *Iuvenilia* (for instance, in the *Quaestio ultima de partibus sive de gradibus qualitatis*) which is "latitudo quantitatis." For Piccolomini's use of diagrams of intensity, see Bigotti, "Weight of the Air," 95.

51 On the visualisation of intensity in medicine, see Ian Maclean, "Diagrams in the Defence of Galen: Medical Uses of Tables, Squares, Dichotomies, Wheels, and Latitudes, 1480–1574" in *Transmitting Knowledge: Words, Images, and Instruments in Early Modern Europe*, ed. Sachiko Kusukawa and Ian Maclean (Oxford, 2006), 136–164; Joel Kaye, *A History of Balance, 1250–1375: The Emergence of a New Model of Equilibrium and its Impact on Medieval Thought* (Oxford, 2014), 202–227; Bigotti, *Physiology of the Soul*, 226–238 and idem, "*Gradus Dimetiri*: Intensity of Complexions in 14th-Century Italian Medicine," *Annals of Science*, 4/79 (2022), 1–22.

52 Note that Vittori's work was first published as *Opus theorice latitudinum medicine ad libros Tegni Galeni* (Bologna, 1516).

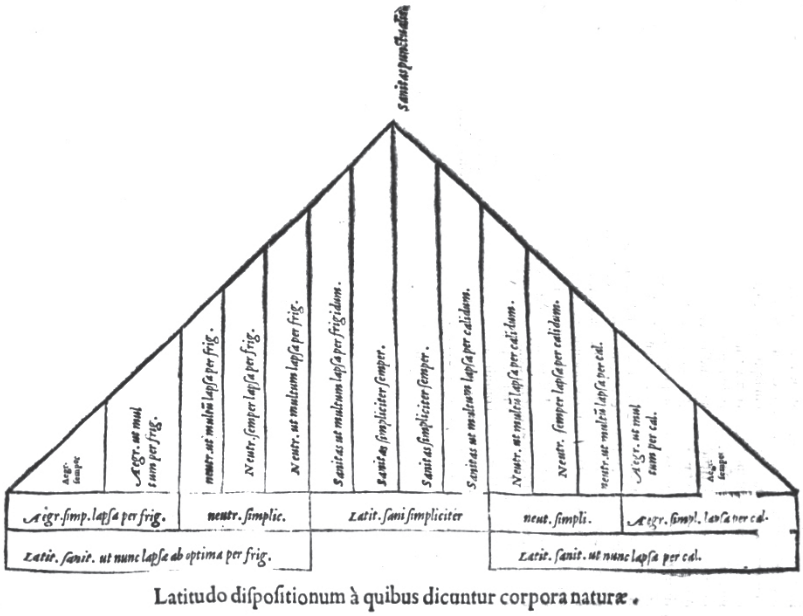

FIGURE 10 Benedetto Vittori's visualisation of the "latitude of health" (*latitudo sanitatis*). The pyramidal diagram shows the intensification of health and disease *uniformiter difformis*, that is as a constant decrease or increase in the strength of a given disposition in time. From Benedetto Vittori da Faenza, *In Hippocratis Prognostica Commentarii. His accessit Theorica latitudinum medicinae liber* (Florence, 1551), 201

The operationalisation of this concept is evident in the case of thermometers, pulsimeters and hygrometers. The indications they provide, in fact, are read by means of a graded bar of either linear or circular shape: the higher/lower a temperature, the faster/slower a pulse, the drier/the wetter a weather condition will be, the more it will approach one or the other extreme of the graded segment.

The question is slightly more complicated in the case of scales. Let us consider, for example, the movement of an equal-armed scale deflected from its point of equilibrium (see Fig. 11). On a linear plane, this scale will project segments that are all the shorter in proportion to the intensity of the force applied to move it from its point of equilibrium. The result is therefore the opposite of what we would expect.

