Chapter 7
The Measuring Instruments

Abstract As the title suggests, this chapter deals with the most famous of the devices which Sanctorius developed to measure and to quantify physiological change: pulsilogia, thermoscopes, hygrometers, and balances. Having attracted considerable scholarly attention, they form the backbone of the narrative that identifies Sanctorius as a great innovator, who founded a new medical science, a science to which mechanization, measurement, and numerical values were integral. The findings of the foregoing chapters allow us now to go beyond this selective account of Sanctorius and his works and to reevaluate his celebrated measuring instruments and their use from a closer perspective. To this end, I explore their design and basic functioning, the contexts in which they emerged, how Sanctorius possibly used them, and what precisely they measured. In this connection, I also analyze two steelyards for the measurement of climatic conditions which have hitherto been largely ignored, thereby covering the whole range of Sanctorius's measuring instruments. Moreover, I present the results of my reconstruction of the Sanctorian weighing chair and the attendant replication of his experimental practice, and thereby show how this approach opened up new perspectives on Sanctorius's works, his doctrine of static medicine, and the function and purpose of his weighing chair.

Keywords Material culture · Measuring instruments · Replication · Sanctorian chair · Weighing

The index of the *Commentary on Avicenna* contains sixteen items that can be subsumed in the following types of measuring instrument: *pulsilogia*, thermoscopes, hygrometers, and balances (Fig. 4.1). As already seen, this group comprises the most famous instruments devised by Sanctorius, which have already attracted considerable scholarly attention (Sect. 4.2, fn. 16). They form the backbone of the narrative that identifies Sanctorius as a great innovator, who founded a new medical science, a science to which mechanization, measurement, and numerical values were integral. I have pointed out earlier that this storyline omits some important points. It concentrates solely on those parts of Sanctorius's works that are, or appear to be innovative, isolating them from the context in which they emerged. The analyses of the preceding chapters allow me now to go beyond this selective account of

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Sanctorius and his works and to reevaluate his famous measuring instruments and their use from a broader perspective. Against this backdrop, it is possible to critically review the image of Sanctorius and to ask whether it is still tenable to label him the innovator of a new medical science.

In the following, I will analyze all of Sanctorius's measuring instruments, including two steelyards for the measurement of climatic conditions which have hitherto been largely ignored. Priority disputes are considered only insofar as they provide important insights into Sanctorius's social and intellectual milieu and thus allow some conclusions to be drawn about the way in which the physician developed his innovative ideas. Here, too, instead of focusing only on the *Commentary on Avicenna*, I will examine the measuring instruments with regard to all of Sanctorius's books. However, in order to fully grasp the material dimensions of Sanctorius's quantitative approach to physiology, it is necessary to look beyond the written and pictorial sources. Illustrations and descriptions of the instruments represent codified forms of the knowledge produced in the very process of their invention, from the first idea to their realization and use. They are the end products of active processes of knowledge making. The reconstruction of such instruments and the attendant replication of the experiments conducted with them is a means for the historian to gain insight into these active processes of knowledge making, and of knowledge in its uncodified form (Smith and Schmidt 2007: 3 f.; Smith 2017: 372 ff.). In my attempt to understand how Sanctorius developed his quantitative approach to physiology and to trace the mechanical and practical knowledge involved in his undertakings, I reconstructed his most famous instrument, the weighing chair, and sought to replicate his experimental practice. This opened up new perspectives on Sanctorius's works, his doctrine of static medicine, and the function and purpose of his weighing chair. But before addressing this, at the end of this chapter, I will begin my study of Sanctorius's measuring instruments by examining two other balances that the Venetian physician devised.

7.1 Two Balances to Measure Climatic Conditions

In addition to the famous weighing chair, Sanctorius developed two other balances, which enjoy far less renown: one, to measure the *impetus* of wind (Fig. 7.1); the other, to measure the *impetus* of water currents (Fig. 7.2).[1]

Sanctorius described the design of the two balances in the *Commentary on Avicenna* as follows:

[1] I use here the term *impetus*, because this is the term that Sanctorius always uses in his description of the two steelyards to measure climatic conditions. This term was highly relevant at the time and played an important part in Galileo Galilei's theory of motion. There is no standard translation of *impetus*, as its meaning has often changed over time and been further differentiated. Today, there is no direct equivalent for *impetus*. For more information on the term and concept *impetus*, see: Elazar 2011, Van Dyck and Malara 2019.

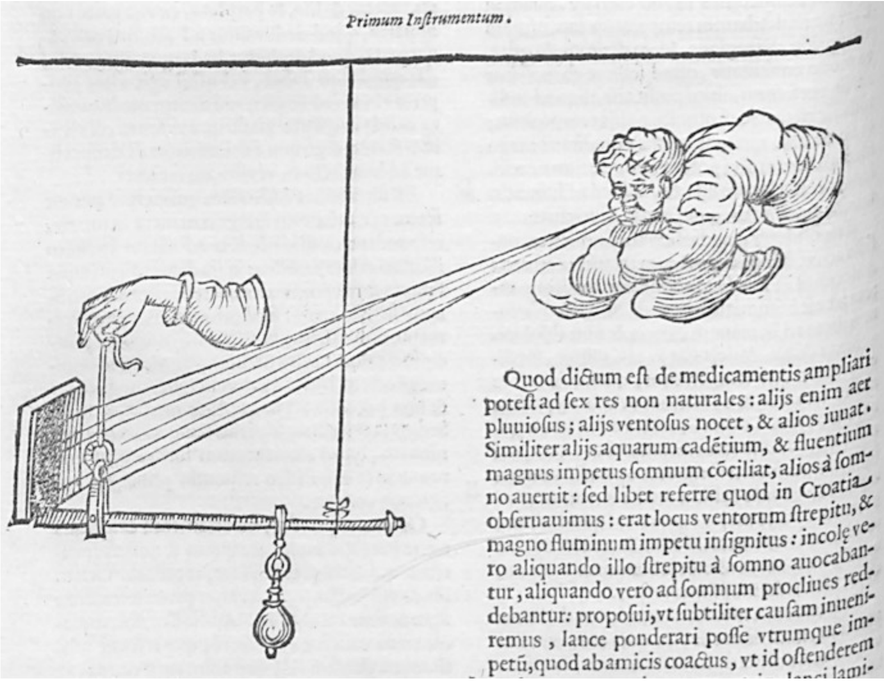

Fig. 7.1 Balance to measure the *impetus* of wind (Sanctorius 1625: 246). (© British Library Board 542.h.11, 246)

> I proposed … that both impetuses can be weighed with a scale pan and, encouraged by friends to show this, I provided two balances, the first for the impetus of wind, the second for the impetus of water and added to both scale pans an iron plate. With the one, in which the iron plate is above [the beam], we weigh the impetus of wind. … But by means of the other [balance], to which the same plate is attached, we discern how much the weight of the impetus of flowing water is (Sanctorius 1625: 246 f.).[2]

[2] "… proposui, …, lance ponderari posse utrumque impetum, quod ab amicis coactus, ut id ostenderem praestiti duobus stateris, per primam ventorum, per secundam vero aquae impetum, utrique; lanci laminam ferream apponendo: illa, in qua lamina ferrea supereminet, perpendimus ventorum impetum: …. Alia verò cui appensa est eadem lamina aquae currentis impetum dignoscimus quanti sit ponderis." See: Sanctorius 1625: 246 f. It is interesting to note that Sanctorius refers here to *the weight of the impetus* (*impetum … ponderis*). The physical concept of force as we use it today, did not yet exist, but contemporaries like Galileo Galilei used the term *force* (*forza*). As with *impetus*, the concept behind this was in flux and cannot be mapped seamlessly onto the modern physical concept of force. The attempt to measure with a balance the *impulsive forces* (in Galileo: *forza della percossa*) then assumed to be proportional to the *impetus*, was nothing new at the time. The English mathematician and philosopher Thomas Harriot (1560–1621), for example, dropped balls from different heights onto the pan of a balance with equal arms. Similar to Sanctorius, Galileo tried to measure with a scale the *force* of an impinging water jet. But Galileo used an equal-armed balance and falling, not streaming water as Sanctorius did. The fact that Sanctorius wrote of the *weight of the impetus* is not surprising, since it is derived ad hoc from his experimental arrangement—a scale measures weights. See: Settle 1996, Schemmel 2008.

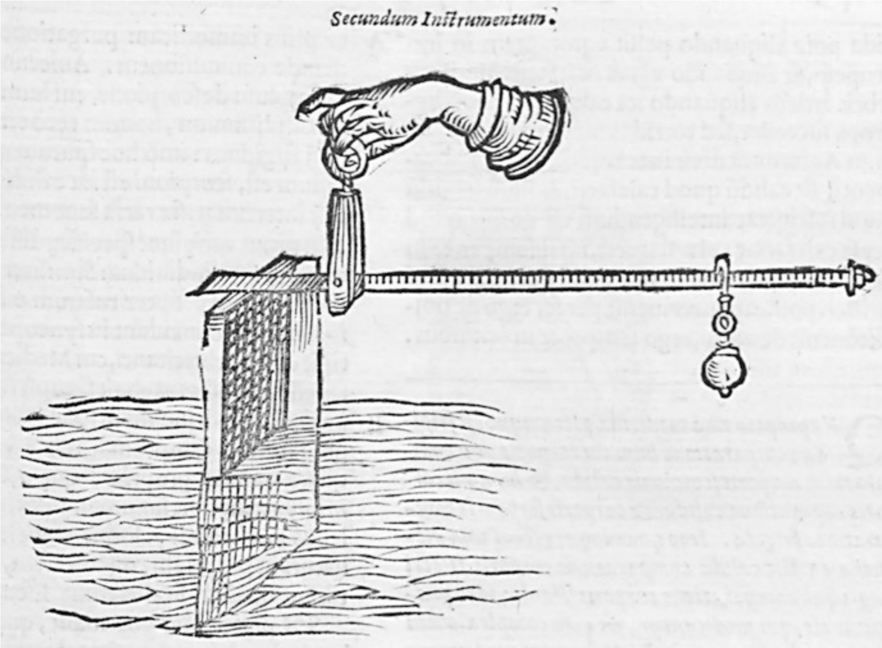

Fig. 7.2 Balance to measure the *impetus* of water currents (Sanctorius 1625: 247). (© British Library Board 542.h.11, 247)

These scant remarks, together with the illustrations, are the only information that Sanctorius gave about how the two balances work. Therefore, it is difficult to understand how he came to design and use these devices. That historical studies on the development of anemometry and hydraulics have mostly overlooked his devices further aggravates the problem.[3] Thus, a comprehensive analysis of Sanctorius's two balances is required. Notwithstanding that such an analysis goes beyond the scope of the present work, I will present a first step in this endeavor.

[3] In his study on the invention of meteorological instruments, W.E. Knowles Middleton describes Sanctorius's anemometer only in a few sentences and does not consider instruments for the measurement of moving water (Middleton 1969: 185, 187). Arthur Frazier's article on Sanctorius's "water current meter" does not discuss the design and functionality of the instrument (Frazier 1969) and is basically reproduced in Frazier's later study on water current meters, which contains some inaccuracies regarding Sanctorius and his works (Frazier 1974: 18–21). Other historical studies on the measurement of moving water ignore Sanctorius's steelyard for the measurement of the *impetus* of water currents completely, see: AWWA Meter Manual 1959, Maffioli 1994, Di Fidio and Gandolfi 2011.

7.1.1 Technical Interpretation of the Steelyards

The illustrations of the two instruments (Figs. 7.1 and 7.2) indicate that Sanctorius used Roman steelyards. Scales of this type were widely in use at the time, especially in a trading hub like Venice, Sanctorius's second home. Merchants and traders used steelyards the size of those depicted by Sanctorius to weigh small items of merchandise in ounces. Thus, it can be assumed that Sanctorius used the steelyards already in circulation for his measurement of the *impetus* of wind and water currents. This is also implicit in his statement that he "provided two balances" (Sect. 7.1). The Roman steelyard consists of a straight beam with arms of unequal length (Fig. 7.3). The beam is suspended from a defined pivot (C), which is flanked by two arms. The longer arm is graduated and incorporates a counterweight (A), which can be moved along the arm to counterbalance the object to be weighed, the load (B), hanging on the short arm. When the two arms are balanced in a horizontal position about the pivot, the weight of the load is indicated by the position of the counterweight on the graduated arm. Thus, the weight can either be read directly from the graduation marks or calculated according to the law of the lever (Robens et al. 2014: 169; Hollerbach 2018: 129).

In order to measure the *impetus* of wind and of water currents with a steelyard, Sanctorius had to adapt its design, as he himself explained in the quoted citation. He added an iron plate to the short arm, in the place where usually the load is positioned, and, depending on what he wanted to measure, placed the plate either below, or above the arm. From the illustrations, it seems that both plates are firmly mounted perpendicular to the beam. Under the influence of air or water flow, the plate is pushed to the side and the pressure thereby generated is transformed into a downward or upward movement, due to the plate affixed to the beam. This movement can be compensated by moving the counterweight until an equilibrium is gained, whereupon the weight can be read in the usual way described above. However, contrary to the weighing of a load, Sanctorius's measurements were complicated by the erratic character of air and water currents. Therefore, the arrangement of the iron plate was crucial, particularly in the case of the anemometer, as wind, even more than water, not only arrives from unforeseeable directions but also in irregular gusts. The rope attached to the long arm of the beam might have had a dual function: to better orient the instrument toward wind direction; and to (generally) enhance stability. Even

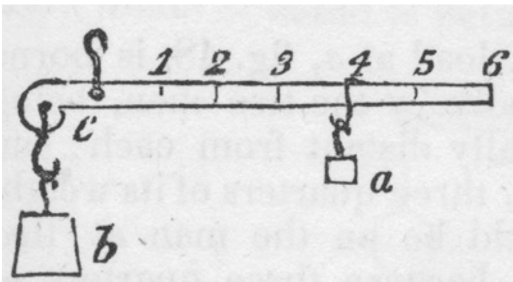

Fig. 7.3 Illustration of a Roman steelyard (Comstock 1836: 69)

though the illustration does not show any device to determine wind direction, it is possible that Sanctorius used a wind vane for this purpose, as these simple devices had long been known, in his day, and were often attached to church towers in the Middle Ages. But generally, it is quite questionable how Sanctorius conducted a measurement with his anemometer in strong wind given that the latter affected the whole steelyard and not only the iron plate (Middleton 1969: 177, 185).

With regard to the measurement of the *impetus* of water currents, other questions arise.[4] Why did Sanctorius use a grid here, rather than a continuous plate (Fig. 7.2)? To guarantee the comparability of the measurements taken, the grid has always to be immersed in water to the same depth. How did Sanctorius achieve this, especially in strong currents and given the fact that both steelyards were operated by hand? It's easy to imagine how difficult it must have been to keep a steady hand and not inadvertently falsify the measurements, especially when the wind or water currents were strong. Moving the counterweight must have been a challenge, too, and even more so when strong currents of water or air were continuously pushing against the iron plate at the other end of the steelyard.[5] Further investigation is necessary, in order to better understand these difficulties and how they were possibly overcome. In the 1960s, the medical historian Loris Premuda made replicas of the two steelyards, but they are not fully functional, as one can see (Fig. 7.4): both are insufficiently stable for the plate to be mounted above the beam. Since the replicas were made in the context of an exhibition, I assume that they served purely illustrative purposes. New replicas of Sanctorius's two steelyards as well as a reenactment of his measuring procedures would be necessary to shed more light on their respective design and use. This, however, lies beyond the scope of the present study.

The initial assessment, here, of Sanctorius's two steelyards implies that the practice of taking measurements was not impossible but certainly, very difficult. Although clearly identifiable graduations on the beam of each instrument suggest that reading and comparing measurements was possible, at least, Sanctorius made no mention of the numerical outcomes of his weighing procedures with the two steelyards. The only indication that the devices were ever put to use is Sanctorius's remark, that he demonstrated how they worked to his friends. Accordingly, there is much to suggest that Sanctorius conducted the weighing procedures with the two steelyards in thought only, and never in deed. The practical difficulties of using Sanctorius's anemometer might also explain why it was neither adopted nor advanced by other scholars and practitioners and has received little attention from historians. In fact, a look into the history of anemometry reveals that Sanctorius is the only scientist ever to have suggested using a steelyard to measure the *impetus* of wind (Sanctorius 1625: 246 f.).

[4] For more information on the larger topic of Renaissance hydraulics and the measurement of water flow, see: Maffioli 1994.

[5] I thank Jochen Büttner, Bernadette Lessel, and Markus Hollerbach for their help with the technical interpretation of Sanctorius's two steelyards for the measurement of the *impetus* of wind and of water currents.

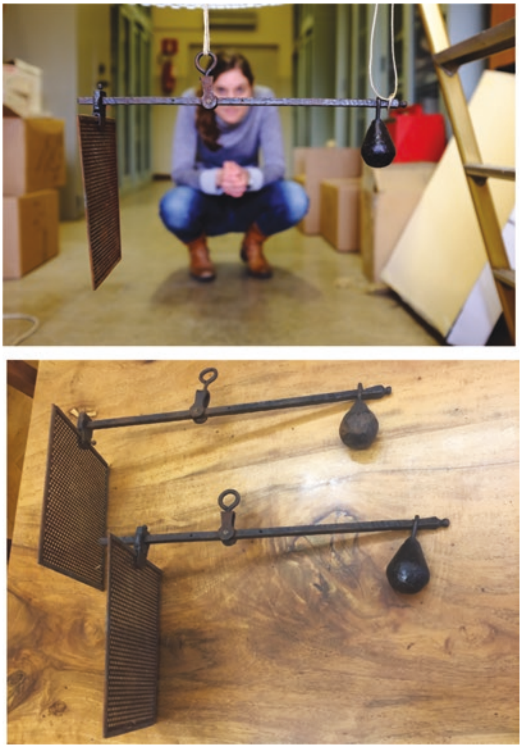

Fig. 7.4 Replicas of Sanctorius's steelyards for measuring the *impetus* of wind and water currents. (These replicas were made by Loris Premuda for an exhibition held in 1961 at the University of Padua, where they can still be found today (Biblioteca medica 'Vincenzo Pinali antica' dell'Università degli Studi di Padova, © Philip Scupin))

7.1.2 The Technological Context

The swinging-plate instrument devised by the Italian scholar Leon Battista Alberti (1404–1472) is generally regarded as the first anemometer, followed by the wind plate of Leonardo da Vinci (1452–1519), which was most probably inspired by Alberti's device. Alberti described and illustrated his anemometer in the work *Ex ludis rerum mathematicarum* (On the Pleasures of Mathematics), which was completed sometime between 1450 and 1452. Alberti's anemometer was a little swinging board, directed into the wind by a vane, and equipped with an arc on which its degree of deflection could be read (Fig. 7.5). A sign swinging in the wind, or sheets drying on a clothes line may have given him the idea for the design of his anemometer.

The illustration of Alberti's anemometer shows that it is quite different from Sanctorius's instrument, the only similarity being the plate, whose deflection serves in both devices to indicate the strength of the wind. Without going into a detailed comparison of the two devices, it must be noted that Alberti's instrument was not operated by hand and was therefore not prone to the imprecision caused by irregular movements of the hand and arm. What is more, Alberti proposed that his anemometer be used in the context of sailing, while Sanctorius's device had a clear medical purpose. It is likely that Sanctorius was familiar with Alberti's *Ludi matematici*,

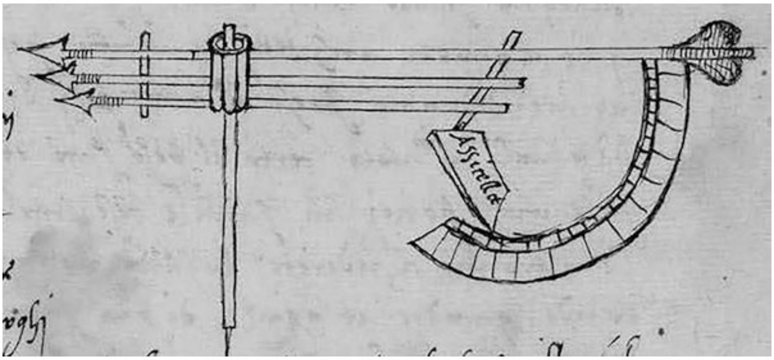

Fig. 7.5 Illustration of the anemometer by Leon Battista Alberti (Wassell 2010: 64)

whose popularity grew after its release in print in 1568. Thus, despite the many differences between the two anemometers, perhaps Alberti's illustration inspired Sanctorius to attach a plate to one end of a steelyard in order to determine the *impetus* of wind. What is more, as mentioned earlier, for the idea of using a pair of scales to measure the strength (*vis*) of wind, Sanctorius could draw on another work—the *De staticis experimentis* of Nicolaus Cusanus (Sect. 5.3.2) (Sanctorius 1625: 246 f.; Middleton 1969: 182 f.; Wassell 2010: 64–77).

A slightly different picture emerges with regard to Sanctorius's instrument for measuring the *impetus* of water currents. Even though I was unable, also in this case, to find any earlier device based on the manual steelyard mechanism described above, the so-called *hydraulic steelyards* presented in the eighteenth-century works of Jacob Leupold (1674–1727) and Francesco Michelotti (1710–1787) do bear similarities to Sanctorius's instrument (Leupold 1724: 150 f., tab. LIX, fig. 1; Michelotti 1771: 116 ff., tavola II). In his article, "Dr. Santorio's Water Current Meter, circa 1610," Arthur Frazier argued that Sanctorius's steelyard had started a vogue, and named further similar devices. However, in the absence of any reference to Sanctorius by the designers of these instruments, it is hard to say whether they knew of, or were influenced by Sanctorius's steelyard. Further research would be required to clarify this issue, for it lies far beyond the period under consideration here (Frazier 1969: 251 ff.).

In Sanctorius's direct context, sixteenth-century Italy, the investigation of moving water, especially the study of rivers and the engineering problems associated with river control, was a matter of deep and widespread concern, and could look back on a long tradition. It responded, both to the preservation of the Venetian lagoon and the very practical issue of flood prevention, especially along the river Reno, in the Bologna region. Finding solutions to such technological problems played a significant role in Renaissance hydraulics, which remained a largely empirical undertaking until the early eighteenth century. People involved in designing and supervising the construction of waterworks were therefore called architects (*architetti*), water experts (*periti delle acque*), foremen (*proti*, in Venice), or simply, engineers (*ingegneri*). One of the most famous representatives of this profession is Leonardo da Vinci, who, among other things, used rod floats to determine the velocity of river currents.[6] It can be assumed that Sanctorius was familiar with the practical hydraulics of the time, living and practicing frequently in Venice as he did. His development of an early form of a water current meter shows his interest in, and receptivity to contemporary practical technologies, which he endeavored to put at the service of medicine.

