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MATHEMATICA MEDICA. Santorio and the Quest for Certainty in Medicine

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Abstract

Along with mechanics and astronomy, medicine played an important role at the beginning of the sixteenth century in the process that led to a new understanding of measurement and its importance for the progress of knowledge. A pivotal figure in this sense can be considered the Italian physician Santorio Santori (1561-1636) who, with his work *Ars de statica medicina* (Venice 1614), originated an entire path of experimental procedure across the Europe. Santorio was quite aware of the modern idea of experimentation as he experimented daily for over twenty five years. For the sake of scientific certainty, he felt also the need to devise and construct new instruments, such as the 'weighing chair' (*statera medica*), the hygrometer, the first graded thermometer, and the 'pulsilogium' (an early pulsimeter). Through these devices he managed to assess each of the many parameters involved in the complex calculation of the *perspiratio insensibilis* (insensible perspiration of the body). Relying on his quantitative experiences, Santorio envisaged the body as a clockwork, and explored its main functions by means of mathematical parameters (numero, pondere et mensura). As part of a major international project devoted to investigating the *Emergence of Quantifying Procedures in Medicine at the End of the Renaissance*, funded in 2015 by the Wellcome Trust and hosted by the Centre for Medical History (CHM) of the University of Exeter, this paper explores some aspects of the legacy of the Italian scientist.

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Introduction

> I send to His Lordship the two books on the Avicenna's text and I pray His Lordship to read them carefully, because He will read new thoughts, yet based on the authorities of Hippocrates and Galen, as far as both practice and experience are concerned. [...] All the more, HL will see the advantage that is possible to glean from the use of the statics I invented and that, for sure, is possible to call 'medical mathematics' (*mathematica medica*) so much we gain in certainty regarding medical things[1].

With these very words, extracted from a letter addressed in the 27th of December 1625 to his friend Senatore Settala, the Italian physician Santorio Santorio described not only his two major works, *the Commentaria in Primam Fen Primi libri Canonis Avicennae* (Venice 1625) and the celebrated *Ars de statica medicina* (Venice 1614), but also his scientific legacy. While showing respect to the traditional physiology, this legacy develops new ideas aiming to grant certainty to the practice of medicine by means of the use of mathematics.

Santorio's Life and Scientific Legacy

Santorio Santori – this the real name in written documents – was born in Capodistria, today Koper in Slovenia, in 1561. Capodistria was then under the protection of the Serenissima Republic of Venice where Santorio went to study under the guidance of the Morosini family. In 1575, he undertook the study of medicine and mathematics in Padua, where he finally got a degree, between 1582/83. After this date he is supposed to have started his statics experiments on the weight of the so-called *perspiratio insensibilis* (1590). Hereafter he spent also some period travelling in the Venetian dominion and East Europe as a physician: surely he visited Carlstadt (Karlovac) in Croatia, where he tells us he conducted other experiments in order to measure the *impetus* of

1 Mando a V. S. li 2 libri sopra la parte di Avicenna et prego V. S. che li lega con diligenza perché legerà pensieri nuovi fondati però sull'autorità di Hippocrate et Galeno, nella pratica et nell'esperienza. [...] Di più vedrà spesso li benefitij che cavar si può dal uso della statica inventata da me la qual certo si può chiamar mathematica medica tanto si fa certi nelle cose di medicina»; Letter addressed by Santorio Santorio to Senatore Settala, 27 Dicembre 1625, in CASTELLANI 1958, p. 5.

flowing water or wind, and he also went to Poland possibly at the court to Sigismund III Vasa. In 1611 he was appointed professor of theoretical medicine at the University of Padua (*ad theoricam ordinariam primo loco profitensis*), where he would taught until 1624, finally retiring from teaching in order to practice medicine in Venice, where he eventually died in 1636 **(Figure 1)**.

Considered until the eighteenth century one of the most important physicians of modern medicine, his reputation was so related to the centrality of the so-called *perspiratio insensibilis* for health, that, when this process began to be regarded as more peripheral in the economy of life, so did Santorio's scientific legacy. Today he is quite a forgotten figure in the major books of history of science and very few scholars recognize him except as the inventor of the thermometer. In the past, however, physicians like Martin Lister (1639-1712) and Giorgio Baglivi (1668-1707) could consider medical statics as one of the two pillars of modern medicine – along with Harvey's discovery of the circulation of blood – widely commending Santorio's methods, but in the late nineteenth century those methods suffered some criticism.