It is therefore quite significant that Santorio did not carry out his medical experiments on an equal-arm balance, but on a steelyard. In the steelyard, the point of equilibrium is offset and one arm is longer than the other. Projected on a linear plane, its movement produces segments that are longer in proportion

EQUAL ARM SCALE

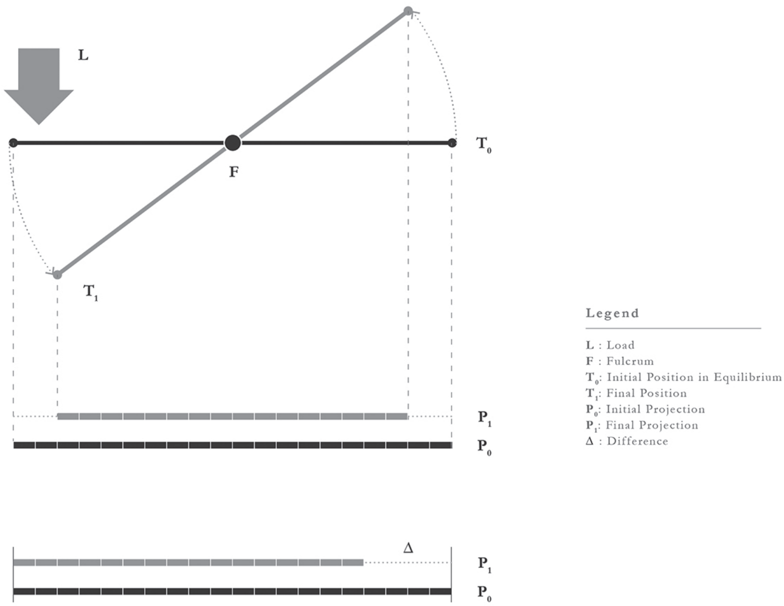

FIGURE 11 Motion of an equal-arm scale projected on a linear plane

to the force required to restore equilibrium, with the weight on the longer arm moving progressively towards its end (Fig. 12).

Since Santorio associated an abnormal increase in weight with the onset of a latent disease, it is clear that, even in the case of the weighing chair, larger segments correspond to an increase in weight and hence to a more severe condition.[53] In this sense, all of Santorio's quantification instruments can be understood as intensity meters: they quantify the severity of a disease (*magnitudo morbi*, *quantum morborum*) by tracking the variation in the intensity of qualities (heat/cold, humidity/dryness, weight/lightness).

Their invention stemmed from a pressing concern of the time: the unreliability of medical diagnosis. In Galenic medicine, diagnosis is based on symptoms which become manifest when a vital function is impaired (*ex laesis*

53 It is worth noting that the use of the steelyard was also motivated by practical reasons: the aim of Santorio's experiments is to show that the body has the capacity to return to the same weight every day, unless prevented by the onset of a latent disease. Since he was conducting long-term experiments on the same person (himself), he had little need to change the position of the weight and thus to use an equal-arm scale.