However, Sanctorius also considered other practical applications for his steelyard. In the *Commentary on Avicenna*, he referred to its great potential for milling (*molendis efficiendis*), which implies that he was thinking of the water milling technology of his day. What is more, as Frazier assumed, the design of his instrument might well have been provoked by his experience of rowing (or of being rowed), or more specifically, by his observation that an oar or paddle in water tends to be pushed backward by the current. Noteworthy, here, is that Sanctorius saw the greater potential for flood prevention, not in his steelyard for measuring the *impetus* of water currents, but in the anemometer. For this instrument could, he believed, determine an incipient increase in the *impetus* of wind and thus easily predict imminent sea storms and high tides (Sanctorius 1625: 247; Frazier 1974: 8, 18; Maffioli 1994: foreword, 6–25).

Another important detail proffered by Sanctorius regarding his two steelyards is that he designed and used them in Croatia. This, together with Sanctorius's reference to sea storms, led Mirko Grmek to conclude that Sanctorius developed the steelyards somewhere between Senj and Trsat, close to the north Adriatic coast. But Sanctorius's reference to Croatia is interesting also for another reason. Sanctorius spent time in Croatia as a practicing physician sometime between his graduation in 1582 and his appointment as professor of *theoria* at the University of Padua in 1611. This was also when he started his static observations of insensible perspiration, for which he used a special weighing chair suspended from one of the beams of a large balance—hence, a steelyard, here, too (Sect. 2.2). Thus, it seems likely that Sanctorius was simultaneously engaged in several studies with steelyards, which may well have been interrelated. And indeed, he connected his use of the steelyards for measuring climatic conditions with the doctrine of the six non-natural things (Sects. 3.1 and 3.3) (Sanctorius 1625: 246; Grmek 1952: 14, 48).

7.1.3 The Dietetic Context: The Six Non-Natural Things

In the *Commentary on Avicenna*, Sanctorius explained that just as the effect of a drug depended always on the complexion of the patient taking it, so, too, the effect of the six non-natural things had to be considered in relation to the human body.

[6] For more information on Renaissance hydraulics and the developing "science of waters," see: Maffioli 1994. For Leonardo da Vinci's use of rod floats to measure stream velocities, see: Frazier 1974: 8–11.

Rainy air was harmful to some people, while windy air made others suffer, and others again found both rainy and windy air beneficial, per Sanctorius. Similarly, falling and flowing water with a big *impetus* lulled some people to sleep, while keeping others awake. In a Croatian town with noisy winds and a river with a strong current (*magno impetu*), Sanctorius continued, he had observed that these factors at times hindered the inhabitants' sleep and, at other times, positively fostered it.[7] By means of his two devices, Sanctorius intended to measure variations in the *impetus* of wind and of water currents, which were, according to him, responsible for the various effects that these climatic conditions had on the Croatians' sleep. According to his own testimony, he investigated which *impetus* was healthy and which was harmful and, on this basis, why the larger or smaller *impetus*, or noise was sometimes the cause of health and sometimes the cause of disease (Sanctorius 1625: 246 f.).

It has been mentioned earlier that the non-natural pair air and water was thought to have a considerable impact on health and disease (Sect. 3.3.1). With his two steelyards, Sanctorius attempted to determine this impact quantitatively by measuring the *impetus* of wind and of water currents. According to him, these measurements were a means for the physician to identify the correlation between the external factors of air and water and the well-being of his patient. The two steelyards thus helped the physician make a correct diagnosis and identify general patterns or regularities regarding the effect of the *impetuses* of wind and of water currents on health and disease. In Sanctorius's opinion, such generalization based on repeated measurements enabled one to differentiate between healthy and harmful *impetuses*. Indeed, Sanctorius explained that he most certainly (*certo certiores*) could detect with his anemometer, whether the *impetus* of wind was beginning to increase or to decrease—and so was evidently convinced that his steelyards were capable of measuring such climatic conditions. Furthermore, this statement corresponds with his attempt to enhance certainty in medicine by means of his measuring instruments, as described in the previous chapter. Here again, Sanctorius put forward innovative ideas and integrated them into the traditional framework of Galenic dietetic medicine. Interestingly, in the *Commentary on Avicenna*, Sanctorius related the influence of the *impetus* of wind and of water currents to another non-natural thing, sleep, but remained completely silent on the effects these climatic conditions might have on insensible perspiration. Despite the strong relation of the two steelyards to the six non-natural things and the fact that Sanctorius also used a steelyard to measure insensible perspiration, there is no connection to the *De statica medicina*. Likewise, the static aphorisms bear no trace of the two devices (Sanctorius 1625: 246 f.).

[7] Carlo Zammattio suggests that the location to which Sanctorius refers here may have been at the Škocjan Caves (now in Slovenia), around twenty kilometers east of Trieste. There, a river disappears with a strong roar into a huge underground cavern. Moreover, the gale force bora wind sweeps the region (Frazier 1969: 251, 1974: 20).

7.1.4 The Context of Pharmacology

A last remark must be made concerning the embedding of the two steelyards in the pharmacological context. As outlined above, Sanctorius compared the effect of drugs with the effect of the six non-natural things, before launching into a description of his devices (Sect. 7.1.3). Remarkably, before ending that description, he resumed this comparison, asking:

> Wherefore, if the larger or smaller impetus, or noise is at one time a healthy cause and at another an unhealthy cause, how much more must the strengths of the ingested drugs weigh? (Sanctorius 1625: 247).[8]

Thus, Sanctorius seems here to ponder the possibility of measuring the strengths (*vires*) of drugs in relation to their effect on the body. His statement implies that he wondered whether it was feasible to differentiate between healthy and harmful strengths of drugs by means of weighing, in a way similar to that used for the measurement of the *impetuses* of wind and of water currents. This is further indicated by his use of the Latin verb *perpendo*, which he also employed in the description of the two steelyards (Sect. 7.1, fn. 2). But it remains unclear whether Sanctorius really considered it possible to quantitatively determine the degrees of intensity, or strength of Galenic pharmacological theory, described in Sect. 5.2.2. He formulated this idea only as a question and did not further explain how such a measurement or weighing procedure might be conducted. Instead, he resumed his commentary on a passage of Avicenna's *Canon* in a traditional manner, by discussing doubts (*dubitatio*). Even though these discussions concerned the complexion of drugs and their faculties, no further reference was made to quantification. Moreover, as stated earlier, in other passages of his works Sanctorius clearly concluded that it was impossible to know for certain the strength of a remedy (Sect. 6.2.2) (Sanctorius 1625: 247 ff.).

In conclusion, Sanctorius's presentation of the two steelyards to measure climatic conditions shows that he looked beyond the confines of medicine and was attentive to the practical technologies of the time. The Renaissance engineering tradition in Italy was the backdrop against which Sanctorius came up with novel methods to measure the *impetus* of wind and of water currents. Yet, regarding the measurement of the *impetus* of wind, Sanctorius did not use the contemporary technology of Alberti's anemometer, but came up with a different method that does not seem to have been oriented toward practical use. His familiarity with handling a steelyard, gained through the use of his weighing chair to quantify insensible perspiration, probably encouraged him to apply this technology to other areas, too. This notwithstanding and despite the fact that steelyards, anemometers, and instruments to examine water currents did not originate with Sanctorius, his dealings with such devices as a practicing physician were exceptional, as was his later inclusion of them in his university lectures on a traditional textbook, the *Commentary on*

[8] "Quare si maior, vel minor impetus, vel strepitus modo est causa salubris, modo insalubris: quanto magis erunt perpendendae vires medicamentorum quae intus sumuntur?" See: Sanctorius 1625: 247.

Avicenna, Sanctorius's strong interest in practical technologies, more specifically, mechanics, was anything but ordinary for a physician. While it is widely known that Sanctorius brought physiology and mechanics together in the *De statica medicina*, his use of steelyards to measure climatic conditions and to detect their influence on health and disease is largely unknown. Despite the unclear relation between his study of insensible perspiration and his examination of the *impetus* of wind and water currents, it is significant that Sanctorius worked with steelyards in both cases, thereby relating the same instrument to very different applications. Moreover, as touched on above, he found a further use for them in meteorological studies, such as weather forecasting. Traditional dietetic medicine, according to which the environment had an important influence on the health and disease of a body, provided the framework in which Sanctorius combined the quantification of meteorological factors with medical diagnosis and treatment. Sanctorius's efforts, albeit most probably not put into practice, illustrate how medicine contributed to the development of meteorology and spurred the use of quantification and measurement methods in this field.[9]

7.2 The *Pulsilogia*

Sanctorius presented an instrument that he described as a *pulsilogium* as early as 1603, in his first publication *Methodi vitandorum errorum*. However, he limited himself in this work to describing the function and purpose of his allegedly newly invented device, offering neither technical details nor an illustration. Nine years later, in the *Commentary on Galen*, he revealed that the instrument relied on the properties of the pendulum; and thirteen years after that, he published illustrations and descriptions of several types of *pulsilogia* in his *Commentary on Avicenna*. In what follows, I will outline the design, functioning, and use of these instruments, and consider the historical context in which they emerged. Since the reception of Sanctorius's *pulsilogia* has been dealt with in the secondary literature, I will refer to this in some detail, too.[10] Moreover, going beyond existing studies, I will provide new reflections on the actual practical application of Sanctorius's *pulsilogia* as well as on the relation between these instruments and the efforts of Nicolaus Cusanus and Girolamo Cardano, who were both engaged in studies of the pulse (Sanctorius 1603: 109r–109v; 1612b: 374; 1625: 21 f., 77 f., 219–22, 346, 364 f.).

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[9] For further information on Renaissance meteorology, see: Martin 2011.

[10] In a recent paper, Fabrizio Bigotti and David Taylor have closely analyzed Sanctorius's *pulsilogia* and also considered their reception. Their study is not only based on written documents but also refers to insights that were gained by reconstructing and experimenting with one type of these instruments. My following account of Sanctorius's *pulsilogia* draws largely on this study. See: Bigotti and Taylor 2017.

7.2.1 *The Use of the Pendulum: How Did the* **Pulsilogia** *Measure?*

Sanctorius put forward five designs of *pulsilogia*, to all of which he ascribed two uses: to record pulse frequency and to measure time. As the illustrations in the *Commentary on Avicenna* show, these five designs, depending on their form and appearance, fall into three main types: the beam type (Figs. 7.6 and 7.7), the dial type (Figs. 7.8 and 7.9) and the pocket watch type (Fig. 7.10). At least four of the five *pulsilogia* designs are based on the properties of the *pendulum*.

The simplest and, according to Sanctorius, also handiest version consisted of a thread to which a lead ball was attached (Fig. 7.6). The physician used this handheld pendulum by synchronizing the swing of the pendulum with the patient's pulse at two pulse strokes per pendulum cycle. In order to do so, he adjusted the length of the pendulum cord until the swing matched the patient's pulse. The length of the cord was then measured with a measuring rod that was divided into eighty degrees. To make it easier to read the measurement, a vertical white line marked the circumference of the lead ball (letter C in Fig. 7.6). Although Sanctorius described this *pulsilogium* as easy to handle (*paratu facile*), from my perspective, the use of the instrument in medical practice required some dexterity, as the physician had to operate the pendulum with both hands and, at the same time, to determine the pulse of his patient by touch. During this process, the hand holding the pendulum had to be kept as still as possible so as not to falsify the measurements (Sanctorius 1625: 21 f.).

Maybe in response to these difficulties, Sanctorius presented a second, advanced version of the beam type *pulsilogium* (Fig. 7.7). Based on the same principle, the pendulum here was not handheld but attached to a horizontal beam which, in turn, was attached to a wall or a fixed vertical stand in order to guarantee stability. The length of the thread could be adjusted by means of a tapered peg mounted to the bottom right of the instrument. Another difference to the first beam type *pulsilogium* was the scale, which was divided here not into the range zero to eighty degrees, but into seventy unnumbered parts or degrees. Fixed to the thread over the scale was a knot or a little wooden bead (letter O in Fig. 7.7), which indicated the degree measured. Based on the empirical testing that Fabrizio Bigotti and David Taylor undertook with their replica of the device, made in the framework of their recent study of Sanctorius's *pulsilogia*, they argued that the beam was actually angled horizontally and not vertically as in Sanctorius's illustration.[11] This means that the broad face of the beam was laid flat with the scale uppermost. The contemporary depiction of a similar device in the frontispiece of the book *De proportione motuum* (On the Proportion of Motions, 1639) by the physician Jan Marek Marci (1595–1667) further corroborates this assumption. It shows a portable version of the *pulsilogium* with the beam angled horizontally (Fig. 7.11). Following this line of argument,

[11] For more information on the technical and empirical factors that led Bigotti and Taylor to assume that the beam of this type of *pulsilogium* was horizontally angled, see: ibid.: 78 ff.

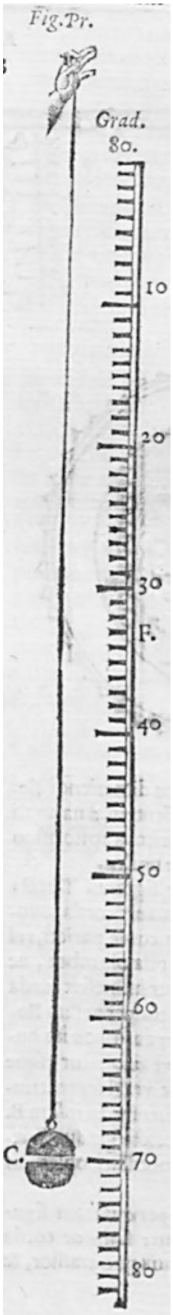

Fig. 7.6 Simple beam type *pulsilogium* (Sanctorius 1625: 22). (© British Library Board 542.h.11, 22.)

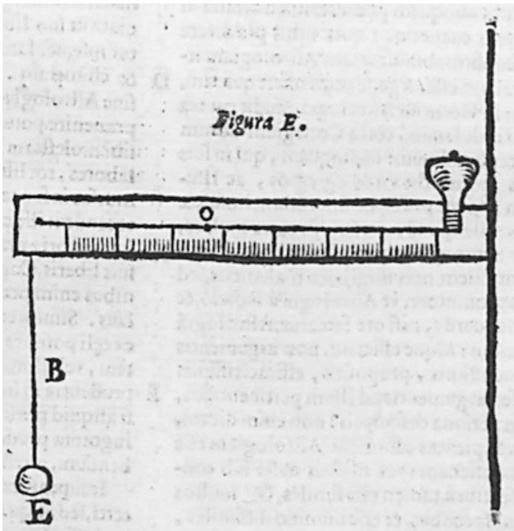

Fig. 7.7 Advanced beam type *pulsilogium* (Sanctorius 1625: 77 f.). (© British Library Board 542.h.11, 77 f.)

Fig. 7.8 First version of a dial type *pulsilogium* (Sanctorius 1625: 220). (© British Library Board 542.h.11, 220)

Sanctorius presented the instrument in perspective in order to show the reader its overall function. However, since the device was mounted to a wall, it is also conceivable that the physician used it horizontally when adjusting the length of the pendulum cord and inclined it vertically afterwards, to facilitate reading the measurement while simultaneously taking his patient's pulse (Sanctorius 1625: 78; Marci 1639: frontispiece; Bigotti and Taylor 2017: 70–82).

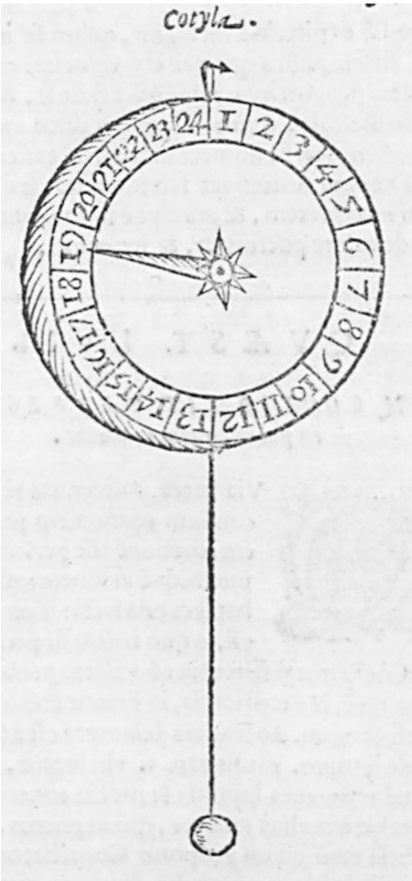

Fig. 7.9 Second version of a dial type *pulsilogium* (Sanctorius 1625: 364). (© British Library Board 542.h.11, 364)

Hence, the design of the second beam type of *pulsilogium* improved the reliability of measurements by avoiding interferences that occurred in the first type due to its manual operation. Moreover, it enabled the physician to adjust the swing rate and to read the cord length while the pendulum was still in motion. Therefore, compared to the simple handheld *pulsilogium*, it provided more reliable measurements and its use must have been more convenient in medical practice.

With regard to the dial type of *pulsilogia*, the illustrations in the *Commentary on Avicenna* suggest that they were likewise based on the use of a pendulum (Figs. 7.8 and 7.9). It seems that the pendulum cord could be wound around a pivot at the back of the dial in order to adjust its length. If, as one may assume, this pivot and the hand on the front of the device were connected, then winding the cord would move the hand and so indicate on the dial the degree measured (Fig. 7.12). The number of degrees into which the dial was divided differed in the two instruments, being twelve in the one, and twenty-four in the other. Interestingly, the *pulsilogium* with the twelve-degree dial seems to have not only a moving hand, but also a moveable dial, as the latter is shown rotated clockwise in the illustration (Fig. 7.8). What is more, Sanctorius occasionally described both devices as *cotyla*, which could be

Fig. 7.10 Pocket watch type *pulsilogium* (Sanctorius 1625: 78, 220, 346). (© British Library Board 542.h.11, 78)

Fig. 7.11 Detail of the frontispiece to Jan Marek Marci's work *De proportione motuum* displaying a *pulsilogium* (Marci 1639: frontispiece). (Courtesy of Niedersächsische Staats- und Universitätsbibliothek Göttingen (SUB Göttingen))

translated as "concave bowl." Against this background, the sketches respectively underneath and behind the dial can be interpreted as some kind of bulky boxes (Sanctorius 1625: 219–22, 364 f.).

Fig. 7.12 Replica of Sanctorius's second version of a dial type of *pulsilogium*. (The replica was made by Loris Premuda for an exhibition held in 1961 at the University of Padua, where it can still be found today. The replica's winding mechanism of is imperfect, since it does not operate smoothly and the connected hand moves through all the degrees on the dial after winding up only a very small length of the cord (Biblioteca medica 'Vincenzo Pinali antica' dell'Università degli Studi di Padova, © Philip Scupin))

In his descriptions of the dial *pulsilogia*, Sanctorius indicated that the instruments measured both time and pulse frequency. It must therefore be assumed that they provided comparisons of degrees. In view of this, the bulky boxes as well as the movable dial might have been part of a special mechanism that allowed the two values to be registered simultaneously—a hypothesis that must, however, be further investigated (Sanctorius 1625: 222).

In this context, it is important to note that Sanctorius intended both devices to measure, besides pulse frequency, also and particularly the respiration cycle. In doing so, he tried to evaluate the difference between the "diastolic" and "systolic" pulses. Whilst this distinction seems somewhat counterintuitive today, since the focus now is on examining the succession of pulse beats, in Galenic medicine the pauses between single pulse beats were thought to be important, too. These pauses were conceived of as the phases of arterial contraction and described as "systolic" pulses, whereas the "diastolic" pulses referred to arterial expansion—hence, the converse of modern terminology. Within a complicated body of theory, the pauses revealed qualitative features such as the pulse's "width" or "breadth," thereby alluding to the dimensions of the arteries. Since, according to Sanctorius, the systolic pulses, i.e., the pauses, were "not made apparent by touching the pulse with our fingers" (Sanctorius 1625: 364), he came up with another method to detect them: via respiration.[12] As explained in Sect. 3.2.6, in Galenic medicine, inspiration corresponded to diastole and expiration to systole. Accordingly, Sanctorius held that if expiration was faster than inspiration, the systolic pulse would be faster than the diastolic pulse, too. Likewise, faster inspiration indicated a faster diastolic pulse. In order to measure the duration of inspiration and expiration, respectively, Sanctorius synchronized the swing of the pendulum with the cycle of respiration. But confusingly, he detected the latter by "putting the hand over the heart" of the patient (Sanctorius 1625: 364).[13] This implies that he actually measured the heart and not the respiration cycle. Most probably, this differentiation was not important, to him, since the medical theory of his day held that these two processes were coincident. However, it did have major implications for his measurements (Sanctorius 1625: 364 f.; 1630: 594; Bedford 1951: 427; Bacalexi and Katouzian-Safadi 2019: 3).

As is known today, diastole and systole are of very brief duration, less than one second. Hence, it is not at all clear how Sanctorius managed to synchronize the swing of a pendulum with these processes. In a general sense, it was certainly possible to determine whether the duration of systole was shorter than the duration of diastole. But measuring the frequency of diastole and systole along a scale of twelve or even twenty-four degrees is questionable, at best. Moreover, it is difficult to understand why the systolic pulses apparently could not be identified by touching the wrist of a patient, but were detectible by feeling the beat of his heart.

Adding to the curiosity, the only measuring result that Sanctorius mentioned in this context was that he usually detected two or three pulses between inspiration and expiration. Hence, he observed here the quantitative relation between pulse and respiration without differentiating between diastolic and systolic pulses. Furthermore, the number of pulse beats to which he referred could not be measured when working with the heart cycle as an indicator of the respiration cycle, due to the problems outlined above. Perhaps his statement that he "put the hand over the heart" has to be interpreted differently. Sanctorius might have simply put his hand on his patient's chest, probably close to the heart, to determine its movement during respiration. In this manner, it would be possible to differentiate the frequency of inspiration and expiration according to different degrees, since respiration is much slower than the processes of systole and diastole. Yet, there remains the problem of how Sanctorius differentiated between diastolic and systolic pulses, since this would have required him to somehow simultaneously account for the pulse beats occurring within the time span of inspiration and expiration, respectively. Moreover, his explicit reference to the heart does not make much sense, if he in fact measured the movement of the chest. Given that Sanctorius did not provide any further details of

[12] "… systole digitis nostris pulsus tangentibus non occurrit …." See: Sanctorius 1625: 364. The English translation is taken from: Bigotti and Taylor 2017: 95.