Considering qualitative experimentation the main way to evaluate biological processes, the French physiologist Claude Bernard (1813-1878) disparaged statics experiments by claiming that the use of such a method was like 'attempting to give an account of what passes through a house, by evaluating what pass by the door and exit by the chimney'[2]. More recently, however, Santorio's contribution has been revalued both in scientific and historical terms. 1st October 1931, the *Journal of Clinical Investigation* of America published an extensive article by Newburgh, Wiley and Lashmet which described how matter of perspiration could be used for a scientific account of the total and basal metabolism[3], re-employing and perfecting the same method already used by Santorio three hundred years before. Also medical historians changed their mind, for example the American historian Lois N. Magner who revised her judgment about Santorio between the first and the second editions of her *A history of medicine* (1992), finally claiming that:

> Santorio did not reject the legacy of Hippocrates and Galen, but he was a champion of scientific medicine and an opponent of the superstitious, mystical, and astrological influences so common in his era. The spirit of invention was marvellously developed in this physician, even if his results were not commensurate with the painstaking nature of his investigations[4].

Further to these brief considerations it should be added that no recent studies have been made on Santorio's life and work. Above all, it seems that his scientific ideas need to be studied afresh by taking into consideration his historical background as well as his results. In this paper I would like to start by giving a framework of Santorio's work by bearing in mind the particular place he holds in the history of ideas as a leading figure between two centuries.

Figure 1 Santorio Santori.

Santorio's Method

Santorio was one of the few sixteenth-century physicians to be fully aware of the modern idea of experimentation. He conducted many experiments on insensible perspiration for over thirty years, and he was also aware of the importance of quantification in medicine, for the sake of which he personally invented several instruments. These aspects of his scientific personality are well reflected in his works.

Santorio's output occupies four volumes of an edition in 4° (*in quarto*) published in Venice in 1660 by Francesco Brogiolo, which also hosts his only known portrait. The first volume contains the 'Commentary on Galen's Medical Art' (*Commentaria in Artem medicinalem Galeni*); the second the 'Method to avoid all errors that happen in medical art', in fifteen books (*Methodi vitandorum errorum omnium*, *qui in arte medica contingunt libri quindecim*), the third the 'Commentary on the first Fen of the first book of Avicenna's Canon' (*Commentaria in primam Fen primi libri Canonis Avicennae*); the fourth and last the 'Commentary on the first section of Hippocrates aphorisms' (*Commentaria in primam sectionem Aphorismorum Hippocratis*), the 'Invention of cures' (*De remediorum inventione*) and the 'Medical statics' (*Ars de statica medicina*). The progression does not reflect any chronological need but it is intended for didactical purposes, from the more conventional to the most innovative works. Indeed, the first book published by Santorio was the *Methodi vitandorum errorum omnium* (Venice 1602, *apud societatem*), a work that

[2] Bernard 1912, p. 207.
[3] Newburgh, Wiley, Lashmet 1931.
[4] Magner 1992, pp. 213.

could be easily regarded as a methodological introduction to his thought and that also allows us to look closer to his background, as it shows his studies as well as his scientific commitment. As the title declares, the book would present a method to avoid all errors that happen in medical practice by focusing on experience, analogy and deduction. The work is also clearly reminiscent of the influence of Jacopo Zabarella (1533-1589), Santorio's teacher in Padua and one of the most important logicians of the XVI century, celebrated author of the *Opera logica* (Venice 1578) whose sections show a particular emphasis for methodological questions. But Santorio will rely also on another work of Zabarella, the *De naturalibus rebus libri XXX* (published in Venice in 1590), as far, at least, as it concerns his notions of physiological optics. The *Methodus vitandorum errorum omnium...libri XV* is also important as it testifies early interest by Santorio for quantification, especially as far as it regards mixtures (book VII, chap. 9) and quantification of drugs (Book XIII, chap. 1-2) as well as for the description of an instrument of precision, the so called *pulsilogium*, or pulsimeter, which the author claimed to have invented:

> It happens sometimes that a physician find the pulse of a healthy man to such an extent anomalous, irregular and in other terrible conditions that the doctor who in the understanding and treatment does not touch and does not observe other things, behaves like a blind person: it is therefore important to observe mainly the motion [of the arteries] always in healthy men, because in the state of disease we can measure (*metiri*) much better the speed and the others conditions of the pulse and we can get a certain knowledge (*certo scire possemus*) of how much (*quantum*) it differs from the natural state, we can also observe all proportions and, whether present, even measure the irregularities and many other factors pertaining to the motion [of the arteries]. Now, for the sake of the exact knowledge [of the motion] and its quick comparison (*pro qua cognitione exacte, et cito comparanda*) I invented an instrument called 'pulsilogium' in which everyone can measure, observe and firmly remember with absolute certainty the motion and the stasis of the arteries, and then to compare them with the pulse of previous days. Indeed, the instrument shows all the differences of the movements that mount to one hundred thirty-three, starting from the observation of slowest pulse up to the fastest. In fact, the reason why these [movements] are not more than those I mentioned, I will display – with the favour of God – in my book Medical instruments not previously seen[5].

The last entry is actually a reference to the *De instrumentis medicis non amplius visis* a book that Santorio actually never published, even though the manuscript of it was still probably in his hands in 1625, when he refers to it as about to be published in the already mentioned letter to Senatore Settala[6]. The quote, instead, is taken from the chapter seven of the fifth book of the *Methodus vitandorum*, and it stresses two main aspects of Santorio's method, namely the centrality of quantification (expressed by the use of verbs like *metior* – *dimetior*) and the quest for certainty, achieved by inventing precision instruments.

Galileo and Santorio on the Discovery of 'Pulsilogium' and 'Thermometer'

As far as the pulsilogium is concerned, there still is a controversy whether has been invented by Galileo or by Santorio. The pulsilogium, later described widely in his 'Commentary to Avicenna's Canon', consists of a pendulum suspended on an adjustable wire (made of flax or silk), whose lead ball oscillates over a graded bar. The ball bears on the middle axle a white line which indicates the frequency of the pulse. Santorio suggests that the physician should compare the frequency of the pulse with that of the pendulum in order to find the exact match between the two. The controversy arises from the fact that, according to Galileo's first biographer Vincenzo Viviani (1622-1703)[7], Galileo already knew the isochronisms of the pendulum and the so-called 'law of the wire' (according to which the period of the pendulum depends on the square root of the wire) when he started his teaching at the University of Pisa, which means in the period between 1589 and 1591. But Galileo seemed not have seriously considered the property of the pendulum until November 1602 when, in a famous letter addressed to Guidobaldo del Monte (1545-1607), he said he was studying a possible proof for the isochronism of pendulum in correlation to the law of chords. It was the same year in which Santorio is supposed to have published his *Methodus vitandorum*, providing the earliest known description of such an instrument.

Antonio Favaro and other Galileo's scholars have argued that Santorio embezzled the results of the Pisan astronomer. As far as I can say hitherto, it is possible that Santorio and Galileo worked independently on the same subject and with a very different purpose. According to Viviani's account, Galileo discovered the isochronism of pendulum by comparing it with his pulse; Santorio, conversely, implied the pendulum as a precision instrument to evaluate the pulse and, in so doing, he converted the *explanandum* into the *explanans*.

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[5] SANTORIO 1631, Lib. V cap. 7, p. 289: [...] Solet enim medicus aliquando invenire pulsum sani hominis adeo inequalem, intermittentem, et aliis deterrimis conditionibus donatum, ut Medicus, qui alias non tetigerit, et observaverit, in cognitione et curatione, caeorum more incedat: esset igitur operae pretium in sanis hominibus semper motum praecipue observare, quia in aegritudine longe melius crebritatem pulsus, et caeteras conditiones metiri, et certo scire possemus, quantum recedant a naturali statu, possemusque omnes proportiones observare, et intermittentiam, si adest, dimetiri, et plura alia ad motum pertinentia: pro qua cognitione exacte, et cito comparanda instrumentum pulsilogium invenimus in quo motus, et quietes arteriae quisque poterit exactissime dimetiri, obervare, et firma memoria tenere, et inde collationem facere cum pulsibus praeteritarum dierum; exhibet enim instrumentum omnes aequalium motuum differentias, quae sunt centum et triginta tres incipiendo ab observatione rarrissimi motus usque ad creberrimum; cur autem non sint plures, in proprio libro de instrumentis medicis non amplius visis Deo favente declarabitur [...].