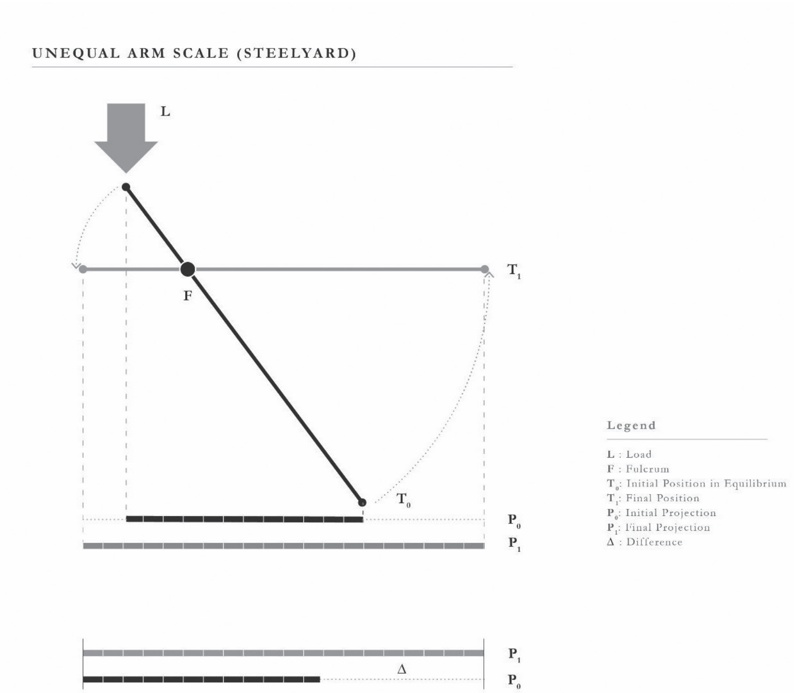

FIGURE 12 Motion of an unequal-arm scale (steelyard) projected on a linear plane

officiis). Because health and disease vary over a range, their gradual change is imperceptible (*lapsus est insensibilis, insensibiliter laeduntur operationes*) and remains latent (*occultus*), rendering doctors' diagnoses conjectural (*per coniecturam*) and remedies ineffective.[54] By detecting the very small and imperceptible changes in a patient's condition, which could lead to the onset of a disease, the invention of early modern precision instruments addressed this

54 The terminology *lapsus insensibilis*, *insensibiliter laedi* and similar terms was standard in medicine at the time, especially in relation to diagnosis and prognosis. For more explicit references to the connection between diagnosis and the impairment of vital functions, see Benedetto Vittori da Faenza, *Theorica latitudinum medicinae* in *In Hippocratis Prognostica Commentarii. His accessit Theorica latitudinum medicinae liber* (Florence, 1551), 192, 231, 241. On the connection between the insensible impairment of vital functions and the certainty provided by the measurement of insensible perspiration, see Santorio, *Medicina statica* (1614), I.42, c. 10r: "Prima morborum semina tutius cognoscuntur ex alteratione insolitae perspirationis, quam ex laesis officiis." The fact that diagnosis without the aid of the new instrument remains conjectural is again emphasised by Santorio in Santorio, *Commentaria in primam Fen* (1625), Quaestio VI: "Qua ratione ars medica sit coniecturalis," coll. 21–24.

very need. They magnified and made visible (*sensibilis*, *manifestus*) the transition from health to disease, and vice versa, therefore granting certainty to diagnosis. Conceptually, the focus shifted from viewing disease as a qualitative state, unique to each individual, to understanding disease as a force (*potentia*) that acts upon the body with a measurable magnitude (*quantum morborum*). To obtain a measure of this force, diseases are first conceptualised as distances from the healthy condition (*recessus*, *latitudines*) and then spatialised into segments, which are measured in degrees, providing an indication of how severe the disease is. A continuous magnitude, like the segment corresponding to the latitude of health, is thus converted into a discrete one, being the series of degrees as units of equal value. Similarly to mathematical analysis (*resolutio*), precision involves resolution or fine-graining, entailing the pursuit of division down to its ultimate elements (*possumus dimetiri ultimos gradus recessus*) in phenomena that are essential to grasp but elude human perception (*imperceptibilia*, *insensibilia*).[55] As the load shifts over the steelyard graded bar, marking the intensification of the force with which the disease acts on the body, degrees cease to refer to ideal mathematical proportions and turn into scruples and ounces providing an exact measurement of the phenomenon under scrutiny.

In light of this, we can do justice to Santorio's claim that his instruments, and especially his "medical statics" (*medicina statica*), can be described as "medical mathematics" (*mathematica medica*), and understand why documents such as Bonomo's are so important: they allow us to better understand how theories of intensity were embedded in early modern instrument making.[56] Perhaps more importantly, they now allow us to reconstruct some of these instruments with historical accuracy, while at the same time shedding light on their use in everyday practice. Long regarded as mere measuring devices, these instruments actually had a normative application in everyday life and established an experimental agenda that extended beyond the medical field to become a benchmark of early modern scientific development.

55 Santorio, *Commentaria in primam sectionem* (1629), 24. For the term "*imperceptibilia*," see ibid., 70–71. The term is often replaced by *insensibilia* as, e.g., in *Medicina statica* (1614), I.2, 1v.

56 Santorio Santori to Senatore Settala, Venice, 27 December 1625, ASM, Autografi 218, c. 1r: "Di piu vedra spesse li benefitij che cavar si puo dal uso della statica inve[n]tata da me *laqual certo si puo chiamar mathematica medica tanto ci fa certi nelle case di med*[*icin*]*a*" (italics added); and similarly, Santorio, *Commentaria in primam sectionem* (1629), 71: "[…] qua adeo certa sunt [scil. experimenta statica], ut contineant certitudinem mathematicam." See also Bigotti, "Gears of an Inner Clock," 86–87.

Acknowledgements

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