[13] "… manu ad cor admota, …." See: Sanctorius 1625: 364. The English translation is taken from: Bigotti and Taylor 2017: 95.

these procedures, his alleged measurement of diastolic and systolic pulses via respiration leaves many questions open (Sanctorius 1625: 364).[14]

Still, the analysis of the dial *pulsilogia* did serve to reveal an important dimension of Sanctorius's *pulsilogia*: their close integration into Galenic pulse lore.[15] Indeed, since taking the pulse was, along with uroscopy, the physician's main diagnostic tool at the time, every physician was familiar, at least to some degree, with the pulse teachings of Galen. But even university-trained physicians mentioned that they struggled to understand the complexities of the Galenic ideas, according to which the pulse had many variations in almost innumerable combinations, each of either diagnostic or prognostic significance. Moreover, they doubted whether the Galenic doctrines could be implemented in medical practice, discussing, for example, whether analysis of the pauses between pulse beats, i.e., systolic pulses, was possible in practice. Hence, these contemporary issues seem to reflect, in some way, the difficulties one encounters when trying to interpret Sanctorius's dial *pulsilogia* today. In any case, it is within the intricacies of Galenic pulse lore that Sanctorius's *pulsilogia* have to be seen (Horine 1941: 219; Siraisi 1990: 58–127).

The fifth *pulsilogium*, classified as a pocket watch type, is the one that raises the most questions (Fig. 7.10). In his descriptions of the device, Sanctorius ascribed to it the same function as to the other *pulsilogia*, namely to measure pulse frequency and time. He especially used this type as a timekeeper, during the observations that he made with his thermoscope (Sects. 7.3.2 and 7.3.3). However, the illustrations of the *pulsilogium* do not show a pendulum and Sanctorius never wrote a word about how the device worked. Hence, it is unclear how he took measurements and how these related to the scale, which is arranged in this case in two semicircles. Each of the semicircles is divided into seven parts that represented, so Sanctorius, seven divisions (*differentiae*) and seven subdivisions (*minuta*) (Sanctorius 1625: 77 f., 219–22, 346).

The preceding paragraphs have demonstrated how Sanctorius based most of his different types of *pulsilogia* on the swing of a pendulum. This testifies that Sanctorius, like many others at the time, was familiar with this phenomenon and understood its most fundamental property, the production of equal intervals of time.[16] But given that he provided no mathematical details of his grasp of the properties of a pendulum and limited himself to rather general statements, it is difficult to assess the mechanical reasoning underpinning his *pulsilogia*. An attempt to do so has been made by Bigotti and Taylor, but shall not be discussed here, since such an

[14] A reconstruction of the dial *pulsilogia* and their use could help further clarify how Sanctorius might have measured diastolic and systolic pulses via respiration. This, however, lies beyond the scope of the present work.

[15] I use the term "pulse lore" to refer to the study and examination of the pulse, i.e., to the theories and practices connected with taking a person's pulse.

[16] With regard to pendulum motion, Jochen Büttner has aptly summarized: "A characteristic property of pendulum motion is its period, that is the time it takes the pendulum to complete one full oscillation. The assumption that this period does not depend on the initial displacement has become known as the 'isochronism' of the pendulum. The 'isochronism' of the pendulum holds, according to classical mechanics, only approximately. The full solution of the equation of motion of a pendulum, which requires the use of elliptic integrals, shows that the period does indeed depend on the displacement of the pendulum" (Büttner 2008: p. 227, fn. 11).

analysis lies beyond the scope of the present work.[17] Instead, I will focus in the following on the broader context in which Sanctorius's pendulum-based *pulsilogia* emerged and consider its possible influence on Sanctorius's undertakings.

7.2.2 *The* Pulsilogia *in Context*

Long before Sanctorius, scholars such as Nicole Oresme (1320–1382), Giovanni Marliani (1420–1483), Leonardo da Vinci, and Girolamo Cardano referred to observations made with the pendulum.[18] In Sanctorius's times, pendulums became a part of contemporary technology and were built into various machines serving different functions. There is even evidence that they were used as timekeepers in clocks as early as the sixteenth century. What is more, a whole group of intellectuals, including, for example, Isaac Beeckman (1588–1637), Niccolò Cabeo (1586–1650), and Marin Mersenne (1588–1648), tried to integrate the pendulum into their mechanical theories.[19] Hence, theoretical reflection on the properties of pendulum motion and the practical applications of pendulums occurred at the time when Sanctorius put forward his *pulsilogia*. Remarkably, two figures with whom Sanctorius was well acquainted also dealt with the issue: Paolo Sarpi and Galileo Galilei. Without going into analyses of their respective studies of the pendulum conducted elsewhere, it is enough to note that, once again, Sanctorius's network of friends in Venice, the *Ridotto Morosini*, was an important focal point, where topics of current scholarly interest were discussed.[20] Sarpi and Galileo both frequented the meetings in the house on the Grand Canal and it is therefore most certain that Sanctorius discussed and observed the phenomenon of the pendulum with the two scholars, the former,

[17] Bigotti and Taylor have argued that Sanctorius's theoretical mechanical explanation for the *pulsilogium* drew on an understanding of the Renaissance controversy on equilibrium, see: Bigotti and Taylor 2017: 60–3. For more information on the so-called *equilibrium controversy*, see: Renn and Damerow 2012.

[18] Marliani 1482: 4r, Cardano 1550: 50r–51r, Oresme et al. 1968: I.18, 30a–b, Da Vinci et al. 2018: 383–7, 515 ff.

[19] Illustrations in, for example, the work *Theatrum instrumentorum et machinarum* (1569) by the French engineer Jacques Besson (ca. 1540–1576), or in the work *Machinae novae* (1615) by Fausto Veranzio (1551–1617) show that pendulums were used as parts of different machines in the early modern period. See: Büttner 2008: 228. For more information on the use of pendulums as timekeepers in clocks in the sixteenth century, see: ibid.: 228, fn. 15. For a cursory account of Beeckman's attempt to integrate the phenomenon of the pendulum into his mechanical theories, see: ibid.: 232–5. Marin Mersenne corresponded, for example, with René Descartes (1596–1650) on questions regarding pendulum motion, see, e.g., letters written on October 8, November 13, and December 18, 1629 in: Mersenne et al. 1932–1988. For Niccolò Cabeo, see: Cabeo 1646: 93, 98 f.

[20] For more information on the roles that Paolo Sarpi and Galileo Galilei played in the invention of the *pulsilogium*, see: Bigotti and Taylor 2017: 56 ff. For an account of Galileo's studies on the pendulum, see e.g., Büttner 2019 and for Sarpi, see: Sarpi and Cozzi 1996: 111, 408 ff. There are also studies on the relation between Sanctorius and Galileo, in which the inventions of the *pulsilogium* and the thermometer have been of particular interest, see: Bizzarrini 1947, Grmek 1967, Ongaro 2009.

moreover, being his close friend. Yet, recent historical research suggests that it was Sanctorius who first applied the pendulum as a timing device to medicine and that his *pulsilogia* did not result from Galileo's studies of the pendulum, but were rather a source of inspiration for Galileo. Notwithstanding that physicians like Cardano had been interested in the pendulum before Sanctorius, they did not consider its application in a medical context (Büttner 2008: 227–32; 2019: esp. 91 f., fn. 32).

Just as the phenomenon of the pendulum was a topic of great contemporary interest, the counting of the pulse was also practiced at the time. Since the clocks that were then available did not allow brief intervals of time to be measured with any precision, scholars, especially astronomers, used the pulse for this purpose. The pulse beat was a tangible parameter, and hence a suitable measure able to be counted within the longer periods of time that could already be determined rather accurately by clocks, i.e., the period of one hour. In his work *De proportionibus* (On Proportions, 1570), Girolamo Cardano, for example, illustrated very fast movements in the heavens, like those of the moon, by converting the incredibly wide distance covered in one hour into the distance covered during one pulse beat. In this context, he tried to determine the number of pulse beats per hour and came to the fairly accurate number of four thousand pulse beats, which corresponds to sixty-seven beats per minute. Later, in 1618, Johannes Kepler counted the pulse in relation to minutes and assessed that the pulse of a healthy man at rest corresponded to an average of seventy beats per minute. Accordingly, his count could provide a rather reliable indication of the time elapsed in any given observation. However, these attempts did not aim to measure the pulse per se. Rather, they were informed by a general interest in the relation between the human pulse and time, or by the effort to improve the precision of the pulse as a timekeeper (Cardano 1570: 50; Kepler 1618: 278 f.).

But, besides these, there was also an effort to measure the pulse frequency related to medical practice. As was discussed in Sect. 5.3.2, in the fifteenth century, Nicolaus Cusanus already suggested using a water-clock to compare the pulse of different people, in health and in disease. This would help the physician, so Cusanus, in diagnosis, prognosis, and therapy. From the evidence at hand, it is highly probable that Sanctorius knew of his work and was inspired by it to pursue his quantitative approach to medicine. Thus, there is good reason to assume that Sanctorius took from Cusanus's work *De staticis experimentis* the idea of measuring the pulse with an instrument that could record equal intervals of time. As likewise mentioned, Cusanus also put forward the idea of measuring respiration by the same method, based on the water-clock. Interestingly, a good hundred years later, Cardano examined the quantitative relation between pulse and respiration. Moreover, contrary to his count of pulse beats per hour, he did so in a medical context, in his commentary on the Hippocratic treatise *Nutriment* (*Commentaria in librum Hippocratis de alimento*, 1574). He concluded that, independent of age and complexion, this relation would always be 3:1. Given that Cardano did not explain how he arrived at this ratio, whether he used an instrument to this end or not, it is difficult to assess the relation of his observation to Cusanus's proposed measurement of respiration using the water-clock. It is known that Cardano was familiar with the mathematical thoughts of Cusanus, but due to the fact that Cusanus, unlike Cardano, did not consider the relation between respiration and pulse, but suggested measuring both parameters with a timekeeping instrument, it is doubtful whether the two undertakings were in any way related. Yet, it seems significant that Sanctorius knew both authors and presented a method of his own to measure the respiration cycle in comparison with the pulse. By means of his dial *pulsilogia*, he allegedly observed that there were usually two or three pulses between inspiration and expiration. While it is most certain that Cusanus's *De staticis experimentis* stimulated Sanctorius in his measurement of respiration, it remains unclear whether Sanctorius was aware of Cardano's quantification of the relation between pulse and respiration. Notwithstanding that Sanctorius frequently mentioned him in his commentaries, I could not find any reference to Cardano's commentary on *Nutriment*. At any rate, at least in hindsight, Sanctorius's solution appears to be a combination of Cusanus's and Cardano's efforts (Cardano 1574: 230v; Sanctorius 1625: 364; Kümmel 1974: 4–12).

In summary, it can be said that the phenomenon of the pendulum, occasionally already applied as a timekeeper in clocks, was of interest to scholars, practitioners, and engineers both before and contemporary to Sanctorius. It was a part of contemporary technology as well as of intellectual reflection and discourse. Most likely, it was among the subjects that Sanctorius discussed with people like Sarpi and Galileo in the *Ridotto Morosini*. In a similar manner, the counting of the pulse was a current means to measure time, especially in astronomy. What is more, the importance of assessing the frequency of the pulse in a medical context had been recognized long before Sanctorius by Cusanus, who had suggested that respiration be measured, too. In the sixteenth century, Girolamo Cardano not only studied the motion of the pendulum, but also counted the pulse and compared the frequency of pulse with the frequency of respiration. However, it was Sanctorius who brought these different strands of contemporary interest and investigation together by devising a series of instruments called *pulsilogia*. Most importantly, he put his instruments at the service of medical practice and was thereby the first to *apply* the pendulum and the measurement of the frequency of the pulse to medical diagnosis, prognosis, and therapy.

The Reception of the *Pulsilogia* Following Sanctorius's description of the *pulsilogium* in the *Methodi vitandorum errorum*, many other physicians and scholars remarked on the device. And in fact, someone else had already announced it in writing, a year before Sanctorius first did. This was Eustachio Rudio (1548–1612), professor of practical medicine at the University of Padua and a member of the College of Physicians of Venice, who died shortly after Sanctorius, too, entered these two institutions (Facciolati 1757: 332 f.; BNMVe n.d.: f. 23r). Rudio wrote in a treatise on the pulse (*De pulsibus libri duo*, 1602):

> I just want you to know that in our age an instrument, which it is possible to call a *pulsilogium*, has been invented in order to discern the quickness and slowness of the pulse. Its author is Sanctorius Sanctorius, a physician, a philosopher, and a man provided with all kinds of erudition (Rudio 1602: 23v).[21]

[21] "Sed pro crebritate & raritate dignoscenda unum volo vos admonere, hac scilicet nostra tempestate quoddam instrumentum, quod pulsilogium vocari potest, fuisse excogitatum à Sanctorio Sanctorio Medico & Philosopho, & omni eruditionis genere praestantissimo, …." See: Rudio 1602: 23v. For the English translation, see: Bigotti and Taylor 2017: 58.

Hence, Sanctorius must have already shown the *pulsilogium* to his friends and colleagues in Venice around 1600. In a collection of opinions on medical and philosophical problems published in 1611, the Venetian physician Antonio Fabri (life dates unknown) stated that he had had the opportunity to participate in a demonstration of the *pulsilogium* by Sanctorius. Johannes Ravius (1578–1621), a physician from the German town Rinteln (today, in Lower Saxony), reported from a visit to Padua in 1618 that Sanctorius's instruments were especially remarkable, among them, a *pulsilogium*. Three years later, in 1621, another German physician, from Rostock, Peter Lauremberg (1589–1635), claimed to have replicated and successfully applied the *pulsilogium* to examine the usually imperceptible differences in the pulse rate. Lauremberg's account is interesting, since at this time Sanctorius had not yet published his *Commentary on Avicenna*, which contained the illustrations of his *pulsilogia*. Consequently, Lauremberg could not rely on any printed depiction of the *pulsilogium* for the design of his replica. It seems that he was not in direct contact with Sanctorius either, as he explained that he had heard from others that Sanctorius was the inventor of such an instrument ("*qualia à Sanctorio excogitata accepimus*"). This implies that he had to rely on oral accounts or manuscript sheets describing the instrument, and also supports Sanctorius's complaint of 1625, that his instruments were known to, and copied by his disciples across Europe. However, given that Lauremberg neither published an illustration of his version of the *pulsilogium* nor gave any details of its design or use, it remains uncertain whether he really did devise and deploy such a device. A few years later, according to his own testimony, Isaac Beeckman took inspiration from Sanctorius's *pulsilogia* for his observations on vibrating chords (Bartholin 1611: Exercitatio Nona, Problema VIII; Johannes Ravius to Ernst Schaumburg-Holstein 1618; Lauremberg 1621: 28 f.; Beeckman and de Waard 1945: 174 f.).

The list of references to Sanctorius's *pulsilogia* in the first half of the seventeenth century and beyond could be extended much further.[22] However, the few names cited should suffice to show that Sanctorius's *pulsilogia* were well known among physicians and scholars in Europe and, probably, also copied. As stated above, Marek Marci put forward his own *pulsilogium* based on the properties of the pendulum (Sect. 7.2.1). The same is true of Athanasius Kircher (1602–1680), but neither scholar alluded to Sanctorius. Whether Marci and Kircher had direct knowledge of Sanctorius's devices or not, their instruments further attest the spread of *pulsilogia* in the seventeenth century. It seems therefore that Sanctorius, in inventing the *pulsilogium*, had put a finger on the pulse of his era—if you will excuse the pun. The contemporary interest in, and preoccupation with the pendulum phenomenon, combined with the concern for timekeeping methods, including the counting

[22] Further examples for references to Sanctorius's *pulsilogia* are Malvicini 1682: 213, Schwenter 1636: 415 f. While Giulio Malvicini was a student of Sanctorius in Padua and therefore probably saw the instruments in Sanctorius's university courses or private lessons, the German scholar Daniel Schwenter heard about the device from a physician (*doctore medicinae*) and erroneously assumed that Sanctorius lived and practiced in Paris ("Santes Sanctorius ein sehr berühmter Medicus zu Paris hat ein Instrumentum von ihme Sphigmaticum genennet erfunden: ….").

of the pulse, can certainly explain the immediate and enthusiastic reception and broad dissemination of Sanctorius's *pulsilogia*. What is more, the utmost relevance of pulse lore as one of the physician's main diagnostic tools probably further fueled interest in a device that heralded a marked improvement in his daily practice of "taking the pulse" of his patients (Marci 1639: Propositio XXXXI, Problema II; Kircher 1665: 51 f.).

Establishing the extent to which *pulsilogia* instruments actually entered into daily medical practice would require further research, however. Around 1714, Giovanni Battista Morgagni mentioned Sanctorius's *pulsilogium* in his university lectures in Padua on Galenic pulse lore, but it is clear from his words that it had not yet become a standard tool for physicians and that even if Morgagni himself used such a device, it played no major role in his medical practice.[23] Interestingly, it is not clear even how much Sanctorius used his *pulsilogia* in his daily practice. He did repeatedly use the plural when referring in his published works to the subjects of his measurements (*sani*/*aegri homines*), and stated that he was able to distinguish 133 variations in the frequency of the pulse. This implies that he made considerable use of the *pulsilogia*. However, Sanctorius did not further specify the 133 distinctions; how exactly he determined them as well as how they relate to the scales on the *pulsilogia* remains unclear. Furthermore, the ratio that he put forward regarding respiration and pulse is the only numerical outcome of his procedures with the *pulsilogia* that he mentioned. In addition, the technical interpretation of the dial type of *pulsilogia* casts some doubt on their practicability and usability (Sect. 7.2.1). Still, it should not be overlooked, here, that physicians at the time were very experienced in the practical challenges of determining a patient's pulse, and this assured at least some of them a considerable sensitivity also to minute variations in pulse. Thus, handling Sanctorius's *pulsilogia* might have been much easier for contemporary practitioners than one can imagine today. In fact, the experiments made by Bigotti and Taylor with their replica of the second, more advanced, beam type of *pulsilogium*, showed that at least this type of instrument can be conveniently used even by non-physicians and provides very reliable measurements. Last but not least, Sanctorius often directed his readers to his planned but never published book *De instrumentis medicis* for more information on his *pulsilogia*, which might explain the lack of data on the quantitative outcomes of his measurements in his other works. In any case, the French physician François Boissier de Sauvages de Lacroix (1706–1767) explained as late as 1752 that he worked with a Sanctorian *pulsilogium* in order to measure the pulse of his patients, and he recommended its use (Sanctorius 1603: 109r–109v; 1612b: 229 f.; 1625: 77 f., 364 f.; Boissier de Sauvages de Lacroix 1752: 30 f.; Morgagni et al. 1961: 64, 70).

From a preliminary perspective, it does not seem that the measurement of pulse frequency became a major component of pulse theory or of the practice of taking the

[23] Morgagni stated with regard to Sanctorius's *pulsilogium*: "Qua in differentia ut omnes mutationes quae possunt contingere certò diagnoscamus, excogitavit Sanctorius Instrumentum Pulsilogium ipsi vocatum, cuius descriptionem, et imaginem dedit in Comment. Fen p. 29 et 310." See: Morgagni et al. 1961: 64.

pulse subsequent to Sanctorius's *pulsilogia*. This notwithstanding, his instruments immediately attracted considerable attention among physicians and were well known across Europe in the seventeenth century. Remarkably, François Boissier de Sauvages de Lacroix still considered a Sanctorian *pulsilogium* a useful device for measuring a patient's pulse more than a century after its invention. Hence, the question of the practical medical application and usability of Sanctorius's own *pulsilogia* as well as of the replicas made by others remains certainly a difficult one. Without attempting to answer it, here, a closer examination of the purposes that Sanctorius ascribed to the instruments will shed more light on his use of them, and provide some possible explanations for their immediate and long-lasting popularity.

7.2.3 The Purpose of the Instruments: What Did the **Pulsilogia** *Measure?*

As explained above, Sanctorius applied various scales to his *pulsilogia* which differ in terms not only of form, i.e., beam, dial, or semicircle, but also of division. They range from eighty, seventy, twenty-four, or twelve to seven degrees, each degree of which, in the latter case, is further subdivided into seven degrees.[24] Still, they have one thing in common: they are all linear. Consequently, Sanctorius's *pulsilogia* did not permit a direct reading of pulse frequency and provided only a relative measurement. In fact, Sanctorius intended them exactly for this purpose. According to him, the *pulsilogia* should be used as comparators. In the *Methodi vitandorum errorum*, he highlighted that:

> we should know … how exactly the pulse of the previous attack [of disease] compares with the present pulse. For only from this comparison can we obtain a certain and infallible judgement on whether the patient is in a better or worse condition. … I invented "a device that measures the pulse" [*pulsilogium*], by means of which everyone can precisely measure the movement and the rest of arteries, observe and firmly remember, and subsequently make a comparison with the pulses of the previous days (Sanctorius 1603: 109r).[25]

Thus, the *pulsilogia* enabled the physician to take repeated measurements of the pulse of his patients, in health and in disease, which he could remember and directly compare with each other. Comparison was central to this process whereas the measurement of absolute values of the pulse rate was irrelevant. The instruments showed

[24] The various scales that Sanctorius applied to his *pulsilogia* are difficult to interpret and most probably represented different measurement resolutions. For more information, see: Bigotti and Taylor 2017: 72–6.

[25] "… sciamus exactè conferre pulsus praeteritarum accessionum cum pulsu praesentis; quoniam solum ex hac collatione certum & infallibile iudicium colligemus, an aeger sit in meliori, vel deteriori statu; … instrumentum pulsilogium invenimus in quo motus, & quietes arteriae quisque poterit exactissime dimetiri, observare, & firma memoria tenere, & inde collationem facere cum pulsibus praeteritarum dierum; …." See: Sanctorius 1603: 109r. The English translation is based on: Bigotti and Taylor 2017: 87 f.

the variation of the pulse through time and allowed health trends in patients to be monitored. In this context, the focus was on the small increases or decreases in the pulse frequency, so Sanctorius, since, without a *pulsilogium*, these were very difficult, if not impossible, to perceive, even by well-trained physicians. Accordingly, his instrument was meant to overcome the limits of the physician's senses and to allow him to determine what would otherwise remain obscure and unknown (Sanctorius 1625: 21 f.; 1629: 135 f.).