[6] CASTELLANI 1958, p. 7: Manderò poi fare un libro de instrumenti medici dove si conterranno tutte le mie invenzioni che non sarà per altro fine che per dichiararli al mondo che già mi veggio vecchio di 64 anni ma per la gratia di Dio molto prosperoso.

[7] Viviani 1968, pp. 597-632

Scholars of early modern mechanics, such as Wolfgang Lefèvre and Jochen Büttner have recently claimed that a reassessment of the historical evidence indicates that the pulsilogium mentioned by Santorio was not an invention by but rather a source of inspiration for Galileo[8]. Moreover, Büttner advances as proofs the fact that already Leonardo da Vinci (1452-1519) studied the property of the pendulum in the Codex Madrid I (ff. 147, 182-183) meaning to use it as a regulator of clockwork. He also maintains that some pendulum clocks were already been made in 1580s in Osnabruck in Germany by a certain Jost Bodeker and, probably even earlier, by Benvenuto della Volpaia (1486-1533) in Italy[9]. If so, the pendulum could have been applied to the mechanism of clock, long before than Galileo started to think to it, and Santorio could have seen such an application, or even had some news of it, given the relationship between Padua and the so called Natio Germanica, which was a large delegation of German students at the University. Providing further evidence for his claim, Lefèvre shows some examples of the application of the pendulum before Galileo, taken from the *Theatrum instrumentorum et machinarum* by Jacques Besson (c. 1540 – 1573), a work originally published in Latin in 1578 but later translated also into Italian in 1582. Though being friends, neither Galileo nor Santorio ever discussed the priority of their invention, so Viviani seems to be the only source to have raised such an argument. There was a similar controversy among historians regarding the invention of thermometer, today undoubtedly attributed to Santorio, who described it the *Commentaria in Artem medicinalem Galeni* published in Venice 1612: while Galileo's thermoscopy shows only the increase and the decrease of temperature, Santorio's thermometer indicates exactly the degree of it[10]. Both authors, however, are relying on a principle content in the book *Pneumatica* by Heron of Alexandria (c.10 - c.70 AD) which had already been translated into Latin by Federico Comandino in 1575[11].

Leaving aside for the moment the question of the priority of invention between Galileo and Santorio, I would like to consider the real core of Santorio's method, which is the concept of quantification.

Santorio's Idea about Quantification

Quantification seems to have been considered by Santorio in three main ways:

- as measurement of a physiological process through definite parameters;
- as designing and manufacturing of devices to use in order to guarantee certainty in measurement;
- as a repeated and controlled experimentation.

In keeping with traditional physiology, Santorio was interested in assessing three main phenomena: *perspiratio insensibilis*, pulse and fever. For each of them he adopted precise parameters, namely the change in weight for insensible perspiration; degrees of heat for fever and frequency for pulse. To measure each of these parameters he invented instruments of precision, such as the statera medica, thermometers, hygrometers and several types of pulsilogium. In the *quaestio sexta* of his 'Commentary on Avicenna's Canon', Santorio introduced his quest for certainty and the need of precision instruments by answering the general question 'Why medicine is a conjectural discipline' *(Qua ratione medicina sit conjecturalis)*:

> Medical art is conjectural because of the quantity of the disease, of the cures, of the faculties, because of the idiosyncrasies or property of the nature, and because of the peculiar conditions of the patient. [...] As far as regards the quantity of disease, in the 9th book of the De *methodo medendi* Galen states indeed that: in order to apply a cure we must know not only the specie of the disease but also its quantity, which, according to Galen in the chapter 14th of the 9th book of the same text, is a determinate measure of how much the morbose state differs from the natural one, and such a quantity is possible to know only by a conjectural way. We have pondered for a very long time how to know such a quantity, even though this is possible only in particular conditions and not always, and we have invented four instruments[12].