It is pertinent here to again mention the similarities between Sanctorius's use of his *pulsilogia* and Cusanus's proposed measurement of the pulse by means of a water-clock. Like Sanctorius, Cusanus suggested a comparative measurement of the pulse that would result in relative values for the pulse frequency. While Sanctorius used the length of a pendulum cord as the reference parameter, defining it by means of different scales, Cusanus suggested measuring the weight of the water which fell from a water-clock during the time of one hundred pulse beats (Sect. 5.3.2). He probably thought that this would make the measurements easier to communicate and to compare, given the lack of standard units of measurement. However, as standardized water-clocks didn't exist either, at the time, the reliability of his measurements would still have depended on using absolutely identical devices. Be this as it may, the fact that Sanctorius used his *pulsilogia* as comparators, a method that had been already suggested by Cusanus in his *De staticis experimentis*, further implies that Sanctorius was inspired by the latter work (Kümmel 1974: 3).[26]

In keeping with Sanctorius's effort to determine the quantity of diseases by means of his four measuring instruments, Sanctorius's *pulsilogia* was meant to record, as it were, the "latitude of the pulse" and thus help determine the deviation of a body from its natural, healthy state (Sect. 6.1.1). But the frequency of the pulse was only one of several parameters that indicated whether a pulse was healthy or not. In fact, according to Sanctorius, frequency *per se* was equivocal, since the frequencies of a healthy pulse might include frequencies that could also be found in morbid states. Therefore, it was necessary first to assess the general condition of the patient, so that changes in frequency could be associated, for example, with diseases such as fevers. What is more, the physician had to determine how the pulse of his patient fitted within the Galenic classification of pulses. As mentioned earlier, this was a complicated body of theory, according to which variations of the pulse were broken down into several different components, which included, besides frequency, the dimensions of the arteries and the strength of pulse beats. A good illustration of the way in which Sanctorius used his *pulsilogia* within this context of standard Galenic medicine is his repeated emphasis on the possibility of distinguishing, with his *pulsilogia*, between the *pulsus invalidus* and the *pulsus humilis*, two types of pulses specified by Galenic pulse lore. He explains:

[26] It is interesting to note in this context that the French physicist Guillaume Amontons (1663–1705) tried to substitute Sanctorius's *pulsilogium* with a water-clock in 1695. Most probably he was ignorant of Cusanus's work *De staticis experimentis*, as he made no reference to it. See: Amontons 1695: Avertissement, Bigotti and Taylor 2017: 69.

> if the pulse that was previously strong and frequent decreases in strength and frequency it will be called *humilis*, whereas it will be called *invalidus* when it mostly does not present such a condition, that is, of becoming quieter: if the difference between the major or minor frequency is very small, physicians cannot distinguish it without the *pulsilogium* (Sanctorius 1629: 137).[27]

Thus, it was important for the physician to detect not only the frequency of the pulse, but also its strength, in order to decide whether the patient had a *pulsus humilis* or *invalidus*. Only with regard to frequency could the *pulsilogium* provide reliable measurements, due to its ability to detect also minute variations. This illustrates again that Sanctorius's *pulsilogia* were strongly integrated into Galenic medicine. Against this backdrop, they served to ascertain one of several variables that occurred in the pulse over time: its frequency. For the other variables, the physician still had to rely on traditional qualitative assessments of the pulse. Given the persistence of Galenic pulse theory—Galenic observations of the pulse being still included in standard sphygmology textbooks in the late nineteenth century (Nutton 2019: 472 f.)—I consider it plausible that it was precisely its strong roots in Galenic pulse lore that guaranteed the enduring popularity of Sanctorius's *pulsilogia*—a hypothesis that does, however, need further investigation.[28]

To conclude, Sanctorius's *pulsilogia* allowed physicians to collect, record, and compare the frequency of the pulse of their patients. By this means, not only health trends in individual patients could be detected, but general ranges of healthy or morbid pulses could be determined, provided that enough measurements were taken in healthy and sick people. In this connection, comparisons would be made between the data measured not only of one patient, but of several. However, before using the instrument, the general condition of the patient had to be assessed and the measurements always needed to be related to Galenic pulse lore with its classification of different pulse species and its qualitative methods of determining the pulse. Still, within the intricacies of pulse lore, the measurements with the *pulsilogia* could provide reliable reference points, permitting the "latitude of the pulse" to be shown, i.e., its variation in healthy and unhealthy conditions, expressed comparatively in degrees. Since Sanctorius published neither records nor results of his measurements, it remains unclear how often he used the device and on how many different people. Notably, the *pulsilogium* was the first and only measuring instrument whose description Sanctorius published as early as 1603. From his written records it can be assumed that he had already been engaged for several years in his observations of insensible perspiration with the weighing chair, by this time, and it is also probable that he conducted the studies on his two steelyards to measure climatic conditions before 1603 (Sects. 2.2 and 6.1.2). This notwithstanding, it was only the *pulsilogium* that Sanctorius mentioned in the *Methodi vitandorum errorum*, without

[27] "… si pulsus, qui antea fuit vehemens & frequens remittat vehementiam & frequentiam, dicitur humilis: invalidus verò ut plurimum caret hac conditione, quod scilicet fiat quietior: haec maior vel minor frequentia si perexigua sit, à medicis sine pulsilogio dignosci non potest." See: Sanctorius 1629: 137. The English translation is taken from: Bigotti and Taylor 2017: 96 f.

[28] On the long-lasting relevance of the Galenic doctrine of the pulse, see: Tassinari 2019: 514 f.

reference to any other devices. Moreover, nowhere did he relate the use of the *pulsilogia* to the six non-natural things or to insensible perspiration, despite their evident strong connection, as illustrated, for example, by the fact that certain emotions or forms of exercise accelerate the pulse. It seems, therefore, that Sanctorius did not use the *pulsilogia* in relation to his static observations, but nonetheless ascribed great importance to these instruments, probably also with regard to his own medical practice, given their early description in his published work. The strong interest in the device among other scholars, such as his colleague Rudio, might have confirmed him in this view.

7.3 The Thermoscopes

The historical development of the thermometer has long attracted intensive scholarly attention and Sanctorius's thermoscopes are no exception in this regard.[29] In the following, I will briefly outline the basic features of these instruments and Sanctorius's use of them, and consider the historical context in which they emerged. Adding to the existing literature, I will present some further reflections on Sanctorius's application of the thermoscopes to medical practice within the framework of Galenic fever theory and the doctrine of the six non-natural things. Moreover, I will examine his exceptional use of the device to demonstrate the falsity of an astrological argument.

7.3.1 Design and Basic Functioning of the Thermoscopes

Sanctorius first referred to his thermoscopes in 1612, in the second volume of his *Commentary on Galen*. Two years later, he mentioned them again in an aphorism of the *De statica medicina*, but, as with all of his instruments, he published descriptions and illustrations of the thermoscopes only in the *Commentary on Avicenna,* in 1625. He put forward six different versions of the device, most of them equipped with a scale and thus, already representing thermometers (Figs. 7.13, 7.14, 7.15, 7.16, 7.17, and 7.18).[30]

The basic design and functioning of these thermoscopes is the same and can be summarized as follows. Each consists of a tiny vessel full of water at its base, from which a thin pipe vertically emerges, the upper part of which mostly leads to a bowl.

[29] Recent studies on the historical development of the thermometer are Borrelli 2008, Valleriani 2010: 155–90 and Bigotti 2018. The following account of Sanctorius's thermoscopes draws largely on these studies.

[30] I refer to "thermoscopes" rather than "thermometers," when writing generally about the devices that Sanctorius suggested to measure degrees of heat and cold, since not all of them are thermometers, i.e., equipped with a scale.

The bowl and the upper part of the pipe are empty, i.e., filled only with air. By, for example, touching the bowl, the air is heated and expands, pushing the water downwards. In the absence of touch, the air cools and contracts, which tends to create a vacuum and hence pull the water upward. Since the device is not hermetically sealed, expansion and contraction of the air occur, owing to changes not only in temperature, but also in pressure. However, the influence of atmospheric pressure was still unknown in Sanctorius's day (Sanctorius 1612b: 62, 105, 229, 375; 1614: 20v–21r; 1625: 7, 22 ff., 76 f., 144, 215, 219–22, 304 ff., 346, 357, 360).[31]

Without analyzing the design of Sanctorius's different versions of thermoscopes in detail, I just want to point out a few aspects which highlight the particular, medical application that Sanctorius foresaw for these instruments. In the *Commentary on Avicenna*, he explained that he had adapted the device "so that it serves to discern the cold and hot temperature of the air, and of all parts of the body, and to learn the degree of hotness of those who have fever" (Sanctorius 1625: 23).[32] Following the basic design described above, in order to determine the "temperature" of his patients, Sanctorius had them touch the bowl at the top of the device, which enabled him to measure the heat of the skin of their hand (Figs. 7.13 and 7.18). Furthermore, Sanctorius put forward thermoscopes in which the bowl was exchanged either for a small ball that the patient could take into his mouth (Fig. 7.15), or for a semicircular top piece that could be attached to different body parts (Fig. 7.16) or, in a slightly different version, could be breathed into (Fig. 7.17). As stated above, most of these devices have a graded scale (Figs. 7.14, 7.15, 7.16, 7.17, and 7.18) and only in the initial versions of the thermoscope were measurements recorded, as Sanctorius himself explained, by means of a compass.[33] In the first illustration of a thermoscope in the *Commentary on Avicenna*, one can see two threads round the tube, which presumably could be moved to mark the level of liquid in it (Fig. 7.13).[34] Even though Sanctorius depicted most of his thermoscopes with a scale already in the *Commentary on Avicenna*, he explained only five years later, in a second revised edition of the *Commentary on Galen*, how he obtained such a scale. He determined terms of comparison for its extremities, i.e., for the hottest and coldest temperature, so that he could divide the scale as he wished. He found those terms in snow and the fire (or flame) of a candle (Sanctorius 1612b: 62, 229; 1625: 23, 219–22; 1630: 762; Middleton 1969: 45 f.).

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[31] For an entirely different view, see: Bigotti 2018. In conjunction with his assertion that Sanctorius adopted a corpuscular theory, Fabrizio Bigotti has argued that Sanctorius was aware of the influence of atmospheric pressure and that some of his thermoscopes worked as sealed instruments.

[32] "Nos verò illud accomodavimus, & pro dignoscenda temperatura calida, & frigida aeris, & omnium partium corporis, & pro dignoscendo gradu caloris febricitantium, …." See: Sanctorius 1625: 23. The English translation is taken from: Borrelli 2008: 109 f.

[33] The marks along the tube of the thermoscope, which Sanctorius designed to measure the heat in the patient's mouth, most probably represent tick marks (Fig. 7.15).

[34] Interestingly, Sanctorius replaced this illustration with a less elaborate sketch of a thermoscope in the second edition of his *Commentary on Avicenna*, published only one year after the first, in 1626. See: Sanctorius 1626: 22, Bigotti 2018: 80, 92.

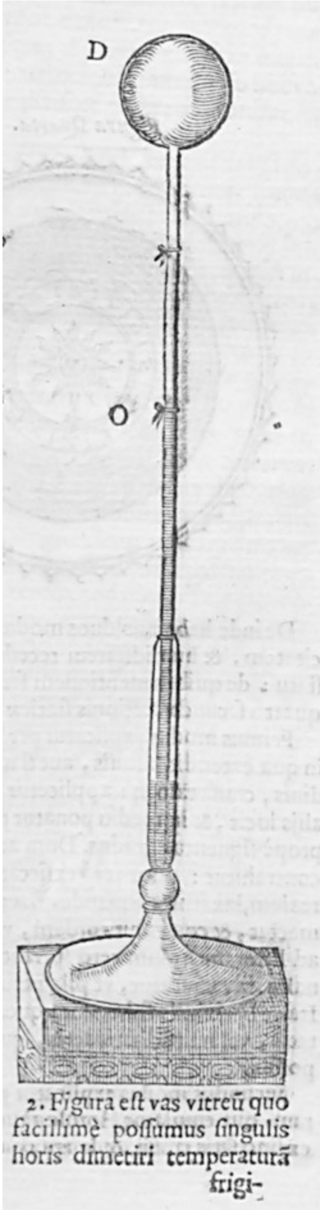


Fig. 7.13 Sanctorius's first illustration of a thermoscope (Sanctorius 1625: 22). (© British Library Board 542.h.11, 22)

7.3.2 *What Did the Thermoscopes Measure?*

The above quote shows that Sanctorius applied his thermoscopes to the outside air and to the his patients' body parts. With regard to the latter, the theoretical context was, of course, again the Galenic concept of latitudes (Sects. 5.2.1, 5.2.2, and 6.2.1).

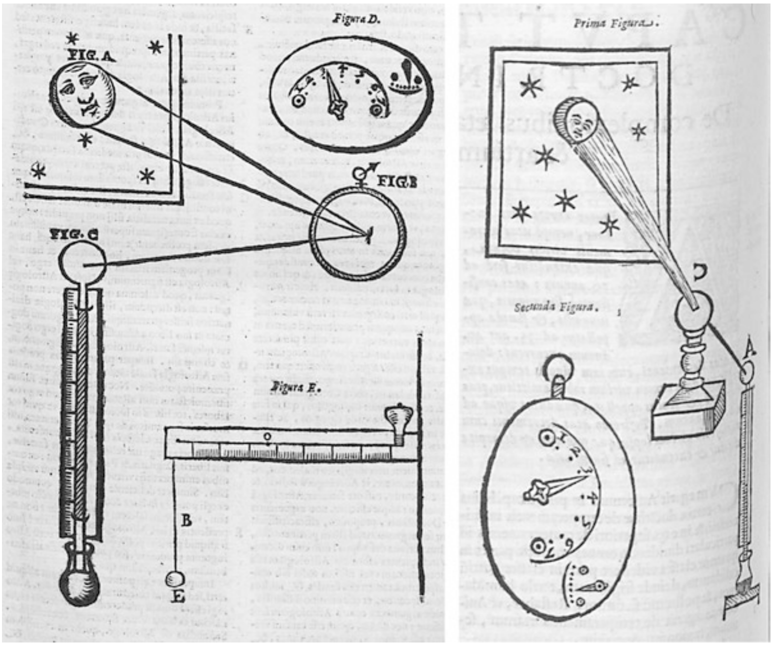


Fig. 7.14 Illustrations of a procedure to measure the heat of the moon by means of thermometers (left: Fig. C, right: letter A) (Sanctorius 1625: 77, 346). (© British Library Board 542.h.11, 77, 346)

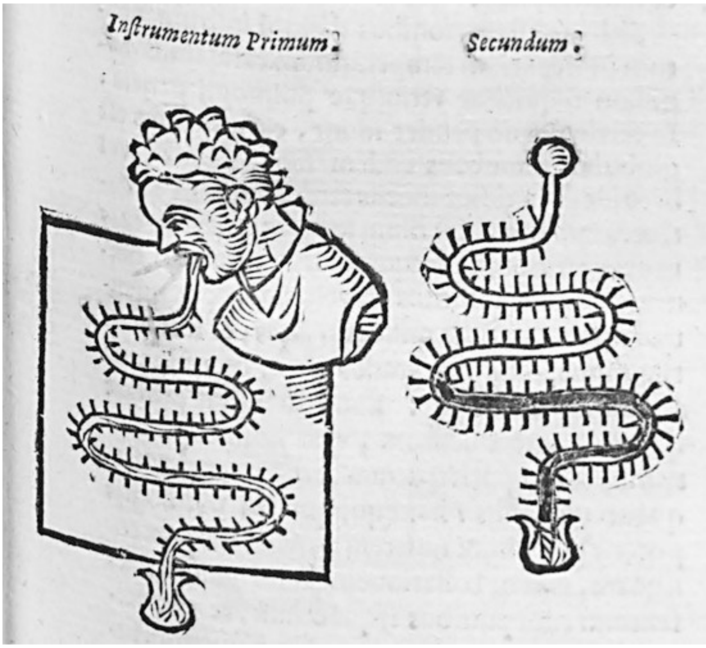


Fig. 7.15 Thermometers to measure the heat in the mouth of the patient (Sanctorius 1625: 219). (© British Library Board 542.h.11, 219)

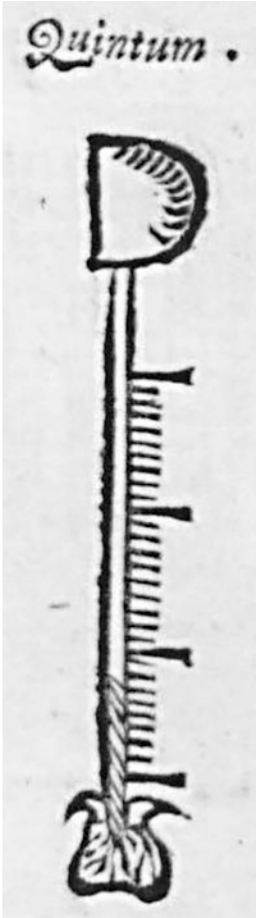


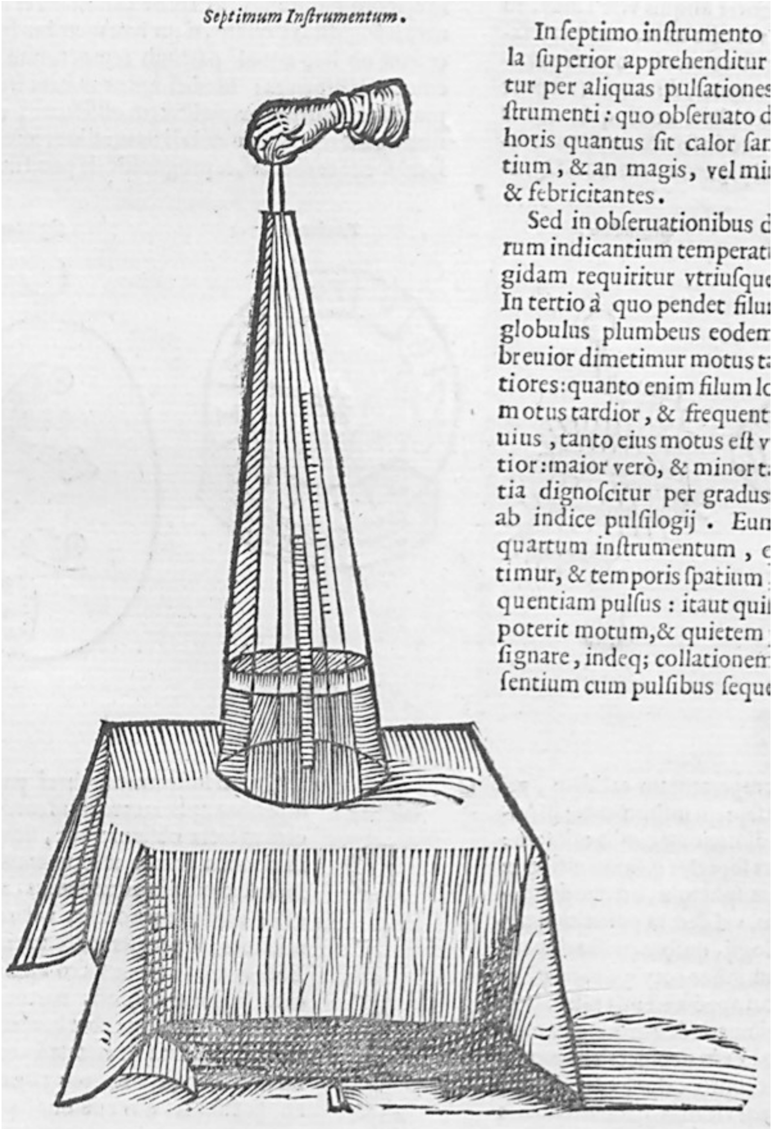
Fig. 7.16 Thermometer to measure the heat of body parts (Sanctorius 1625: 220). (© British Library Board 542.h.11, 220)

By using a thermoscope to determine the degrees of hot and cold in the complexion of a patient, the physician no longer needed to rely on his sense of touch, as Sanctorius remarked, but had an instrument at his disposal that allowed measurements to be taken repeatedly, and to be compared, even more accurately so when the instrument was equipped with a scale. The direct connection to Galen's teachings is particularly evident in the way in which Sanctorius developed the scales for his instruments. As mentioned earlier, Galen already had suggested measuring the temperate complexion as the medium against the extremes found in reality—ice and boiling water, or fire (Sect. 5.2.2). Thus, Sanctorius replaced Galen's subjective appreciation of the primary qualities of hot and cold by means of the hand of the physician with his thermoscopes. But, he used the same method as proposed by Galen in order to define a point of reference for comparing degrees of hot and cold. This point was a body's natural, healthy state, the balanced complexion. Accordingly,

Fig. 7.17 Thermometer to measure the breath of the patient (Sanctorius 1625: 221). (© British Library Board 542.h.11, 221)

despite the fact that Sanctorius used the same vocabulary as is used today for temperature measurement, his notion of "temperature" was, to be sure, very different from the modern one (Sanctorius 1625: 357, 360; 1630: 262 f., 762).

In order to know the quantity of diseases, that is, the deviation of a body from its natural, healthy state, it was important, per Sanctorius, to measure the temperature not only of the skin of the hand, but also of other body parts. As was seen, he adapted the design of the thermoscopes, so that they could measure the temperature of the breath, or of inside the mouth, or of other body parts. In this context, Sanctorius especially referred to the ability of the instruments to measure the "hot or cold temperature of the heart." Measuring the temperature of the heart was of particular importance since, according to Galenic medicine, the body's innate heat originated in the heart and was distributed from there throughout the whole body. It was specifically relevant for fever patients, so Sanctorius. Following contemporary Galenic views of fever, Sanctorius conceived of the disease as a qualitative change in the innate heat. Hence, the organ which was first affected by fever was the heart. From here, Sanctorius explained, the febrile heat arrived at the other organs, affecting their innate heat, too. It seems that Sanctorius understood the measurement of the temperature of the heart with his thermoscopes in the literal as well as the figurative sense. He explicitly stated that the thermometer with the semicircular top piece


Septimum Inſtrumentum.

In ſeptimo inſtrumento
la ſuperior apprehenditur
tur per aliquas pulſationes
ſtrumenti : quo obſeruato d
horis quantus ſit calor ſar
tium, & an magis, vel mi
& febricitantes.
Sed in obſeruationibus d
rum indicantium temperat
gidam requiritur vtriuſque
In tertio à quo pendet filu
globulus plumbeus eoden
breuior dimetimur motus t
tiores: quanto enim filum lo
motus tardior, & frequent
uius, tanto eius motus eſt v
tior: maior verò, & minor t
tia dignoſcitur per gradus
ab indice pulſilogij. Eun
quartum inſtrumentum, e
timur, & temporis ſpatium
quentiam pulſus: itaut qui
poterit motum, & quietem
ſignare, indeq; collationem
ſentium cum pulſibus ſequ

Fig. 7.18 Thermometer to measure the heat of the palm (Sanctorius 1625: 221). (© British Library Board 542.h.11, 221)

(Fig. 7.16) should be applied to the region of the heart to detect whether the heat of the heart increases, decreases, or remains constant. Given that the principal product of respiration was thought to be the heat which was generated and distributed by the heart and the arteries, Sanctorius could determine the heat of the heart also by measuring the breath of his patients (Fig. 7.17). The thermometer whose upper part could be inserted into the mouth was probably also intended by him to measure the breath of the patient (Fig. 7.15). Or, he referred here to an indirect measurement of the heart's heat because all body parts received heat from this organ. Sanctorius most certainly had this in mind with regard to the thermometer that the patient should touch with the palm of his hand (Fig. 7.18). As described above, according to Galenic medicine, the most temperate part of the body was the skin of the hand, which was why it was able to give a rather reliable indication of the general complexion of the patient (Sect. 5.2.2) (Sanctorius 1625: 219–22; 1629: 312, 355 f.; Lonie 1981: 20–8).

As the preceding paragraph suggests, besides the concept of latitudes, traditional fever theory provided the framework for Sanctorius's use of his thermoscopes. Since fever was a central preoccupation of early modern medicine with its main diagnostic sign being heat, an instrument that could measure changes in bodily heat must have seemed especially promising to practicing physicians.[35] Yet, the "quantity" of heat was only one parameter that served to differentiate between normal, healthy heat and febrile heat, which was also characterized by qualitative adjectives such as "sharp" (*acris*) or "biting" (*mordax*)—by differences of kind rather than just of degree. Moreover, besides hotness, a patient's pulse, tongue, respiration, skin, visage, eyes, bowels, or urine indicated a fever's character. Indeed, Galenic fever theory specified many different fever types and sub-types that a physician had to distinguish. On the basis of the substances involved in the production of heat—vital spirits, humors, and flesh—three main genera of fever were identified: *ephemeral*, *putrid* or *humoral,* and *hectic* fevers. Another distinction of fevers referred to its frequency of presentation, an example being the intermittent fevers. Here, the differentiation resulted from the observation that there was a specific regularity or intermittency that was independent of age, constitution, diet, and other variables. These brief remarks on traditional fever lore should be enough to delineate that the Galenic concept of fever was certainly very different from today's, with hotness, albeit important, being only one of several symptoms of the disease. Within this framework, the repeated and comparative measurement of heat by means of a thermoscope certainly helped the physician to observe health trends in his patients and to diagnose fevers. However, since there was no single measure to diagnose fever, the degrees of hot and cold that he determined always needed to be related to the Galenic teachings on fever with their qualitative methods and classification of various fevers (Siraisi 2012: 504; Hamlin 2014: 4–64; George 2017: 31 f.).

Interestingly, in his discussion of fever and febrile heat in the *Commentary on Hippocrates*, Sanctorius did not even mention his thermoscopes. Nor did he refer to the instruments in the *De statica medicina*, when dealing with the topic of fevers.

[35] For more information on Renaissance fever pathology, see: Lonie 1981. This is, however, the only relevant study that I could find which specifically focuses on Renaissance concepts of fever. With regard to Renaissance *practices* of diagnosing and treating fevers, I was unable to find any study.

Instead, he emphasized the role of blocked perspiration as a cause of the disease.[36] In fact, as mentioned in Sect. 3.2.9, already in traditional medicine, hindered or blocked perspiration was identified as a major cause of diseases, also of fevers. Despite the connection between febrile heat and an accelerated pulse in Galenic medicine, Sanctorius did not explicitly relate his *pulsilogia* to fever diagnosis; and when he used the thermoscopes and *pulsilogia* as complementary instruments, the latter served only as timekeepers.[37] According to Christopher Hamlin, this was, however, very much in line with early modern Galenic medicine, which neglected the pulse as a mode of assessment for fevers, even though Galen had fixated on the pulse as the chief indicator of the disease.[38] While these observations do not allow certain conclusions to be drawn, they do call into question the importance of Sanctorius's thermoscopes in the diagnosis and treatment of fevers. They show that traditional qualitative fever lore, and likewise the monitoring of insensible perspiration by means of the weighing chair, were of great relevance for Sanctorius in this context, too. They caution us to not let our modern concept of fever and its very familiar measurement with a fever thermometer distort our view of Sanctorius's thermoscopes (Sanctorius 1629: 170 f., 222–5, 300–4).

Sanctorius's application of the thermoscopes to the outside air, for its part, must be considered against the backdrop of traditional dietetic medicine, according to which air was one of the six non-natural things and as such influenced the health and disease of a body (Sect. 3.3.1). The temperature of air, just like the temperature of human bodies, was conceived in complexional terms and, thus, a healthy human body and a temperate climate would have the same temperature, namely a balanced one. Notably, Sanctorius noted the connection between his measurements with the thermoscopes and the doctrine of the six non-natural things only once in his books. In the *Commentary on Galen*, he addressed the requirement that the non-natural factors be optimally temperate and asked how the physician could know this in terms of degrees (*quo ad gradum*). With respect to air, Sanctorius explained that he was able to detect the medium between too hot and too cold with his thermoscope. In an earlier passage of the same work, he referred to his thermoscopes in a discussion of the most temperate climate or region, stating that each climate had its own temperate climate depending on the complexion of its inhabitants. This shows that the temperature of ambient air was intrinsically tied to the temperature of human bodies and that the physician needed to measure both, the temperature of the ambient air as well as the temperature of the human body, in order to make a diagnosis. However, as mentioned earlier, Sanctorius alluded to the thermoscope only in one

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[36] For Sanctorius's references to fever in the *De statica medicina*, see: Sanctorius 1614: 3v, 10v–11r, 27r, 28r–28v, 30r–30v, 53r, 54r–54v, 76v–77r, 1634: 14r–14v, 16r–17r, 18v, 40v.

[37] Only in one passage of the *Commentary on Avicenna* did Sanctorius refer to fever in his description of *pulsilogia*. He explained that the *pulsus humilis* decreased in frequency during fever, while the *pulsus invalidus* did not; and that this could be detected only by means of his *pulsilogium*. See: Sanctorius 1625: 22.

[38] Unfortunately, Christopher Hamlin has not explained *why* early modern Galenic physicians neglected the pulse in the diagnosis of fevers. See: Hamlin 2014: 72.

of the many aphorisms in the *De statica medicina* and did not relate his measurements with the instrument to the observation and quantification of insensible perspiration. Thus, in view of the strong connection between the ambient air and the complexion of human bodies, Sanctorius was surprisingly silent about the use of his thermoscopes within the medical framework of the doctrine of the six non-natural things (Sanctorius 1612b: 62, 104 f.; 1614: 20v–21r).

7.3.3 Measuring the Heat of the Moon

Besides determining the temperature of the ambient air and the body parts of his patients, Sanctorius used his thermoscopes also for another purpose: to measure the heat of the moon. An opponent of astrology, he hoped to show that the moon did not emit cold rays, as some astrologers claimed. Since this use of the thermoscope—to physically demonstrate the falsity of an astrological argument—was quite extraordinary, I will consider it in some detail. In the *Commentary on Avicenna*, Sanctorius explained and illustrated how he measured lunar heat (Fig. 7.14) (Sanctorius 1625: 76 f., 346).

On the night of a full moon, he took a large concave mirror made of glass (Fig. B in Fig. 7.14, left) and used it to "collect" moonbeams (Fig. A in Fig. 7.14, left).[39] He positioned the mirror at such an angle that the reflected moonbeams would touch on the upper part of a thermometer (Fig. C in Fig. 7.14, left), which would then reveal their temperature. The next day, around noon, he repeated the same procedure, this time measuring the heat of sunbeams and comparing their temperature to that of the moon. According to his measurements, in a time period of ten pulse beats, the lunar heat was ten degrees, while the solar heat reached 120° after only one pulse beat. Hence, Sanctorius not only measured lunar heat, but also solar heat, in order to have a point of comparison. Given the lack of standard units of temperature, his contrasting juxtaposition of the effects on the earth of the moon and the sun, respectively, served to emphasize that the physical effects on the earth of any heavenly body other than the sun were extremely small. He was able thus to refute astrologers' claims, by demonstrating that the moon neither influenced the body through any supposed heat, nor emitted cold rays (Sanctorius 1625: 76 f.).

It is interesting to note that Sanctorius compared here not only the measurement results that he obtained with the thermometer, but also the duration of his observations. To this end, he used his pocket watch type of *pulsilogium* (Fig. 7.14, left: *Figura D*, right: *Secunda Figura*). In fact, with regard to measurement of the temperature of the ambient air and the body parts, Sanctorius, too, noted the need to register time intervals by means of his *pulsilogium*. However, while he usually recommended that measurements be taken at equal intervals of time, he referred to

[39] In a later passage of the *Commentary on Avicenna*, Sanctorius proposed to replace the glass mirror with a crystal sphere, or with a water-filled drinking cup (*phiala*) (Fig. 7.14, right: letter C, printed inversely). See: Sanctorius 1625: 346.

different time periods for the measurement of lunar and solar heat. Most probably, this was to highlight the great difference between them; or because he simply could not register higher degrees of solar heat on his thermometer's scale and therefore decided to limit the measurement to the duration of one pulse beat only. It is in any case doubtful whether he determined the sun's heat to be 120° using a thermometer whose scale spans only eighty degrees (Fig. 7.14, on the left). What is more, it is now known that the illumination of the full moon on the earth is 440,000 times weaker than that of the sun (each in zenith). The moon's illumination level is 0.27 Lux which corresponds to a 100-watt bulb at a distance of 19 m. Consequently, the degrees of heat that Sanctorius allegedly determined for the moonbeams must have been due to other factors, such as still air. Remarkably, Sanctorius's measurement of lunar and solar heat is one of the rare occasions on which he expressed the outcome in numerical values. It is the only instance in which he specified a quantity for the procedures undertaken with his thermoscopes.[40] That he conducted the measurement as a public event therefore seems likely, also given his statement, that he showed it to a large crowd of students (*magna scholarium frequentia*). Moreover, he noted that the measuring results would vary depending on the time intervals and different instruments used. Hence, Sanctorius gave ample cause to assume that he actually took his students outside the university classroom, at night and in the daytime, to demonstrate the insignificance of any supposed lunar heat compared with that of the sun and to do away, once and for all, with the claim that the moon emitted cold rays (Sanctorius 1625: 23 f., 76 f., 219 ff.; Siraisi 1987: 289; Kuphal 2013: 103).

Sanctorius included the description of his measurement of lunar and solar heat in a lengthy and virulent assault on astrology, which was at least partially inspired by his greatest critic, the astrologizing physician of Ferrara, Ippolito Obizzi (Sect. 5.3.2). Without going into the details of Sanctorius's diatribe, which have been described elsewhere, I want to point out a few aspects that elucidate the probable reasons and context of Sanctorius's open and explicit attack on astrology, and his use of the thermometer in this regard.[41] As a prominent feature of Renaissance culture, astrology was closely related to medicine, with astrological knowledge being integrated into the university curriculum of medicine.[42] Yet, as Nancy Siraisi has shown, by the latter part of the sixteenth century there were good reasons for Galenic teachers of medicine to be skeptical about the idea of astral and/or occult causes. They disapproved of the attempts made by certain neoteric physicians to overcome the limitations of physiological and therapeutic complexion-based explanations by

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[40] For Sanctorius's references to the thermoscopes in his published works, see: Sanctorius 1612b: 62, 105, 229, 375 f., 1614: 20v–21r, 1625: 7, 22 ff., 76 f., 144, 215, 219–22, 304 f., 346, 357, 360, 1629: 24, 137, 326, 1630: 262 f., 762. I do not refer here to the 1626 edition of the *Commentary on Avicenna*, as the pagination is identical to that of the 1625 edition.

[41] Nancy Siraisi has analyzed Sanctorius's critical discussion of astrology and occult celestial influences in the *Commentary on Avicenna*. See: Siraisi 1987: 284–9.

[42] For a general account of Renaissance astrology, see: Dooley 2014; and for a study on astrology in medieval medical practice, see: French 1994. With regard to the role of occult qualities in the Renaissance, see: Hutchison 1982.

drawing on occult qualities, celestial influences, and insensible characteristics specific to individual diseases, remedies, or patients. According to the more orthodox Galenists, this was detrimental to reason, system, and *scientia*. Furthermore, the growing emphasis on the collection and precise recording of data derived from sense experience, as exemplified by anatomy, together with the attack by the Counter-Reformation church on most astrology and all magic most probably made these physicians less sympathetic to medical explanations that propounded and amplified the role of celestial influences and occult forces. It is within this framework that Sanctorius's attack on astrology has to be seen (Sanctorius 1625: 72–83; Siraisi 1987: 284; Hübner 2014: 26).

Thus, Sanctorius was not exceptional in refuting astrology and, as Siraisi has argued, his criticism of astrology might well reflect a common professional concern in his day about a new type of unlicensed medical practitioner: exorcists who administered their own medications.[43] What was extraordinary and certainly did set him apart from his colleagues, however, was his recourse to the thermometer—to measurements and observations made by means of his senses—in order to refute an astrological argument. It is indicative of the importance that he ascribed to quantitative methods not only for a strictly medical use, but also regarding meteorological-astronomical observations, as was already seen with regard to his steelyards to measure climatic conditions (Sect. 7.1). In this context, it is important to keep in mind that Sanctorius did not completely reject the concept that the earth was affected by celestial influences. He held that the celestial bodies influenced things on earth only through their motion, light, and heat. According to his understanding, the measurement of lunar and solar heat therefore did not only serve him to refute an astrological idea, but also to show that the rays of these celestial bodies affected the earth through their heat, the moon to a very small, the sun to a very high degree (Sanctorius 1625: 73).

7.3.4 The Thermoscopes in Context

As mentioned above (Sect. 7.3.3), Sanctorius highlighted in the *Commentary on Avicenna* that many students attended his demonstration of measuring lunar and solar heat by means of his thermometer. Already thirteen years earlier, in 1612, in the first reference to the device in the *Commentary on Galen*, Sanctorius had explained that he showed it "very freely to everybody" at his house in Padua (Sanctorius 1612b: 62; 1625: 76). In June of the same year, the Venetian nobleman

[43] For a brief discussion of Renaissance physicians who condemned astrology, see: Wear 1981: 245–50. Although Sanctorius's more general arguments against astrology did not include much that was new, Nancy Siraisi has emphasized that his views about witchcraft, sorcery, and magic "show considerable independence of spirit, since they were written at a time when the Venetian Inquisition was much preoccupied [with these subjects]" (Siraisi 1987: 287 f.).

Giovan Francesco Sagredo (1571–1620) sent a letter to his good friend Galileo Galilei, reporting:

> The Lord Mula was at the patron fair and told me he has seen an instrument by Lord Sanctorius with which one measures the cold and the heat with the divider. Finally he communicated to me that it is a large bowl of glass with a long neck and I immediately applied myself to producing some of them very exquisitely and beautifully (Sagredo 2010: 229).

Evidently, Sanctorius also presented his thermoscope at the fair of the patron saint of Padua, where Agostino da Mula saw it. Da Mula's report to Sagredo and Sagredo's subsequent letter to Galileo show that the thermoscope was among the subjects investigated and discussed by Sanctorius's network of friends in Venice, as all of these men belonged to the *Ridotto Morosini*. Matteo Valleriani has pointed out that it is, however, quite impossible to determine who "invented" the device first. This is because the appearance of the thermoscope was not really a new invention, but rather the result of a gradual process—the transformation of an old pneumatic device into an instrument to measure temperature—which took place in the early seventeenth century. Involved in this process were Galileo, Sagredo, Sanctorius, and various other scholars scattered far and wide, geographically. Yet, current historical research supports the idea that it was Sanctorius, who first applied the thermoscope to medicine. In any case, Sanctorius's development and use of thermoscopes illustrates once again that he was part of a vibrant intellectual and social milieu: fertile ground in which to develop and test his new ideas related to quantification and instrumentation (Sect. 7.2.2, fn. 20) (Valleriani 2010: 156 f.; Siraisi 2012: 505).

Sanctorius first mentioned and presented his thermoscope at the very moment it was about to become a very common instrument. Already by 1624, thermometers were being produced and sold for profit in many workshops and markets. Sanctorius's instruments, too, quite soon gained in popularity. It is striking how repeatedly he stressed that the thermoscopes especially should be integrated into his Paduan lectures, owing to the avid interest of his students, who, as he wrote, "did observe this novelty not without great admiration" (Sanctorius 1612b: 105).[44] Ironically, there is evidence to suggest that even Ippolito Obizzi, the "Great Astrologer" (*Astrologus Magnus*) against whom Sanctorius directed the diatribe, including the measurement of lunar heat in the *Commentary on Avicenna*, had the pleasure to attend a demonstration by Sanctorius of an early type of his thermoscopes. Despite the fact that Sanctorius's thermoscopes were known to many contemporary physicians, it does not seem that they found considerable application in daily medical practice.[45] Only in the nineteenth century did the thermometer come into general clinical use—a

[44] "… quod Patavi ostendimus auditoribus nostris, eiusque usus documus: quam novitatem non sine magna ipsorum admiratione intellexerunt." See: Sanctorius 1612b: 105.

[45] In 1633, the Bohemian philosopher and physician Johan Caspar Horn (life dates unknown) donated a so-called *Hydrolabium Sanctorii* (*Sanctorius's water-catcher*) to the German Nation of the University of Padua and, according to Fabrizio Bigotti, Sanctorius's texts and devices continued to be copied and studied by many medical students, as attested by the notes in the Marmi Collection in the Wellcome Library, London. See: Rossetti 1967: 341 f., Bigotti 2018: 84, 92 f.

development which deserves extended consideration in its own right, although that is, unfortunately, not possible here (Grmek 1952: 43).[46]

To sum up, the development and use of thermoscopes show once again that Sanctorius was receptive to the intellectual and technological trends under examination in his day by different scholars, not only in Italy, but also elsewhere. Having presumably discussed the devices with his Venetian circle of friends, Sanctorius recognized their potential for medical practice and was the first to apply them to medical diagnosis. In this context, he adapted their design and developed a scale in order to better use their most important feature: the recording and comparison of temperatures. Like all of his measuring instruments, the thermoscopes were intended to enhance the physician's perception, in this case, his sense of touch, and to note even minor variations in temperature. As modern as his descriptions of temperature measurements may sound, they can be understood only against the backdrop of Galenic medicine. As we have seen, Sanctorius's use of thermoscopes was related not only to the concept of latitudes, but also to traditional fever lore. Within this framework, fever was not reducible to the "quantity" of heat and thus, a physician needed more than a thermoscope to diagnose the disease. Accordingly, besides highlighting the usefulness of the thermoscopes for fever patients, Sanctorius emphasized in the *De statica medicina* the importance of impeded perspiration as a sign and cause of fevers. In the *Commentary on Hippocrates*, he discussed fevers and febrile heat without alluding either to the thermoscopes or to the weighing chair. Hence, it remains unclear which role the thermoscopes played, along with traditional qualitative methods and the weighing chair, in Sanctorius's diagnosis and treatment of fevers. Indeed, it is generally difficult to assess even the extent to which Sanctorius actually used the thermoscopes in his medical practice. He sometimes used the plural when writing about the subjects whose temperatures he measured (*sani, febricitantes*), and he described how he tested with his thermometer whether the heat in children and young men was the same. But when explaining the procedure, he referred to *a child* and *a young man* and this use of the singular implies that he did not scale-up the procedure to more subjects. At the same time, it also suggests that he thought it possible to move from individual bodies to general groups of people—yet a form of generalization according to age groups was already present in traditional Galenic medicine (Sect. 3.1.3). From the evidence at hand, it therefore seems that Sanctorius used his thermoscopes to observe health trends and fevers in several individual patients without, however, making generalizations about healthy or unhealthy temperatures and their applicability to many individual cases (Sanctorius 1625: 23 f., 159 f., 219, 222, 357; 1629: 170 f., 222–5, 300–4).

[46]Volker Hess has shown that the lack of interest in the quantitative registration of body heat on the part of physicians can be explained by the fever concepts of the seventeenth and eighteenth centuries, according to which the measurement of body heat was simply irrelevant (Hess 2000: 19 ff.). In the same vein, Christopher Hamlin has remarked: "Periodically fever writers had published temperature data, but usually temperatures were facts without signification" (Hamlin 2014: 252).

7.4 The Hygrometers

In the *Commentary on Galen* and in the *De statica medicina* Sanctorius referred to several methods of determining the humidity of air. Thirteen, respectively eleven years later, in 1625, in the *Commentary on Avicenna,* he described and illustrated two instruments for this same purpose. Contrary to the *pulsilogia* and the thermoscopes, Sanctorius's hygrometers have not been dealt with specifically in recent secondary literature.[47] Since an in-depth study of the devices is not possible here, I will limit myself in the following to describing their basic features and to briefly outlining Sanctorius's use of them. Furthermore, I shall summarize the broader historical context of their emergence and consider their relation to traditional dietetic medicine, according to which the environment, including the climate, had an important influence on the health and disease of a body. Against this backdrop, hygrometric measurements could provide physicians with helpful information regarding the diagnosis and treatment of patients. The connection of the hygrometers to Sanctorius's other quantitative observations will be examined, too (Sanctorius 1612b: 105, 229 f.; 1614: 20v–21r; 1625: 23 f., 144, 215, 305).

7.4.1 *Four Methods to Measure the Humidity of Air*

Sanctorius's earliest mention of a method to measure the humidity of air dates back to 1612, when he wrote in his *Commentary on Galen*:

> … we have found a very certain way of diagnosing the humidity of the air, that is to say how much of it there may be each day. This is to take salt of tartar, commonly called alum of the lees; it is exposed to the air, but first it is weighed very exactly.[48] Then in the morning it is weighed again. Now it always weighs more after exposure to the air, but considering the different weights we say that the greater the weight, the greater the humidity, and the less the weight, the less the humidity that reigns in the air (Sanctorius 1612b: 105).[49]

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[47] According to my research, the most recent study on the historical development of hygrometers to have considered Sanctorius's instruments in some detail is: Middleton 1969: 81–132. Furthermore, Mirko Grmek has dealt with Sanctorius's hygrometers in his monograph on Sanctorius and his instruments, see: Grmek 1952: 45 ff. Another, still older account of the devices can be found in: Miessen 1940: 22–6, but it contains several flaws and inaccuracies.

[48] W.E. Knowles Middleton, whose English translation I follow here, has interpreted the term *alumen faecis* ("alum of the lees") as referring to the tartar that builds up in wine barrels (Middleton 1969: 86, fn. 37). In my translation of the aphorism of the *De statica medicina* in which Sanctorius put forward different methods to measure the humidity of air, I translate *aluminis faecum* with "sediment of alum" (Sect. 5.3.2). In his translation of the same aphorism, Fabrizio Bigotti has simply written of "several types of salt" (Bigotti 2018: 88). While it is impossible to verify exactly what Sanctorius meant, when he wrote of *alumen faecis*, he certainly had some kind of salts in mind.

[49] "… nos invenimus modum certissimum pro dignoscenda aeris humiditate, quanta videlicet quotidie sit: & talis est, sumimus tartarum combustum, quod à vulgo dicitur alumen faecis: hoc expo-

Thus, Sanctorius tried to determine the humidity of air by detecting the change in weight of a hygroscopic substance, a substance that absorbs water vapor from the air. This recalls the passage in the *De statica medicina*, quoted above, in which Sanctorius suggested the same method in order to measure the "weight of air" which was, according to him, directly related to its humidity (Sect. 5.3.2). In this aphorism, he specified that the salt had first been dried in the sun before being then exposed to night air. Consequently, Sanctorius does not seem to have measured the humidity at a given moment, but determined it rather over a longer period, namely one day or one night. This was probably because he could detect notable differences in air's humidity only after longer time spans. In fact, it is known today that relative humidity is often considerably higher at night than in the daytime.[50] Hence, it is likely that Sanctorius managed to observe major differences in the humidity of air only by using his salt-weighing method. However, this is purely speculation, as he neither mentioned any measuring results nor gave information on the balance he used, let alone its precision (Deutscher Wetterdienst 2015).