[8] Lefèvre 2008, pp. 20-22, n. 20; Büttner 2008, pp. 227-228.

[9] Büttner 2008, p. 228, n. 15.

[10] Castiglioni 1920, p. 45.

[11] Santorio 1625, Quaest. VI, col. 23.

[12] Ivi, Quaest. VI, coll. 21B –24B: «Ars medica est coniecturalis ratione quantitatis morborum, remediorum, virtutis, ratione idiosyncrisiae, vel proprietatis naturae, et ratione conditionum individuantium. [...] Ratione quantitatis morborum: Galenus enim 9. Methodi 15. dicit, *ut verum exhibeatur remedium, non solum oportet cognoscere morbi speciem, sed etiam eius quantitatem, quae ex Galeno 9. Methodi 14 est certa mensura quantitatis recessus a naturali statu, quae quantitas solum coniectura haberi potest*. Nos diu cogitavimus, quomodo illud quantum morborum aliqua ex parte aliquando cognosci possit. Excogitavimus quattuor instrumenta. Primum est nostrum pulsilogium, quo per certitudinem mathematicam, et non per coniecturam dimetiri possumus ultimos gradus recessus pulsus quo ad frequentiam, et raritatem [...] quod explicatur per primam figuram. [...] 2. Figura est vas vitreum quo facillime possumus singulis horis dimetiri temperaturam frigidam vel calidam, et perfecte scire singulis horis quantum temperatura recedat a naturali statu prius mensurato. Quod vas ab Herone in alium usum proponitur. Nos vero illud accomodavimus, et pro dignoscenda temperatura calida, et frigida aeris, et omnium partium corporis, et pro dignoscendo gradu caloris febricitantium [...]. Deinde habemus duos modos dimetiendi siccitatem, et humiditatem recedentem a naturali statu: de quibus mentionem fecimus aphorismo quarto secundae sectionis staticae nostrae. Primus modus explicatur per figuram tertiam; in qua extenditur funis, aut si mavis corda testudinis, crassa tamen: applicetur corda parieti, vel aliis locis, et in medio ponantur pila plumbea, ac prope signentur gradus. Dum aer humescit corda contrahitur: dume vero exsiccatur per aerem Borealem, laxatur: aliquando enim aer austrinus ita humescat, et contrahit cordam, ut attolatur usque ad litteram A, dum vero spirant venti septentrionales ita exsiccatur, ut pila perveniat ad ipsum B. [...] Secundus modus explicatur per quartam figuram, quae emulatur Horologium: sumitur corda ex lino satis crassa, et longa; quia quo crassior, et longior eo melius inseruit huic officio. Corda est in littera C. adnectitur radio in parte postica: dum igitur corda per aerem humidum vertit radium ad gradus propositos; dume vero per aerem siccum exsiccatur, laxatur, et in alios gradus declinat. Quanti vero momenti sit haec observatio sciunt aegrotantes qui humido, et qui sicco morbo fuerunt oppressi, quos ope istorum instumentorum ad sanitatem perduximus. Quarto nos