In addition to his method of measuring the change in weight of a hygroscopic substance, Sanctorius described in the *De statica medicina* aphorism three other ways to determine the humidity of air. These were, firstly, a greater feeling of cold than what was measured with the thermoscope, since, so Sanctorius, the humidity of air sharpened the sensation of cold (*lima frigiditatis*). Secondly, "the greater or lesser warping of very thin boards, especially of pearwood" and thirdly, "the contraction of lute strings, or hemp cords" (Sanctorius 1614: 20v–21r).[51] With regard to the first, it is interesting that Sanctorius referred to his thermoscope for the measurement of humidity, but the semi-subjective procedure he outlined is somewhat puzzling. According to him, it was the *feeling* of cold that ultimately indicated the humidity of the air, while the measurement of the thermoscope served only as a point of comparison for the subjective perception of cold. Even though Sanctorius recognized the need to measure the humidity and likewise the air temperature in quantitative terms, by means of instruments, he nowhere described the interrelated measurements of both parameters. He did not connect the humidity of air to its temperature, but only to its *felt* temperature. This notion most probably derived from common experience, maybe from walks through foggy Venice. Without further details, however, it is difficult to conclude anything definite from Sanctorius's brief remarks in the *De statica medicina*. Still, it should be noted that Sanctorius differentiated here between "perceived temperature" and "measured temperature,"

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nitur aeri, sed antequam exponatur exactissimè perpenditur; & deinde mane iterum perpenditur: semper enim expositum aeri magis ponderat: nos enim pro varietate ponderis dicimus maius pondus maiorem humiditatem, & minus minorem in aere dominari: …." See: Sanctorius 1612b: 105. The English translation is taken from: Middleton 1969: 86.

[50] Relative humidity of the air is the amount of water vapor which is actually present in the air compared to the greatest amount it would be possible for the air to hold at the same temperature. Relative humidity is usually expressed in percent (Cambridge Dictionary 2014).

[51] "… ex maiori, vel minori incurvatione tabulae subtilissimae praecipuè ex piro. … ex contractione cordarum testudinum, vel ex cannabe." See: Sanctorius 1614: 21r. The English translation is based on: Middleton 1969: 86, Bigotti 2018: 88.

on the basis of the procedures with his thermoscopes. In doing so, he emphasized the discrepancy between what a person feels and what is measured by means of instruments. Yet, despite his claims as to the certainty assured by his quantitative observations and instruments,, Sanctorius proposed using the subjective sense of cold and not measured degrees of cold as a means to determine the humidity of air (Miessen 1940: 24; Bigotti 2018: 88).

The other two methods that Sanctorius described in his aphorism of the *De statica medicina* depended on the measurement of some change in the shape or size of certain substances—pearwood boards, lute strings, or hemp cords. Here again, it can be assumed that Sanctorius drew on common experience. While it is completely unclear how he measured the warping of wooden boards, he revealed eleven years later in the *Commentary on Avicenna* that the contraction of strings, or cords served as the basis for his two hygrometers depicted in that book. This implies that Sanctorius developed these instruments in the time between the publication of the *De statica medicina* in 1614 and the publication of the *Commentary on Avicenna* in 1625. Yet, it is also possible that Sanctorius had already come up with the instruments by the time he released the *De statica medicina*, even though he did not explicitly mention them—because he generally did not offer many details in his concise aphorisms, and did not even describe in this book the weighing chair with which he undertook his static procedures. But the fact that Sanctorius had not referred to the contraction of cords two years earlier, in the *Commentary on Galen*, leads one to suppose that he developed his two hygrometers sometime between 1614 and 1625 (Sanctorius 1614: 20v–21r; 1625: 23 f., 305).

In this context, it is interesting to note that Sanctorius, when dealing with the measurement of humidity in the *Commentary on Avicenna*, did not speak always of his two hygrometers, but rather repeatedly directed his readers to the four methods outlined in the *De statica medicina*. What is more, four years later, in the *Commentary on Hippocrates*, he again referred to “the four ways of measuring dryness and humidity …, which we proposed in the fourth aphorism of the second section of our statics” (Sanctorius 1629: 24).[52] Hence, it seems that Sanctorius still considered these methods valid, even after he had developed his two hygrometers; he evidently did not regard the latter as more advanced or superior. This is especially perplexing with respect to Sanctorius’s suggested use of the subjective perception of cold in determining air’s humidity, which, in this light, can hardly be interpreted as an idea that Sanctorius entertained only during the search for a useful instrument to observe humidity, and later abandoned. From today’s perspective, this shows again that Sanctorius was in a phase of transition: on the one hand, he was beginning to use thermoscopes in order to rule out the uncertainties entailed by a physician’s subjective sense of touch and, on the other hand, he still adhered to the idea that an individual perception of cold could be used to determine air’s humidity (Sanctorius 1625: 7, 144; 1629: 24).

[52] “Tertium consistit in quatuor modis dimetiendi siccitatem, & humiditatem …, quos proposuimus in 4. aphorismo 2. sect. staticae nostrae.” See: Sanctorius 1629: 24.

7.4.2 Two Hygrometers

As mentioned above, Sanctorius's two hygrometers were based on the contraction of cords.[53] The first version (Fig. 7.19) consisted of a cord, or a thick lute string that was stretched between two pegs in a wall. To the middle of the cord there was attached a lead ball which moved, depending on humidity, along a graduated scale drawn on the wall behind it. Contrary to what one might intuitively suppose, when the air was moist, the cord would contract and the weight would be elevated, indicating a high degree of humidity on the scale. Conversely, when the air was dry, the cord would loosen and the weight would be dropped, pointing to a low degree of humidity. However, the illustration shows that, according to Sanctorius's graduation of the scale, the highest degree of humidity would be 1, while the lowest degree would be 10. Therefore, the scale might be also interpreted as referring to the dryness of the air rather than its humidity. In fact, Sanctorius wrote of "degree[s] of moisture or dryness." Judged from this technical understanding of the instrument, it is conceivable that this version of the hygrometer enabled Sanctorius to measure what today is called relative humidity (Sect. 7.4.1, fn. 50). What is more, measurements did not need to be recorded over lengthy time spans, as was the case with the salt-weighing method. This device could most probably also determine immediate changes in the humidity of air (Sanctorius 1625: 23; Miessen 1940: 24; Hodgson 2008: 50).

In the second version of a hygrometer that Sanctorius presented in the *Commentary on Avicenna*, a thick and long flaxen cord was wound up around a clock-like disc (Figs. 7.20 and 7.21). He explained that the cord was attached to a peg at the back of the disc, which was, in turn, connected to the sun-shaped hand on the front of the device. Depending on the humidity or dryness of the air, the cord would contract or loosen, thereby moving the hand so as to indicate the measured degrees on the dial. Contrary to the first hygrometer, the scale ranged not from 1° to

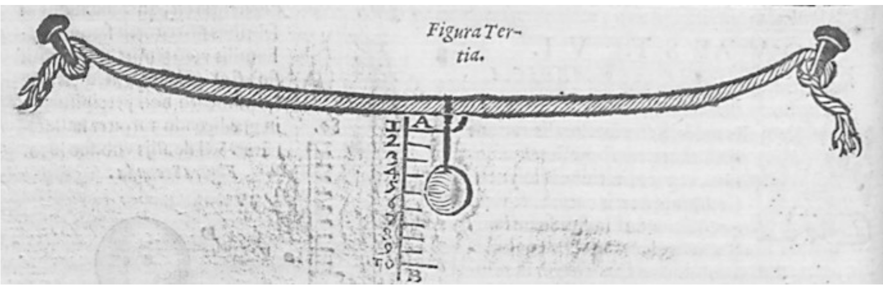

Fig. 7.19 First version of a hygrometer (Sanctorius 1625: 23 f.). (© British Library Board 542.h.11, 23 f.)

[53] I use here the term "hygrometer" instead of "hygroscope," because the instruments that Sanctorius depicted in the *Commentary on Avicenna* are both equipped with a scale (Figs. 7.19 and 7.20).

Fig. 7.20 Second version of a hygrometer, modeled on a clock (Sanctorius 1625: 23, 215). (© British Library Board 542.h.11, 23)

Fig. 7.21 Replica of Sanctorius's clock type of hygrometer. (The replica was made by Loris Premuda for an exhibition held in 1961 at the University of Padua, where it can still be found today. The replica is imperfect, however, since the cord is affixed to the disc by glue and nails, and is thereby prevented from contracting or loosening (Biblioteca medica 'Vincenzo Pinali antica' dell'Università degli Studi di Padova, © Philip Scupin))

10°, but from 1° to 12°. This might imply that the device had a higher measurement resolution. Or Sanctorius simply chose this range because the hygrometer was modeled on a clock, whose dial is usually divided into twelve sections (Sanctorius 1625: 23 f.; Del Gaizo 1936: 15).

From the written and pictorial evidence in the *Commentary on Avicenna*, it is difficult to assess whether the instrument actually worked and could be used in the way Sanctorius described. On the one hand, he specified materials to be used (a flaxen cord) and gave instructions regarding the dimensions of the cord, which to "better serve the purpose" should be as thick and long as possible (Sanctorius 1625: 23 f.).[54] This suggests that he really built and worked with the device. On the other hand, questions arise as to how the winding of the cord affects its contraction or loosening and whether the long length of the cord changes so much due to humidity that a differentiation into twelve degrees is feasible. In any case, Sanctorius did not present this version of hygrometer as an advancement on the first and there is nothing to suggest a stated preference for one or the other device. Notably, however, in his study of the historical development of hygrometers, W.E. Knowles Middleton has argued that Sanctorius's clock-hygrometer "has had no offspring," while the first hygrometer "was the parent of a large family of hygrometers" (Middleton 1969: 87). The fact that Sanctorius seems to have been the only one who proposed a clock type hygrometer can be seen as an indication that it was difficult, or maybe even impossible, to realize measurement of the air's humidity with this design (Sanctorius 1625: 23 f.).

7.4.3 What Did the Hygrometers Measure?

As outlined above, the hygrometer was one of the instruments that Sanctorius put forward in order to measure the quantity of diseases, i.e., the deviation of a body from its natural healthy state (Sect. 6.1).[55] Surprisingly though, Sanctorius gave no hint that he applied the instrument to the body of his patients, but only referred to the measurement of ambient air. Since he thus did not determine degrees of dryness or humidity in the complexion of bodies, but rather was concerned with determining these degrees in the complexion of air, the doctrine of the six non-natural things rather than the concept of latitudes must be seen as the theoretical context in which Sanctorius employed his hygrometers (Sect. 3.3.1).

In order for the air to be healthy, its complexion, or temperature did not need to be balanced only with respect to the primary qualities of hot and cold, but also concerning the other two primary qualities of wet and dry. Hence, the thermoscope and the hygrometer allowed Sanctorius to measure all of the four primary qualities contained in the complexion of air. However, as pointed out earlier (Sect. 7.3.2), the complexion of ambient air was intrinsically tied to the complexion of human bodies. With regard to his hygrometer, Sanctorius therefore stated that the healthiest degree of humidity and dryness for each person "varies according to the variety of complexions, seasons, and regions" (Sanctorius 1625: 215).[56] Accordingly, the optimal

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[54] "… sumitur corda ex lino satis crassa, & longa: quia quo crassior, & longior eo melius inservit huic officio." See: Sanctorius 1625: 23 f.

[55] For the sake of simplicity, in what follows I subsume under the term "hygrometer" both, the methods of measuring air humidity as well as the two instruments Sanctorius developed for this purpose, unless otherwise indicated.

[56] "… variatur pro varietate temperaturae, temporis, & regionis: …." See: Sanctorius 1625: 215.

degree of humidity differed for Venetians and Paduans, so Sanctorius. In fact, the hand of his clock type hygrometer, presented in the *Commentary on Avicenna*, points to two degrees of humidity, a value that was, based on Sanctorius's experience, "more beneficial to Venetians than to Paduans" (Sanctorius 1625: 215).[57] But how could he know this, if he was not able to measure the degrees of humidity or dryness in the complexion of his patients? Since Sanctorius gave no further information on this point, the only conclusion that I can draw is that he based his diagnosis of a patient's degree of humidity and dryness on traditional, qualitative methods relating to sign theory and the collection of a syndrome of signs.

Sanctorius's specification of a healthy degree of humidity for Venetians is interesting also for another reason. It is the only instance in which he mentioned a numerical outcome of his procedures with the hygrometers. Remarkably, he referred here, to the clock type of hygrometer, which implies that, despite the aforementioned doubts regarding its functioning, he actually was able to measure differences in air's humidity with this version of the hygrometer. What is more, it suggests that Sanctorius used the instrument in different locations, Padua and Venice, and compared his measurements. As a result, he was able to make regional generalizations, as when defining a healthy value of humidity for the inhabitants of Venice. However, at the same time, he highlighted that the measurements needed always to be related to individuals, as a healthy degree of humidity also varied with bodily complexions. This reflects the tension between patients' broad-ranging individual differences, on the one hand, and the need to generalize, on the other: a balancing act which physicians faced then and still face to this day, in their daily practice (Sanctorius 1625: 215).

In the description of the first hygrometer, in the *Commentary on Avicenna*, Sanctorius indicated how he determined the scale of the instrument (Fig. 7.19). Similar to the procedure that he followed in developing the scale for his thermometers, he searched for terms of comparison for the extremities of air's humidity and dryness. These were, according to him, air from the south (*aer austrinus*) and north winds (*venti septentrionales*). He explained that the "air from the south moistens and shortens the cord so much that the ball rises to the letter A" and that "while the north winds blow, they dry it [the cord] until the ball reaches B" (Sanctorius 1625: 23).[58] But in contrast to snow and fire—used by Sanctorius as the extremities to determine the scale of thermometers—southern air and north winds were not always, but only "sometimes" (*aliquando*) or "often" (*saepe*) extremely humid or dry. Thus, Sanctorius had to measure these winds at least a few times to determine their extremes. Developing a scale for his hygrometer was therefore more difficult than for the thermoscope and required repeated measurements and careful comparison of the results (Sanctorius 1625: 23, 306).

57 "… magis proficuus est Venetijs, quam Patavij, sicuti experti fuimus." See: ibid.: 215.

58 "… aliquando nam aer austrinus ita humectat, & contrahit cordam, ut attollatur usque ad litteram A. dum verò spirant venti septentrionales ita exsiccatur, ut pila perveniat ad ipsum B." See: ibid.: 23. The English translation is taken from: Middleton 1969: 87.

In defining southern air, or winds as extremely humid and northern winds as exceedingly dry, Sanctorius followed the Hippocratic-Galenic teachings. In the *Commentary on Galen*, he stated that, according to Galen, the complexion of south wind was warm and moist and the complexion of north wind cold and dry. Therefore, north wind cooled and dried, while south wind heated and moistened. In fact, in more recent times, Volker Langholf has shown that the authors of the Hippocratic treatises *De aere, aquis et locis* (On Airs, Waters, and Places) and *De morbo sacro* (On the Sacred Disease) already associated north wind with dry, and south wind with rainy air. This notion most probably derived from an even older ancient folk tradition, per Langholf, since in the ancient Greek poem, the Iliad, attributed to Homer (ca. ninth or eighth century BCE), the north wind was described as dry, while the south wind was referred to as covering the mountaintops with mist. Furthermore, the Greek word for south wind, *nótos*, originally meant "wet wind." Hence, just as with the thermometers, Sanctorius used traditional medical concepts rather than experience as the starting point for the development of a scale for his hygrometers (Sanctorius 1612a: 383 f.; Langholf 1992: 170–4).

In this context, it is interesting to note that Sanctorius measured the humidity of winds, and, more generally, air, with a focus on their impact on health, and did not consider his hygrometers in connection with weather forecasting, as he did with his anemometer. As stated above, he claimed that the latter device could be used to predict sea storms and so mitigate the dangers of flooding (Sect. 7.1.2). Remarkably, despite the strong relation between the hygrometers and the two steelyards to measure climatic conditions, especially the anemometer, Sanctorius did not associate these devices with each other in his works. Moreover, notwithstanding that Sanctorius measured air's humidity and not bodily humidity, he mostly presented his hygrometers in the context of determining the quantity of diseases; only in one passage of his works did he explicitly relate the instruments to the doctrine of the six non-natural things (Sanctorius 1612b: 104 f.). As previously mentioned, he did not include the hygrometers in his observation and quantification of insensible perspiration. The aphorism in the *De statica medicina* in which he put forward the four methods to measure humidity deals with the determination of the "weight of the air." Given that Sanctorius attributed to humidity the cause of air's weight, he regarded his hygrometers as tools to quantify the element and non-natural factor of air (Sect. 5.3.2, fn. 26) (Sanctorius 1614: 20v–21r).

7.4.4 The Hygrometers in Context

In Sect. 5.3.2, I already referred to Nicolaus Cusanus's proposal to measure the weight of the air by means of a method very similar to the one described by Sanctorius, based on the weighing of a hygroscopic substance. Interestingly, contemporary to Cusanus, there was another writer who explained that he "determine[d] the heaviness or dryness of the air and winds" by putting a sponge on a balance (Alberti 1986: 214). This writer was Leon Battista Alberti, the aforementioned inventor of a swinging-plate anemometer (Sect. 7.1.2), who referred to this sponge method in the tenth book of his work *De re aedificatoria* (On Architecture, completed in 1452). According to W.E. Knowles Middleton, it is unclear whether Cusanus and Alberti came independently to such notions, or through concerted efforts. But what their works clearly show is that the measurement of air's humidity by weighing a hygroscopic substance—Alberti suggested a sponge, Cusanus, wool—was known as early as the mid-fifteenth century. A few years later, this method was revived by Leonardo da Vinci, who made a drawing in his notebooks that showed a sponge counterbalanced by a weight, and to which he added the following note: "Mode of weighing the air and of knowing when the weather will change" (Da Vinci and Richter 1970b: 220, fn. 999).[59] Historical research suggests that Leonardo was familiar with Cusanus's work and thus most probably also knew of, and took inspiration from, the latter's proposed method of measuring air's humidity (Middleton 1969: 85–90; Alberti 1986: publisher's note, 214).

Hence, several scholars before Sanctorius examined the possibility of measuring the humidity of air, which they, like Sanctorius, assumed was related to its weight. From the evidence at hand, it can be quite safely assumed that Sanctorius was inspired by Cusanus's book *De staticis experimentis*, in his effort to measure air's humidity (Sect. 5.3.2). Most probably, he also read Alberti's famous and influential work *De re aedificatoria* and, therefore, might well have been familiar with the hygrometric procedure presented in the book. However, Sanctorius went further than these earlier writers and investigated different methods to measure humidity. Most importantly, his newly invented hygrometers were based not on the weighing of a hygroscopic substance, but on the contraction and loosening of cords. Another aspect that distinguishes Sanctorius's approach from earlier ones is that he considered the measurement of humidity in a medical context, in an attempt to improve the daily work of physicians. In keeping with this, traditional dietetic medicine provided the framework in which he developed the scales of his hygrometers.

In the following, I will make some general remarks on the reception of Sanctorius's hygrometers. Sanctorius's first cord hygrometer, displayed in the *Commentary on Avicenna*, was further developed and improved on in Italy in the 1660s. The physician Francesco Folli (1624–1685) and the mathematician Vincenzo Viviani (1622–1703), for example, made similar yet superior instruments (Fig. 7.22).

Both recognized that their hygrometers would have a nonuniform scale, contrary to the devices illustrated by Sanctorius. In fact, already in 1636, Marin Mersenne discussed in his work *Harmonicorum libri* (Books on Universal Harmony), problems regarding the interpretation of the scales of Sanctorius's hygrometers. While Mersenne explicitly referred to Sanctorius, the relation of Folli's and Viviani's hygrometers to Sanctorius's devices seems to be unclear, and requires further investigation. From a preliminary perspective, the practical medical use of hygrometers

[59] "Modi di pesare l'arie eddi sapere quando s'à arrompere il tempo" See: Da Vinci and Richter 1970b: 220, fn. 999. The English translation is taken from: ibid. The drawing of the hygroscope can be found in: Da Vinci and Richter 1970a: 297. Another drawing of a similar hygroscope made by Leonardo da Vinci is preserved in the Codex Atlanticus, see: Da Vinci and Pedretti 2000: 30v.

Fig. 7.22 Vincenzo Viviani's rope hygrometer (*Museo Galileo*—Istituto e Museo di Storia della Scienza, Florence. Inv. 799). (Museo Galileo, Firenze. Photo Franca Principe)

emphasized by Sanctorius did not have much resonance among contemporary and later scholars or physicians, who usually employed the instruments for meteorological studies (Mersenne 1636: 43; Grmek 1952: 46; Robens et al. 2014: 337; Bigotti and Taylor 2017: 108, fn. 18).

In conclusion, the hygrometers, just like the *pulsilogia* and the thermoscopes, allowed Sanctorius to determine, record, and compare degrees, in this case, of the humidity of air. Yet, in contrast to his other two measuring instruments, Sanctorius did not apply his hygrometers to the patient's body, but to ambient air alone. In my view, it is somewhat surprising that he did not try, or at the least, did not mention that he tried, to adapt the design of his hygrometers to measuring also bodily humidity, for example through his patients' breath, in a similar way to how he did this with some of his thermoscopes. It adds to this puzzlement to recall that he referred in the *De statica medicina* to a means of determining the amount of daily respiration, and even specified a quantity thereof. This was based on weighing the water drops that collect on a mirror placed before the patient's mouth (Sect. 3.2.4). Thus, according to Sanctorius, the humidity of breath was related to its weight, exactly as was the humidity of air. Why then, did he not mention his hygrometers in this context? It is a question that must remain unanswered here. In any case, in the *Commentary on Avicenna,* Sanctorius claimed to have successfully treated patients who suffered from moist or dry diseases with the help of his hygrometers. This implies that he frequently used the instruments in his medical practice and related the humidity of air to an imbalance in the moist and dry qualities in his patients' complexion, which he diagnosed by other, most probably qualitative means. Still, since Sanctorius left no clues as to how he knew, for example, that it was his hygrometers, ultimately, that contributed to healing his patients, it cannot be ruled out that this was merely a rhetorical statement (Sanctorius 1614: 2r; 1625: 24).

7.5 The Sanctorian Chair

In the preceding chapters, I have written much about the *De statica medicina*, but little about its actual protagonist: the steelyard that Sanctorius designed in order to conduct his weighing procedures. In a way, this reflects Sanctorius's own silence on the instrument—he published an illustration and a short description of it only in his

Commentary on Avicenna, eleven years after the *De statica medicina* had been released (Sect. 6.1.2). Notably, although historical accounts ascribe an important role to Sanctorius's static medicine, supporting the identification of Sanctorius as the founder of a new medical science, up until now the design of his weighing chair and the method of measurement have not been closely analyzed. The aim of this chapter is to close that gap. Through a collaboration between the Max Planck Institute for the History of Science and the workshops of the Technical University (TU) of Berlin (Institute of Vocational Education and Work Studies), Sanctorius's weighing chair was reconstructed and used to conduct certain experiments. This was partly undertaken in the framework of a seminar in the History of Science Department at the TU Berlin.[60] The project opened up new perspectives on Sanctorius's works and his doctrine of static medicine, and led to a review of the function and purpose of his weighing chair.[61]

7.5.1 Sanctorius's Presentation and Use of the Weighing Chair

In keeping with Pamela Smith's apt description of the historian's use of reconstruction, I was obliged to approach Sanctorius's original method in reverse order.[62] Thus, while the early modern physician tackled the difficult task of translating his making and doing into (preferably published) images and words, I toiled to retranslate his codified output into processes and products. Such "reverse engineering" requires both textual and pictorial research, as well as hands-on research involving reconstruction.[63] The starting point for my investigation was the illustration and attendant description of the weighing chair provided by Sanctorius in the *Commentary on Avicenna*. As these are the only known primary sources on the original instrument, I quote Sanctorius's description at length:

[60] For a detailed visual documentation of the reconstruction project, see: https://www.mpiwg-berlin.mpg.de/research/projects/reconstruction-sanctorian-chair. The website was created with the kind support of Stephanie Hood.

[61] The following chapter is largely based on my article "The Weighing Chair of Sanctorius Sanctorius: A Replica," published in 2018. See: Hollerbach 2018.

[62] With regard to authorship and terminology, and depending on the context, the "I" in the following refers to Teresa Hollerbach, the author of this book, and to the various participants in the reconstruction project. These include Katharina Wegener, Volker Klohe, Matteo Valleriani, and Jochen Büttner as well as the participants in a seminar at the History of Science Department at the Technical University Berlin, during which some parts of the reconstruction and experimentation were undertaken.

[63] According to Eilam 2011, reverse engineering describes "the process of extracting the knowledge or design blueprints from anything man-made." The concept probably dates back to the time of the Industrial Revolution and is usually practiced to obtain missing knowledge, ideas, and design philosophy, when such information is unavailable, either because it is owned by someone who is not willing to share it, or because it has been lost or destroyed (ibid.: 3). Pamela Smith, for example, uses the term in her Making and Knowing Project, to describe the process of reconstructing techniques from a Renaissance manuscript (Smith 2016: 217).

> The proposed aphorisms and those that are contained in our book of statics … are proven true by the use of this chair, from which we draw two advantages. First, how much *perspiratio insensibilis* of our bodies occurs daily: which, if not rightly weighed, renders medicine altogether vain. For nearly all bad illnesses usually originate from a smaller or larger perspiration than is proper. Secondly, sitting in this chair and easily eating in between, we observe when we reach the due quantity of food and drink, in excess of which or in shortage of which, we are injured. The chair is arranged as it appears in the figure [Fig. 7.23], in which the steelyard is suspended from the beams above the dining room, in a hidden place because of the nobles, as it renders the room less appealing, and because of the ignoramuses, to whom all unusual things appear ridiculous. The chair remains lifted from the floor at a finger's height, stable in such a way that it cannot be easily moved; when, due to the ingested food, one reaches the expected weight and the measure previously set, then the outermost part of the balance ascends a little and contemporaneously the chair descends a little. This descent immediately indicates to the sitter that he has arrived at the stabilized quantity of food; which quantity, or weight, of salutary food is advisable for somebody, and how high the insensible transpiration in the individual bodies should be, one weighs comfortably with the chair. This is easily understandable for everyone who reads our book *De statica medicina* (Sanctorius 1625: 557 f.).[64]

Hence, the Sanctorian chair consisted of a chair suspended from one of the beams of a large steelyard and was designed to monitor bodily losses by means of systematic weighing procedures. These losses indicated the quantities of sensible and insensible excretions and allowed Sanctorius to define a healthy quantity of the *perspiratio insensibilis*. Interestingly, the weighing chair also had another purpose, which was to determine the optimal healthy consumption of food for each person using the chair. Before a meal, one had to set a measure corresponding to the quantity of food one intended to ingest. During the weighing procedure, the weighing chair would drop. As soon as one had reached the set measure, the meal would end.

In Sect. 3.3.2, the close connection between insensible perspiration and the non-natural pair of food and drink was already outlined and it was shown how, according

[64] "Propositi aphorismi, & illi, qui continentur in libro staticae nostrae aliquot iam per annos in lucem edito, veritate comprobantur ex usu istius sellae: ex qua duo beneficia colligimus. Primum quanta quotidiè fiat corporis nostri perspiratio insensibilis: qua non rectè perpensa, vana fermè redditur medicina: namq; ob iusto pauciorem, vel largiorem perspirationem omnes ferè malae valetudines fieri solent. Secundum, in hac sella sedendo facilè intercomedendum animadvertimus, quando pervenimus ad debitam cibi & potus quantitatem, ultra vel citra quam, laedimur. Sella accommodatur, sicuti in hac figura apparet, in qua statera ad tigna supra caenaculum in loco ab. dito est appensa propter proceres, quia cubiculi gratiam tollit, ac propter indoctos, quibus omnia insolita videntur ridicula: Sella verò digiti interstitio à pavimento elevata manet, stabilis, ne facilè quassari possit: dum igitur ob cibum ingestum ad debitum pondus, & mensuram antea praescriptam devenimus: tunc staterae extrema pars paululum attollitur, ac una sella illicò paululum descendit: Hic descensus est ille, qui statim admonet sedentem ad debitam ciborum quantitatem pervenisse: quaenam verò ciborum salubrium. quantitas seu pondus unicuique conveniat: & quanta in singulis corporibus debeat esse perspiratio insensibilis quae per sellam commodè perpenditur, ex lib. nostro de statica medicina quisque facilè intelliget." See: Sanctorius 1625: 557 f. The English translation is made with the help of the Italian translation according to Sanctorius and Ongaro 2001: 33.

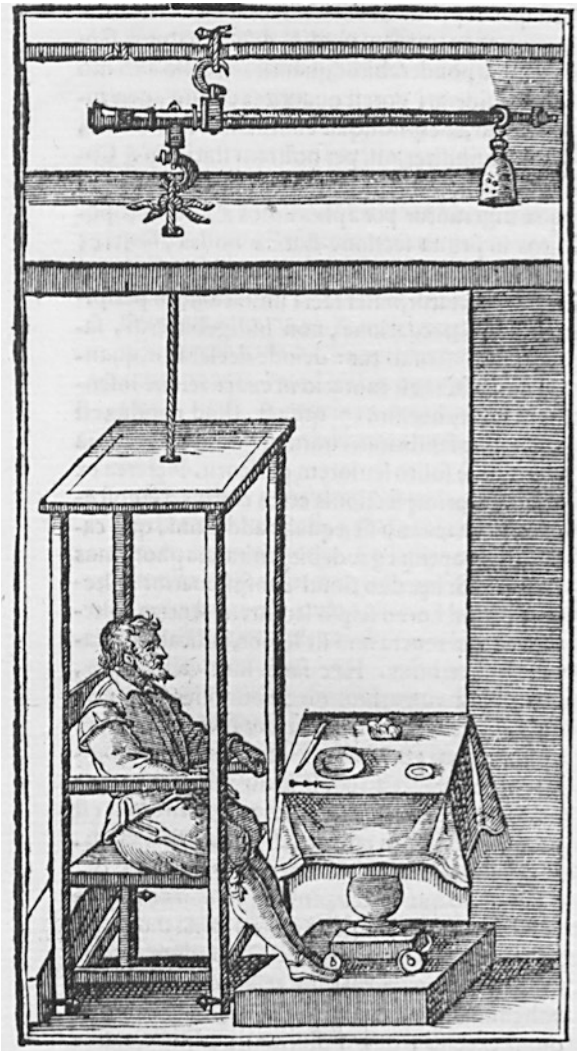

Fig. 7.23 The original illustration of the Sanctorian chair (Sanctorius 1625: 557). (© British Library Board 542.h.11, 557)

to Sanctorius, the healthy amount of food was directly related to the quantity of *perspiratio insensibilis*. The fact that Sanctorius specified the monitoring of food intake as one of the two functions of his weighing chair, in the *Commentary on Avicenna*, shows that food and drink were particularly important with regard to the use of the instrument. This is very much in line with the prominent place that these non-natural factors had in the *De statica medicina* (Sect. 4.1.2). It seems thus that the function and use of the weighing chair, just like the content of the *De statica medicina*, responded to the great contemporary demand for food guidance.

One can only speculate why Sanctorius did not add an illustration and a description of the instrument to the original editions of the *De statica medicina*, even though the book's content is so closely connected with it. He simply might not have felt the need to do so. However, once later publishers or printers added the illustration of the *Commentary on Avicenna* to their editions of the *De statica medicina*, released after Sanctorius had died in 1636, it contributed much to the success of the work, as Giuseppe Ongaro has argued in the introduction to his edition of the *De statica medicina* (Sanctorius and Ongaro 2001: 34). Similarly, Lucia Dacome has identified the illustration of the weighing chair in her article on Sanctorius's doctrine of static medicine as "an integral, non-verbal and crucial component of static medicine's rhetorical apparatus" (Dacome 2001: 475). I shall demonstrate that the development of this illustration is not only indicative of the reception of the *De statica medicina*, but also reveals something about the material dimensions of Sanctorius's weighing procedures themselves.

The Original Use of the Sanctorian Chair No detailed records of Sanctorius's static experiments have been found. It is therefore commonly assumed that he did not leave any. Nevertheless, we know that he conducted them over a long period of time. According to his own claim, Sanctorius observed more than ten thousand subjects over the course of around thirty years (Sect. 2.2, fn. 9). To believe Sanctorius himself, he must have conducted the experiments constantly, as he wrote in the preface to the *De statica medicina*: "… the same experiments, in which I was daily engaged through continued studies for many years, …."[65]

Perusal of this work shows how carefully Sanctorius carried out his experiments. In one of the aphorisms, he specified the quantities of excrement expelled in one night: sixteen ounces of urine and four ounces of stool. This number, together with knowledge of the quantity of the food previously ingested, enabled Sanctorius to determine the quantity of the *perspiratio insensibilis* that was expelled in one night. According to his measurements, it amounted to forty ounces or more (Sanctorius 1614: 13v). In addition to the evacuation of feces, urine, and *perspiratio insensibilis*, Sanctorius also referred to sweat, although in these cases he did not specify exact quantities, but remained vague.[66] Moreover, Sanctorius did not only weigh

[65] "... quandoquidem ipsa experimenta, quibus quotidie assiduis multorum annorum studijs incumbebam, …." See: Sanctorius 1614: Ad lectorem.

[66] Sanctorius was most probably unable to differentiate between sweat and insensible perspiration in his weighing procedures (see below Sect. 7.5.3), which might explain why he did not give any numerical value for the amount of sweat. For his references to sweat in the *De statica medicina*, see ibid.: e.g., 4r, 5v, 10r, 14r–14v. For an analysis of Sanctorius's concept of sweat and its relation to insensible perspiration, see Sect. 3.2.7.

people before and after meals, but at regular intervals during the day and night.[67] Following the list of the six non-naturals, he tried to include parameters like climate, sleep, exercise, age, and even affections of the mind in his weighing experiments. Besides monitoring variations in the *perspiratio insensibilis*, Sanctorius also tried to regulate these variations in order to establish the parameters of an ideal balance between ingestion and excretion:

> How much perspiration is necessary for everyone, in order to preserve a state of perfect health, you will thus know. Observe in the morning, after a more abundant supper, the greatest perspiration which can occur in yourself in the space of twelve hours: suppose it be fifty ounces; some other morning, observe the same, but after having fasted and provided that there was no excess in the previous day's lunch: suppose it be twenty. With this established, choose such a temperance in eating and in the other non-natural causes, which can bring you every day to a mean between fifty and twenty, which is thirty-five ounces. In this way, you will lead a most healthy and long life, lasting to a hundred years (Sanctorius 1614: 14v–15v).[68]

A few aphorisms show that Sanctorius also observed the absolute weight of individuals using the chair. In this context he put forward an example of a healthy weight range between 200 *libbre* and 205 *libbre*. It can be assumed that this weight range referred to adults, perhaps even to Sanctorius himself, since the unit of *libbra* was equivalent to approximately one-third of a kilogram. Given that Sanctorius suggested here a *supposed* ideal weight range, he certainly allowed for other healthy weight ranges, too, dependent on the individual constitutions of people (Sanctorius 1614: 18v, 25r, 47v; Sanctorius and Ongaro 2001: 46).

In view of the scant information Sanctorius left us regarding his experimental setup and the experiments themselves, one might imagine that his brief description of the weighing chair together with the illustration would have given rise to many different interpretations. Indeed, some authors (among them Giuseppe Ongaro in his study of 2001) have felt the need to highlight that there was only a chair—and not a table or a bed, as others claim—hanging from the steelyard (Ettari and Procopio 1968: 64; Sanctorius and Ongaro 2001: 34). However, there seems to be a general consensus on the overall functioning of the weighing chair, and there is little or no discussion at all with regard to the exact design or the measuring method

[67] In the original Latin description of the weighing chair, Sanctorius wrote "… in hac sella sedendo facilè intercomedendum …." See: Sanctorius 1625: 557 f. See also the English translation above. The Latin preposition *inter* can be translated as either "between" or "during." In connection with the verb *comedere*, I consider the translation "between" to be more accurate.

[68] "Quanta conveniat perspiratio cuilibet, ut conservetur in statu saluberrimo, sic dignosces. Observa manè post aliquam pleniorem caenam illam maiorem perspirationem, quae in teipso duodecim horarum spatio fieri possit: esto esse quinquaginta uncias: alio mane; sed post ieiunium, hac tamen lege, ne in prandio praeteritae diei excesseris, idem observa; ponamus esse viginti; hoc praecognito, eligas illam cibi, & aliarum causarum non naturalium moderationem, quae te ad medium inter quinquaginta & viginti quotidie ducere poterit; medium erit triginta quinque unciarum; hoc modo sanissimam, & diutissimam seù centum annorum vitam duces." See: Sanctorius 1614: 14v–15v.

Sanctorius used.[69] Against this backdrop, I set out to reconstruct the Sanctorian chair.[70] Things soon began to look different, as I will show.

7.5.2 *The Reconstruction of the Sanctorian Chair*

I used the replication method to develop a deeper understanding of the mechanical knowledge involved in the *De statica medicina*. This approach can be summarized in three stages: reconstruction of the apparatus, replication of the experiments, and contextualization of the experience gained in the first two stages.[71]

Without discussing this methodology in detail, some aspects of how I applied it to Sanctorius's experiments must be mentioned to explain its potential to elucidate the practical aspects of the weighing experiments. My aim in the reconstruction was not a full *historical* replication, but rather what Hasok Chang would describe as a *physical* replication (Chang 2011: 320). First and foremost, I wanted to build a functional instrument with which I could reproduce the mechanical phenomena that formed the basis of Sanctorius's physiological observations. By using the technical potential of modern tools, my motivation was not to check the historical results, but to develop an understanding of historical practice. Given the anachronism inherent in the project, it was essential to proceed with a keen eye on both research methodology and modern

[69] As Lucia Dacome has pointed out in her article (Dacome 2001), many scholars performed Sanctorius's weighing experiments well into the eighteenth century, in France, Britain, Ireland, Colonial America (South Carolina), and the Netherlands. However, these imitators did not prioritize the historical accuracy of Sanctorius's experiments, but were interested rather in his novel idea and method of quantification. To them, the output was more important than the design and measuring method Sanctorius used. Thus, they left detailed static tables that indicate their commitment to drawing general conclusions concerning the relationship between intake, weight, and health, based on minute calculations of bodily excretions. Most of them did not even describe their experimental setup. Hence, it is not known which balances they used for their re-trials, whether they tried to reconstruct the original Sanctorian chair, or invented novel constructions. There are, however, two exceptions. In his French translation of the *De statica medicina*, the French scholar Louis-Augustin Alemand (1653–1728) pointed out some inconveniences that occurred when using the design of the weighing chair as proposed by Sanctorius in the *Commentary on Avicenna*. To overcome these problems, Alemand proposed another design based on an equal-armed balance. But from his illustration and short description of this device, it seems that he discussed and tried to improve Sanctorius's design of a weighing chair only in thought and not in deed (Sanctorius and Alemand 1695: Explication des Figures). The other exception is Jacob Leupold (1674–1727), who described in detail his own design of a weighing chair and also criticized the design illustrated in the *De statica medicina*. He even stated that this design cannot have been used in the way Sanctorius described it in his *Commentary on Avicenna*. See: Leupold 1726: 63.

[70] Examples for the common discussion in the secondary literature of Sanctorius's weighing chair and, more generally, the *De statica medicina* are: Miessen 1940, Ettari and Procopio 1968, Dacome 2001, Sanctorius and Ongaro 2001, Guidone and Zurlini 2002.

[71] The replication method is an attempt to analyze historical experimental practice, as applied systematically by members of the Oldenburg Group. This group was established in Oldenburg in 1987 under the direction of Falk Rieß (Heering 2008: 350, fn. 15). For an extensive study of the replication method and what the authors call an "experimental history of science," see: Breidbach et al. 2010.

assumptions. The focus of the project was not the historical details of how the balance was produced and used, but rather how it might possibly have been used. Thus, when I staged the experiments on the basis of the information provided in the source material, I tried to develop a deeper understanding of the experimental procedures and the skills involved in conducting them. Simultaneously, I reflected on my own practices with the instrument and how these practices developed over the course of the project (Heering 2008: 350, fn. 15; 2010: 796).

On the basis of the original source material, I developed a design proposal for the weighing chair. The illustration of the weighing chair (Fig. 7.23) indicates that Sanctorius used a Roman steelyard. As mentioned above (Sect. 7.1.1), scales of this type were widely in use at the time, and steelyards the size of the Sanctorian chair were used to weigh sacks of flour or other commodities. Therefore, it can be assumed that Sanctorius used an instrument already in circulation for his weighing chair, as in the case of his balances to measure climatic conditions. In contrast to Sanctorius, who suspended his weighing chair from the ceiling, I had to construct a stable framework in order to make my replica mobile, as I planned to exhibit it in different locales (Fig. 7.24). Moreover, the limited space in the TU workshops did not allow for a permanent installation of the instrument. Consequently, I had to calculate measurements that guaranteed a manageable size. At the same time, I had to make sure that the chair could be used by people of varying weights. I used a beam with a length of 1.5 m and defined a maximum load of 100 kg, including the weight of the chair. To keep the counterweight as light as possible, I decided to work with a ratio of 1:5, which corresponds to a counterweight of 20 kg for a load of 100 kg. This resulted in the following lengths for the arms that flank the pivot: a short arm of 25 cm and a long arm of 1.25 m. With regard to the materials, I chose structural steel for the beam and the pivot, and timber for the chair and the framework. The simple reason for this was that these materials were convenient, economical, and readily available through the stock of the TU workshops. After many hours of work in the wood and metal workshops, I finished a prototype with which I could begin experimenting (Fig. 7.24).

But this is only half the story.

The Measuring Method At first, I assumed that Sanctorius used his model of a Roman steelyard in the traditional way described above (Sect. 7.1.1). But in the course of discussions, I recognized two difficulties. Firstly, Sanctorius wrote very clearly in his description of the weighing chair that a certain measure, which is set before the weighing starts, can be determined from the descent of the chair, that is, the chair's distance from the floor. This indicates that the weight of the load is not read from the position of the counterweight hanging from the beam of the steelyard. Secondly, the actual steelyard was hidden behind the ceiling above the dining room. Thus, the arms of the beam and the counterweight were very difficult to access.[72] Given the fact that Sanctorius used the weighing chair to monitor metabolic changes

[72] Interestingly, Louis-Augustin Alemand already referred to the inconvenience of reaching the counterweight above the false ceiling. See: Sanctorius and Alemand 1695: Explication des Figures. See also above, Sect. 7.5.1, fn. 69.

Fig. 7.24 The first prototype of the Sanctorian chair. (© Philip Scupin)

in many individuals of varying weights, he would have to balance the arms of the steelyard by moving the counterweight for every individual sitting on the chair anew—if he used the steelyard in the common way.

With these considerations in mind, I took another look at the original illustration of the Sanctorian chair. This time I specifically examined the lower part of the weighing chair. I could clearly identify little pointers or pegs at the bottom of the chair, attached to each leg. What were they intended for? Did they point to a scale that indicated to the sitter when he had reached the proper weight? Were they used to add weights to the sitter? Or did they serve to stabilize the suspended chair and prevent it from swinging? It is striking that this detail varies in later reproductions of the original illustration, and that the variation has never been discussed. In the following, I shall briefly refer to one of the reproductions: the frontispiece of a Dutch edition of the *De statica medicina*, written by the physician Heidentryk Overkamp (1651–1693) and published posthumously as part of his *Opera Omnia* (Overkamp 1694).[73]

The frontispiece shows a version of the Sanctorian chair (Fig. 7.25), in which one can clearly identify one little pointer or peg at the rear end of the chair's right-hand stretcher. Moreover, in contrast to the original illustration, it shows not only the person sitting on the weighing chair, but three other people, too. The two on the right appear to be discussing the beam of the steelyard, the part of the weighing chair that is hidden behind the ceiling, in the original. On the left, another person seems to be bending to reach the lower part of the chair, close to the point where the pointer or peg is placed. From this illustration alone, one cannot deduce with any certainty the purpose of the pointer or peg. Nor can it be known whether the person leaning forward is a craftsman, a servant, or a spectator interested in the weighing process. It is known, however, that this person was not there to remove feces from the chair, as the weighing chair was not designed to be used as a lavatory. Sanctorius

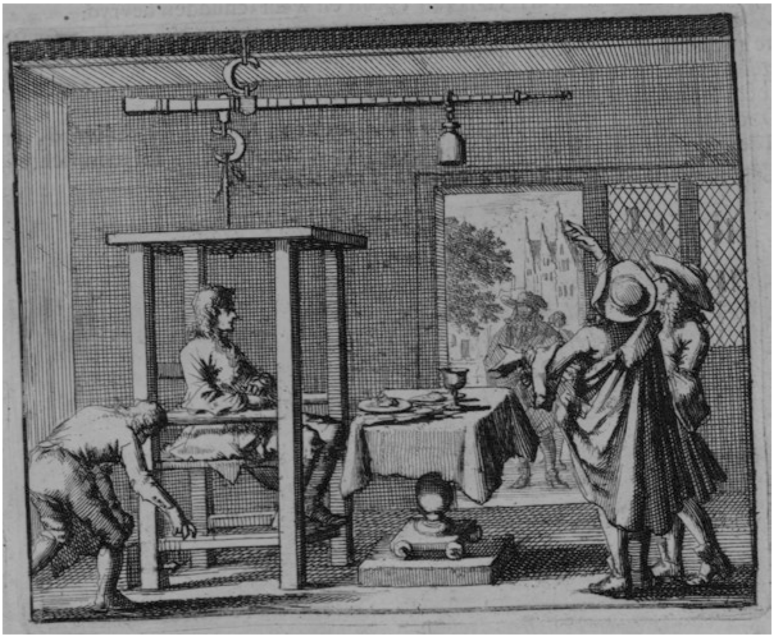

Fig. 7.25 An illustration of the Sanctorian chair (Overkamp 1694: frontispiece). (Courtesy of Niedersächsische Staats- und Universitätsbibliothek Göttingen (SUB Göttingen))

[73] My thanks to Ruben Verwaal, who drew my attention to this illustration of the Sanctorian chair.

stated as much in his own defense, in response to his detractor Ippolito Obizzi's harsh allegation, that the weighing chair was used for the inappropriate practice of weighing fecal excreta (Obizzi 1615: 3, 38 ff.; Sanctorius 1634: 69v).[74]

Therefore, even though many questions remain open, it is evident that the lower part of the chair and its descent are of significance with regard to the weighing procedures, and most probably for the measuring method as well. These were interpreted in the reception of Sanctorius's *De statica medicina* in different ways, but had never yet been included in a historical reconstruction. It was with this in mind that I started the experiments with my replica.