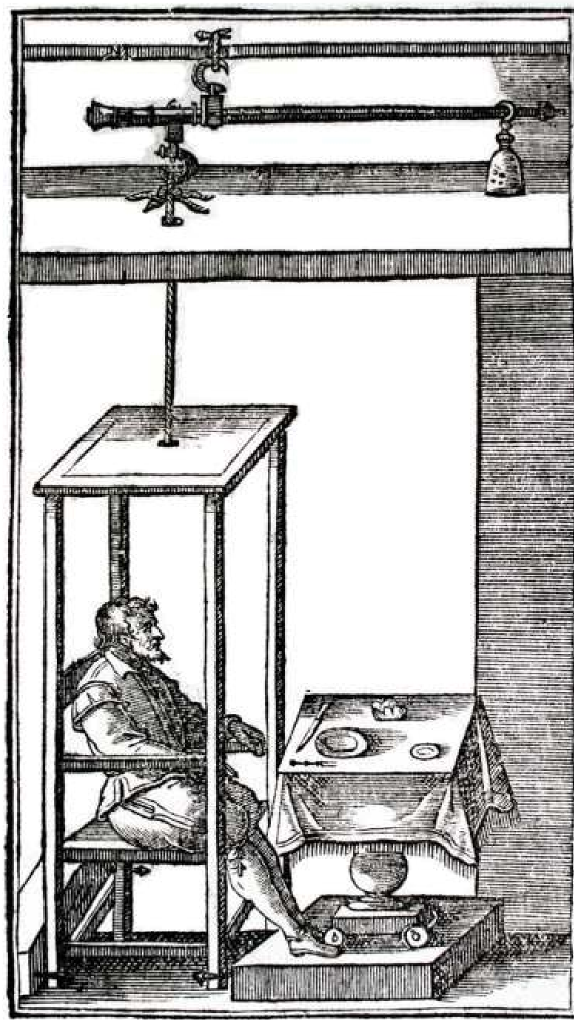

Figure 2 Santorio on his weighing chair.

As we have already described the pulsilogium, let's now consider the other devices.

The thermometer was described for the first time in a Letter by Giovanni Francesco Sagredo to Galileo dated 1612. It consisted of an air thermometer where water – which Santorio used to colour in green in order to evidence differences in level – works as an indicator.

The hygrometer was early described in 1614 in the fourth aphorism of the second section of the *Ars de statica medicina*. Types of hygrometers had been already used by Leonardo da Vinci and Nicola of Cusa (1401-1464). The simplest Santorio's hygrometer consists of a wire of turtle's skin suspended on wall which hosts a lead ball in the middle. As a result of changes undergone in dryness and wetness of the air, the wire shrinks or relaxes itself moving the ball and indicating the corresponding degree.

praeterea cogitavimus, quomodo, ex staticis experimentis mensuram certam perspirationis impeditae certissime colligere possumus: quae experimenta per aphorismos digesta in lucem edidimus».

Santorio's chair, also called *statera medica* **Figure 2**, consists of a movable platform, attached to a steelyard scale for the measurement of the overall changes in the body weight. Its description is absent from the first edition of his medical statics but is hosted in the later ones. The device is intended to measure the insensible perspiration by means of the difference registered in weight day to day. Santorio used these instruments together. For instance, he measured the temperature of a patient within precise parameters of time measured by the *pulsilogium*. The same can be said of hygrometers and *statera*, applied to evaluate particular conditions in which the perspiration took place.

The instruments just mentioned are just the main invented by Santorio; there are in fact many others which he designed for the sake of experimentation in itself (lunar thermometer and other types of *staterae* meant to calculate the impetus of flowing water) as well as for medical care. But what is really impressive about these devices is that they seem to satisfy an overall project of measurement of physiological parameters whose data will finally be collected in the work *Ars de statica medicina*.

The 'Ars de Statica Medicina'

Santorio's medical statics or *Ars de statica* medicina has been considered his masterpiece and, for many centuries, one of the most important contribution to the study of human physiology. Albrecht von Haller (1708-1777) still considered this book the work that had introduced quantification in medicine[13]. It was published in Venice in 1614 and originally consisted by 396 aphorisms reminiscent of Hippocratic style, increased up to 504 in the next editions. The book collects the result of experiments begun approximately in 1590's and achieved by the use of the *statera medica*. Santorio initially experimented on himself, but he progressively introduced other subjects, among whom was also Galileo.

Ars de statica medicina deals with the so-called *perspiratio insensibilis* which is a continuous evacuation of a not perceivable quantity of water steam from the pores of the skin as well as from the respiratory tract and mucous membranes, and is a physiological process today considered part of the metabolism. Already known by Hippocrates and ancient Greek physicians, this process was expanded by Galen who reputed it the main cause of health. Under this perspective it's interesting to note how questions already raised in Hellenistic medicine and revisited by Prospero Alpini's *De medicina methodica* (Padua 1611), were reinterpreted by Santorio in an original fashion[14]. Santorio's method consists in measuring the body every day at the same time in the morning, taking notes of what one eats, drinks, expels in faeces and urine

[13] HALLER 1776, Tom. V, Bk 12, Sect. II, p. 38: «Sanctorius, cujus in ipsa perspiratione nomen perenne superest, quod primus medicorum per experimenta in causas ejus exhalationis menfuras inquisiverit».

[14] The links with Hellenistic philosophy and medicine were indirectly reinforced by the discovery, in 1892, of the papyrus of the Anonymous Londinensis, according to which 'a kind of' statics experiment had already been made by followers of Erasistratus. They tried to prove the existence of insensible perspiration by measuring the weight of a bird locked in a cage after some days of starvation. However, Santorio's aim was not to prove the existence of perspiratio insensibilis, but to determine the exact weight of it. Thus, in his thought the concept of weight becomes central.

and subtracting this quantity by the total of weight of the body. Then, the procedure was repeated several times in different conditions, by observing every particular inclination of the subject, according to the so-called 'six non-natural things' (*sex res non naturales*, that is to say (1) air, (2) food and drink, (3) exercise and rest, (4) sleep and wakefulness, (5) secretion and excretion, and (6) mental affections). Due to his experiments, Santorio was able to establish that, in physiological conditions, perspiration is the most important excretion for the body and its rapport to the ingested food is equivalent to 5/8, namely 5 pounds of perspired matter out of 8 pounds of ingested food[15] and there is an inverse proportion between visible and invisible evacuation of the body. Notably, Santorio's analysis registered not only daily changes but even much longer periods of time, from several months up to a year, identifying cyclical paroxysms and seasonal crisis due to the retention of the matter of perspiration. Attaining an exact definition of the latter meant to him not only to ensuring a lasting health ('slogamento della vita') but also preventing the onset of disease, resulting of the stagnation of the humours not perspired (*humores peccantes*).

As he claims in the third aphorism of his medical statics:

> He only who knows how much and when the body does more or less insensibly perspire, will be able to discern when and how much is to be added or taken away, either for the recovery or preservation of health.

The *Ars de statica medicina* is divided in seven sections that, after a first dedicated to methodological criteria to evaluate the weight of insensible perspiration, contemplate in turn each of the six non-natural factors. One of this 'things' actually is not listed in the index, namely the *inanitio-repletio*, that is to say secretion and excretion, but it is absent for a very good reason: it has been adopted as the key principle to evaluate the process of perspiration. If quantity is a homogeneous principle to life, so the organism can be seen as a machine that fills and empties itself. Not infrequently Santorio compares the organism to the clock, in order to explain the manifestation of occult qualities from the prime matter[16], the generation of the vital spirits through the heart and brain – an example adopted without changes by Descartes in his *Description du corps humain*[17]- the mechanism of plague's contagion[18] and, finally, the body in its entirety[19].

This concept shows another possible way to interpret Santorio's idea of quantification, namely as a 'mechanization of qualities', to borrow a Dijksterhuis expression[20], an idea that later would represent a model developed by Descartes' followers and adopted by the so-called iatromechanical school of physicians. It is not surprising that Jacopo Grandi, one of Santorio's early biographers, in his speech on the anniversary of Santorio's death (addressed to the *Collegio dei medici fisici di Venezia* in 1671) represented him as a new Heron of Alexandria, devoted to finding a way to make more understandable the principal functions of the human body by inventing precision devices and suggesting ways to quantify its dynamics.

Some Conclusion

Santorio's quest for certainty certainly renders him a pivotal figure not only in the history of medicine but, more in general, in the science of the early modern history. His interests for measurement and quantification make his studies sometimes – and it is the case of the experiments on temperature – even more accurate than Galileo's ones. Alike the latter and Francis Bacon (with whom he actually shares the date of birth, 1561), Santorio lived in between two centuries and inherited the Renaissance desire for emulation (*aemulatio*) as well as the lucky idea of *homo faber*, whose hand is able to build the world. Unlike many of his contemporaries, however, he did not reject traditional philosophy and medicine, but utilised the ancient authorities as sources of problems and inspiration rather than answers. Santorio's output is, under this aspect, particularly significant. As required by his professional appointment at the University of Padua (where, like Galileo before him, he was committed to reading classical authors and basing his teaching on them) he wrote *Quaestiones and Commentaria* in the very scholastic genre. By contrast, the content of his books is, most of the time, truly innovative and original. It was probably with his very first work *Methodus vitandorum errorum omnium* that Santorio began to think to ancient problems as questions to be answered in a new way. The value of experience as well as the relevance of the anatomical discoveries made at his time, are already clearly established in his mind, as he decidedly pointed out:

> Today in many Universities of Europe there is in force this foolish thought, according to which people trust more Aristotle, Hippocrates and Galen than their own senses[21].

A claim that is even more supported by the concept of the progress of medical art:

> There are many things in today's medical art that perhaps there were not in the time of Hippocrates and Galen[22]....

These considerations lead me to my final point that is to say, Santorio's place into the history of science.

In his still important work on Galenism, the celebrated historian Owsei Temkin considered the endeavour of Santorio as an example of Hegel's 'die List des Begriffes' (the cunning of the concept). He defended that while for Galen hot and cold, dry and moist were granted with objective existence; at the measurement of the thermometer they become the more or less of something else. Thus, «the metamorphosis of objective qualities into subjective qualities was as destructive to Galenic science as doing away with fire, air, water, and earth as chemical elements»[23].

[15] Santorio 1614, Sect. I, aphor. 6.

[16] Santorio 1602, bk. VIII, ch. 5 and 10. X

[17] Santorio 1612, pars II, quaestio 37 p. 187, cap. 81, pp. 738-739; Descartes, Description du corps humain, I. 4, AT XI, 226.

[18] Santorio 1614, sect. I, aphor. 126.

[19] Santorio 1625, quaest. XII, p. 91, coll. D.

[20] Dijksterhuis 1980, pp. 576-580.

[21] Santorio 1603, p. 198: «Hodierno die in plurimis Europae Gymnasii haec insania invalescat ut magis Aristoteli, Hippcrati et Galeno credant quam sensibus propriis».

[22] Santorio 1625, col. 9: «Multa quoque inveniuntur in medica facultate his temporibus, quae fortasse tempore Hippocratis et Galeni non erant...».

[23] Temkin 1979, pp. 160-161: «Sanctorius's endeavour to help Galenic

I believe it's time to substantially modify this judgment, which has been very common among philosophers of science until a recent time. Indeed, this way to think about early modern philosophers of nature implies that, on the one hand, no forms of scientific quantification were used in ancient philosophy and, on the other hand, 'substantial forms' had not been affected by late-Scholastic revision of the Aristotelian system, known as *calculatio*.

While the former bias can be amended by showing that forms of 'effective quantification' were used in the Hellenistic period both by Galen, as far as it regards the theory of degrees of drugs and quantification of urine, and by Ptolomy in his astronomy, the latter one can be corrected by taking into account the problems of the so-called theory of the *intensio et remissio formarum*. Still alive in Italian medicine of late-Renaissance, this theory had been a consequence of the revision made by Oxonian philosophers on Aristotle's physics in late fourteenth century (starting with the most famous of all, Richard Swineshead (fl. 1340-1353) called calculator). According to the *calculatio* theory, the traditional four qualities (hot, cold, wet and dry) contract and stretch themselves in physical matter, acting in accordance with 'degrees of intensity' susceptible of being quantified. As matter of fact, then, Santorio did not need to prepare the fall of Galenic system by attempting to quantify the degree of cold and hot. More in general, Temkin's judgment is indirectly affected by the bias inducted by the 'myth of scientific revolution', according to which, before Galileo, no true science had ever been made. Under this perspective, I guess, the present case invites the historians to rethink some categories, such as 'revolution' and 'paradigm'. Indeed Santorio was not a revolutionary thinker, and nevertheless is one of the most close figure of the early modern period to come very near to the idea of science as we intend it today: a professional who is always aware of the duty to preserve the knowledge he inherited from the past by enriching it with selected and verified experiences.

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. According to the teaching of the rising physical science, cold and hot were merely secondary qualities, subjective sensations evoked in the body by contact with a physical object. The metamorphosis of objective qualities into subjective qualities was as destructive to Galenic science as doing away with fire, air, water, and earth as chemical elements».

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