7.5.3 Experimenting with the Reconstruction

The experimentation process can be divided into four phases. In the first phase I used the prototype mentioned above (Fig. 7.24), with two people of differing weights. In a second phase I experimented with an adapted and improved version of the prototype, which I constructed in the light of the experience gained in the first phase (Fig. 7.26). In this second series of experiments, seven different individuals used the chair. Subsequently, I again set out to further adapt and improve my prototype. I planned to conduct my next experiments with many different people and had to prepare my reconstruction accordingly.[75] In the fourth and final phase of experimentation, in order to more closely approximate Sanctorius's experimental practice, I took the reconstruction home with me.

The First Two Phases In the first two phases, I conducted the experiments over several hours on one day. The aims were to test the functioning and precision of my reconstruction, to analyze different possible measuring methods, and to define potential scales. I thereby hoped to better understand the mechanical knowledge involved in the weighing procedures Moreover, in performing Sanctorius' experiments myself, I aimed to develop a better understanding of the methodology underlying them. As the purpose and use of the weighing chair are closely connected to its design, these objectives could not be analyzed separately but had to be considered as complementary factors. In the following, I will give a brief overview of the two series of experiments and present the conclusions that I drew from them.

Before any actual weighing can begin, a starting point must be defined. This point guarantees the universal validity of the measuring process, with universal

[74] "Staticus scit pondus faecum, licet eas nec videat, nec perpendat. Corpus ante perpendit & iterum post omnem excretionem: quod deficit est earum pondus: Sic non est indignum perpendere faeces, ut ait trico." See: Sanctorius 1634: 69v. In the secondary literature, it is also sometimes erroneously stated that Sanctorius weighed feces by means of a balance. See e.g., Major 1938: 374, Poma 2012: 215.

[75] I found an opportunity to do so in the framework of the Long Night of Sciences in Berlin, an established public science fair regularly held in Germany (see below).

Fig. 7.26 The adapted prototype of the Sanctorian chair used by Matteo Valleriani and Teresa Hollerbach. (© Paul Weisflog)

means valid for everyone, regardless of each individual's constitution. Sanctorius weighed many people of different weight, so always had to ensure that the beam of his weighing chair was optimally weighted for the person in question, before he could begin his experiments. The beam could be in any position, as long as it was the same for everyone using the chair, but there is good reason to suppose that the preferred starting point was the balanced, horizontal position of the beam about the pivot—the right-angle being a common reference point, most easily measured with the eye. Most probably there was a marking somewhere at the bottom of the chair that indicated when the chair had arrived at the starting point. There are various ways to define this point. The most obvious is to use the steelyard in the classic way, by moving the counterweight attached to the beam above the ceiling. This would have had to be done for every person anew. Another method, not so obvious but far more convenient, is to add weights to the person sitting on the weighing chair, to compensate for the differences in weight. Thus, the beam of the steelyard is balanced once for a rather heavy weight of test person, and further weights are added, as necessary, but this time to the load (that is, to the chair). With this method, the counterweight does not have to be moved for each individual to reach the starting point. In Sanctorius's case, this would have made it possible to balance the weighing chair without always having to climb up to the ceiling above the dining room.[76]

In addition to the starting point, there least one other marking at the bottom of the chair. As mentioned above, Sanctorius referred in his description of the weighing chair to a certain measure that was set before the weighing started and that indicated to the sitter when he had ingested the sufficient amount of food and drink. Sanctorius explicitly stated that the quantity of ingested food and drink was indicated by the *descent* of the chair. Thus, he used the weighing chair not only to observe weight loss, but weight gain, too. Where exactly this second mark would have had to be made—i.e., the mark for the quantity of food and drink Sanctorius would advise an individual to ingest—remains vague for the modern reader. Given the character of the *De statica medicina* as a dietetic handbook and its orientation to the six non-natural things, Sanctorius most probably connected it not only with the amount of excreted insensible perspiration, but also with the six non-natural factors, thereby including a variety of parameters that influenced the quantity of food and drink that an individual person should ingest. This leads one to conclude that Sanctorius based the position of the second mark on contemporary dietetic knowledge and the experience he gained during the weighing procedures.

So, when I tried to define this second mark in my experiments with the replica, I was not dealing with an exact quantity but rather attempting to determine how a certain value (the position of this second mark) could be universally determined for the various individuals using the chair. Here again, there are various options, depending on the method used to determine the starting point. If one balances the beam by moving the counterweight suspended from the steelyard above the ceiling—with regard to the weight of each individual, as explained above—the descent of the chair is proportional to the weight of the load. Therefore, whatever the weight of the occupant of the chair, a single mark would suffice to show when she or he had consumed the amount of food and drink necessary to lower the chair to this preset

[76] At the beginning of the eighteenth century, Jacob Leupold designed a portable weighing chair, the *machina antropometrica*, to which he applied a similar measuring method. In his work *Theatrum Staticum Universale* (1726), Leupold described how the person using the *machina* should determine the counterweight on the basis of an estimate of his own body weight. According to Leupold, this estimate did not have to be accurate, as there were additional weights that the sitter put on the arms of the chair to compensate for inaccuracies and to balance the two arms in a horizontal position about the pivot. See: Leupold 1726: 64–6; table XVIII.

measure. Another option would be to use the steelyard in the common way to determine the weight of a person as well as to set the desired weight of food and drink that this person should ingest, and then also move the counterweight to a position such that the chair not only descends toward, but actually rests on the ground, once the preset measure has been reached. Using the ground floor in this way as an indicator of when the desired amount of food and drink has been ingested is of course also possible for the method mentioned before, instead of setting a mark close to the bottom of the chair. If one uses the other method, namely adding weights to the person sitting on the chair to balance the beam of the steelyard, the amount of food ingested can be indicated by using a graduated scale. Here, the initial weight of the load is the same for everyone using the chair. Thus, the descent of the chair after a meal is not proportional to the weight of the individual person. The addition or removal of weights to or from the chair might have enabled Sanctorius to identify exact quantities not only by looking at the position of the counterweight on the beam of the steelyard installed behind the false ceiling (presumably, a difficult task), but also by noting the chair's distance from the floor.

On the basis of my practical experience of the different measuring methods paired with the examination of the source materials, it appears most plausible that Sanctorius used the steelyard in the classic way, in order to define the starting point for the measurements. Most probably, an assistant climbed up above the false ceiling to move the counterweight until the beam reached the balanced position. The height of the chair was then noted. A second mark was made at the bottom of the chair to indicate when a person had ingested the required amount of food and drink, which was measured exclusively in terms of how far the chair had descended toward the floor. As outlined above, there are good reasons to assume that Sanctorius did not work much with the counterweight and that his daily weighing practice centered rather on measuring the chair's distance from the floor. Yet, although the method of adding weights to the person sitting on the chair necessitates the least use of the counterweight and relies wholly on measuring the descent of the chair, it turned out that it also easily leads to errors. The added weights must be distributed equally over the chair, in an identical position for each measurement, so that the chair does not descend more on one side than on the other. This is extremely difficult, unless a special storage place for the weights is integrated into the chair. Perhaps this is the reason there is no evidence in Sanctorius's illustration and description of the weighing chair either of this solution being used, or, more generally, of weights being added to, or removed from the chair.

Precision of the Sanctorian Chair and of the Replica As soon as I started to include the descent of the chair in my procedures and to test its possible function as an indicator of changes in weight, flaws in the reconstruction came to light. It turned out that the chair was very unstable and sensitive to any kind of movement. Thus, the various persons using the chair not only had to keep still during the measuring process, but also had to adopt an identical seating position. To prevent the chair from rotating to one side, I replaced the rope that suspended the chair in my first version of the prototype with a steel chain that I attached to the chair with the help

Fig. 7.27 The suspension of the chair. (© Paul Weisflog)

of a U-bolt (Fig. 7.27). Additionally, on the basis of the original illustration of the Sanctorian chair, I placed a wood panel behind the chair, attached to the framework (Figs. 7.24 and 7.26). This also helped me prevent major oscillations, even though I had to be careful to keep the friction between the wood panel and the chair legs to a minimum, so as not to falsify the measurements. Even a minor disequilibrium caused perceptible differences in the descent of the chair. As stated above, this became even more obvious when I started to add weights to the person sitting on the chair. The added weights had to be distributed equally over the chair to prevent it from descending more on one side than on the other. A spirit level attached to the top of the chair helped me to monitor its horizontal position.

My experiences showed that suspending the chair from the beam, as in the original illustration, makes the chair prone to rotation, its descent uneven, and hence the measurements hard to read accurately. However, Sanctorius was well aware of this difficulty, as he stated in the description of the weighing chair: “the chair remains … stable in such a way that it cannot be easily moved; …” (Sanctorius 1625: 558).[77] Unfortunately, he did not reveal to the reader how he achieved stability. Thus, I can only speculate that he might have used the pegs near each chair leg for stabilization. Arranged between the wood panel behind the chair and the platform beneath the dining table, the pegs might have served to guide the chair’s descent and make it as steady as possible. Perhaps the pegs were actually iron nails, whose shanks against the chair’s uprights were meant to limit its rotation and prevent it swinging from side to side, while their heads would prevent it from swinging forwards. Furthermore, another detail in Sanctorius’s illustration is interesting with regard to the stabilization of the chair. The feet of the man seated on the chair rest on the dais on which the table is placed (Fig. 7.23).[78] Since this makes no sense with regard to the weighing

[77] “Sella verò … manet, stabilis, ne facilè quassari possit: ….” See: Sanctorius 1625: 558.

[78] It is interesting to note that this detail does not vary in later reproductions of Sanctorius’s original illustration of the weighing chair except for the frontispiece to Heidentryk Overkamp’s edition of the *De statica medicina* (Fig. 7.25), in which the feet of the person, sitting in the chair, do not rest on the platform but on the chair’s bar.

procedure and would even falsify the measurements, it is conceivable that the man is in fact steadying himself *before* the measurements are made. By this interpretation, the illustration does not represent a snapshot view of the weighing procedure, but rather combines discrete operations. This reading of the illustration is very much in line with the assumption that Sanctorius weighed people only *before* and *after* and not *during* meals, even though the illustration shows a laid table (Sect. 7.5.1, fn. 67).[79]

When I tried to determine where to make the second mark, I realized that the chair's descent was not proportional to the weight of the load and, moreover, was affected only by large differences in weight. As the figure shows (Fig. 7.24), in the first version of my reconstruction the pivot is located between two steel rings that are welded together and form the fulcrum, which is attached to the stable framework, my substitute ceiling. In order to make my weighing chair more precise, I had to minimize the distance between the pivot and the lever. However, I had to be careful to find the right distance, as minimizing the distance between the pivot and the lever not only makes the steelyard more precise but simultaneously causes smaller inclinations of the beam, which makes it more difficult to determine minor differences in weight. Hence, I had to find a solution that on the one hand, guaranteed the necessary precision of the weighing chair and on the other hand, still allowed me to read the measurements at the bottom. My modern solution to this problem was a ball bearing (Fig. 7.28). Sanctorius, of course, had to find another method. The original illustration of the weighing chair shows that he connected the lever directly to the hook on the ceiling with some kind of box or rectangular guide, which made the distance between the pivot and the lever relatively small.

The precision of a steelyard also depends on the length of the beam. To adapt this parameter to my needs in relation to the different persons using the chair and to guarantee maximal precision, I replaced the initial suspension hook with three hooks at different positions on the beam of my prototype (Fig. 7.28). This resulted

Fig. 7.28 The ball bearing to minimize the distance between the pivot and the lever. (© Paul Weisflog)

[79] I am grateful to Roger Gaskell for pointing out to me the interpretation of the pegs as iron nails and for suggesting I read the original illustration of the weighing chair not so much as a snapshot but as a stop-motion image, in which the man in the chair might have placed his feet on the dais in order to stabilize himself *before* the measurements were made.

in the following lengths for the arms flanking the pivot. First hook, short arm: 17.5 cm; long arm: 1.325 m. Second hook, short arm: 23.5 cm; long arm: 1.265 m. Third hook, short arm: 29.5 cm; long arm: 1.205 m. My experiments with the different hooks showed that the third, foremost hook (the one closest to the beam's front end), was ideal for my load weight range of 66–75 kg when working with a movable counterweight of 20 kg.

On the basis of the original illustration of the Sanctorian chair, it can be assumed that Sanctorius used a beam with a length of around 3 m—twice as long as the beam in my reconstruction. This enabled him to achieve great precision in his measurements and to reduce the counterweight. Sanctorius might well have equipped his weighing chair with different hooks, too, even though the illustration does not clearly indicate this. Steelyards with up to three suspension hooks had been in use for weighing objects of varying weights since the Roman Empire (Robens et al. 2014: 169).

The adapted and improved version of my prototype with regard to the oscillation of the chair, the distance between the pivot and the lever, and the length of the beam allowed me to measure differences in weight by means of the descent of the chair with a precision of up to 100 g, in the second series of experiments. This comes close to the precision that Sanctorius claimed to have measured in the *De statica medicina*. The minimum quantity to which Sanctorius referred in his aphorisms is four ounces, which, if calculated with the Venetian *oncia sottile*—corresponds to around 100 g (Sect. 5.4.2, fn. 39).[80] In the aphorism mentioned above (Sect. 7.5.1), Sanctorius stated that up to sixteen ounces of urine were usually expelled in one night. In several other aphorisms, especially of the third section, *Food and Drink*, he gave quantities of six, twelve, fourteen, eighteen, and twenty-two ounces. He wrote for example: "Very nourishing foodstuffs, except for mutton, usually do not perspire more than eighteen ounces in the time between supper and lunch" (Sanctorius 1614: 32v).[81] This indicates that he worked with a steelyard that had a precision of one ounce. This in itself is nothing out of the ordinary: at the time, steelyards were used to weigh loads ranging from ounces to tons. But merchants and traders who had to weigh small, ounce-sized merchandise usually used small, portable steelyards of only some ten centimeters in length (Robens et al. 2014: 169). In contrast, steelyards of the size of Sanctorius's weighing chair were commonly used to weigh sacks or barrels of commodities in which precision to the ounce was hardly needed. Thus, the mechanical challenge of the Sanctorian chair is to develop a design that, on the one hand, allows the weighing of heavy loads up to around 80 or 90 kg, and on the other, guarantees precision enough to be able to note even minor variations in weight.

80 For Sanctorius's references to four ounces in the *De statica medicina*, see: Sanctorius 1614: 13v, 33r, 40r–40v.

81 "Cibi multum nutrientes, excepta carne vervecina, à caena ad prandium non solent perspirare ultrà octodecim uncias." See: ibid.: 32v. For further examples, see: ibid.: 32r, 39r–39v, 40r–40v.

Reading of Measurements I developed and tested various methods for reading the measurements. I made marks on the beam of the weighing chair to indicate the respective starting point for each person using the chair. This was relatively easy and became difficult only when I tried to discern differences in weight. Calibration of the longer arm requires skill and great accuracy. Since I worked with a counterweight of 20 kg, it was extremely difficult to record minor weight differences, which corresponded to only very short lengths of the beam. Sanctorius probably did not face these problems, as we can assume that he worked with a calibrated steelyard, a type widely in use at the time.

To monitor the descent of the chair, I developed various solutions that I tested in my experiments. Figure 7.29 shows that I attached to one leg of the weighing chair a wooden arrow, whose height could be marked and then measured on the wood panel behind the chair. Inspired by another reproduction of the illustration of the Sanctorian chair, I attached to a different leg a wooden duct that served to hold upright a steel bar resting on the ground. The steel bar helped me ascertain the chair's distance from the floor (Fig. 7.30).[82] My experiments showed that the use of the arrow to indicate the chair's descent was problematic. Although the arrow's

Fig. 7.29 Wooden arrow as indicator of the descent of the weighing chair. (© Philip Scupin)

[82] For the illustration, see: Beugo n.d.

Fig. 7.30 Steel bar as indicator of the descent of the weighing chair. (© Philip Scupin)

height could be marked on the wood panel, reading the measurements in this way was very difficult. Even though I had already enhanced the stability of the chair in my second prototype, the person seated on the chair still had to remain in a very stable, balanced position to prevent the chair from descending more on one side than on the other. For every measurement, the distribution of the load on the chair had to be identical. The steel bar proved far easier to handle and permitted a highly accurate reading of the measurements. As the figure indicates, a graded scale was still missing at this point. In the next version of the reconstruction, however, I attached a ruler to the steel bar.

Given the depiction of pointers or pegs inserted into each chair leg in the original illustration of the Sanctorian chair, it can be assumed that these might have served as indicators of the chair's descent, similar to the arrow that I used in my experiments. However, this cannot be deduced with certainty. As mentioned above, they might also have served as stabilization. Further, they possibly had a dual function. The two pointers or pegs at the rear end might have served as fixed guides to ensure stability, and the ones at the front end as indicators of the descent of the chair, pointing to the platform on which the table is placed. There is no evidence that Sanctorius used a steel bar as an indicator, since one appears only in a later reproduction of the Sanctorian chair; it also differs slightly from the one I used in my experiments. I applied the steel bar to my reconstruction to investigate different possibilities for measuring the descent of the chair.

The Exhibition of the Sanctorian Chair In a next step, I wanted to test my reconstruction on many different individuals. The Long Night of Sciences in Berlin (Fig. 7.31) seemed a perfect opportunity both to do so and, at the same time, to present my research project to a wider audience. During this annual event, science and research institutions that are usually closed to the public open their doors to visitors. In different formats, such as lectures, demonstrations, or exhibitions, the institutions present themselves to the general public and give an overview of their research topics.[83] In preparation for this third phase of experimentation, I further adapted and improved the prototype. The original balance beam was fitted with an

Fig. 7.31 The exhibition of the Sanctorian chair at the Long Night of Sciences in the Max Delbrück Center in Berlin 2018. (© Stephanie Hood)

[83] For more information on the Long Night of Sciences in Berlin and Potsdam, see: https://www.langenachtderwissenschaften.de. Three years later, I exhibited my reconstruction of the Sanctorian Chair again, on the occasion of the City of Science Berlin 2021, a project to showcase Berlin as one of the most exciting locations for science and research in Europe. For more information and images, see: https://www.mpiwg-berlin.mpg.de/news/mpiwg-exhibits-wissensstadt-berlin-2021-review.

extra length of structural steel, extensible up to 50 cm, as required. This served to enhance precision and extend the weight range of suitable candidates for testing the chair. Moreover, I equipped the chair with a more stable suspension, made of wood and a ball bearing, to prevent any lateral movement. I planned to use the measuring method that I had identified as the most viable one, in the light of the first two phases of my experiments with the reconstruction. However, instead of making marks on the wood panel behind the chair to indicate the the chair's distance from the floor, I would use the steel bar (to which I had meanwhile attached a ruler) to do so, and then record the values on a sheet of paper. Only the starting point for each individual was marked on the instrument itself—on the beam, namely, to show the position of the counterweight when the test person was seated in the chair and the beam was perfectly horizontal. Besides requirements concerning the design and functioning of the reconstruction, the special setting also posed other challenges. While I had previously worked in a closed environment, I was now engaging an audience that was completely unfamiliar with the subject and had no background in historical research. Furthermore, members of this audience became not only "guinea pigs" (test objects) by using the chair, but also factors integral to my ongoing research. This became especially obvious as, despite my extensive planning and preparation, the new experimental setup produced different results than expected.

My initial idea for the public exhibition of the Sanctorian chair was to offer visitors bananas and water between their "weigh-ins," so as both to make weight changes visible by means of the chair's descent and to illustrate the concept behind Sanctorius's weighing procedures. But as it was a very hot day, and visitors were not very eager to eat bananas, I altered the test while sticking to the measuring method. Once an individual was seated, I marked the position of the counterweight on the beam as soon as the balanced position was reached. Simultaneously an assistant noted the chair's distance from the floor, using the steel bar. I then asked our volunteers to neither eat, drink, nor use the toilet prior to their second weigh-in, which was to reveal how much they had perspired. If they cheated, the instrument would betray them. A surprisingly large number of individuals accepted the assignment, and returned at different time intervals to learn more about their *perspiratio insensibilis*. Of course, it was not only insensible perspiration that my instrument measured, but also, and probably to a large extent, sweat.[84] This, however, disclosed a fundamental problem that Sanctorius must have encountered as well. How did he differentiate between sweat and insensible perspiration? Did he do so at all? My experience at the Long Night of Sciences helped me grasp what it must have meant for Sanctorius to indirectly measure invisible bodily losses by means of a balance and changes in weight. It gave good reason to assume that Sanctorius did not give any numerical values for the amount of sweat because he simply was not able to.

[84] In the following, I do not differentiate between sweat and invisible losses, when referring to the experiments with the reconstruction, for the simple reason that we cannot distinguish between the two.

The alternation in the experiment, from measuring gains resulting from the bananas and water consumed, to measuring invisible losses, also had an important consequence for my methodology and conclusions. While the previous tests in the TU workshop mainly served to assess the function and precision of my reconstruction of the chair, as well as to examine different possible measuring methods and the definition of potential scales, they did not concern Sanctorius's experiments in the stricter sense. Before I could tackle Sanctorius's actual research interest, the measurement of *perspiratio insensibilis*, I had to make sure that my replica was working as it should. But in the public setting, encouraged by the active engagement of the visitors, with the knowledge that the steelyard could detect weight changes with a precision of up to 100 g, I endeavored to further the experiment—and I did so with success. The measuring results showed that it was possible to detect invisible losses by means of my weighing chair and with the measuring method that I employed.

Yet, the experiments at the Long Night of Sciences also disclosed some problems arising from using the weighing chair for numerous people. On a general level, my measurements worked and the measuring method that I had chosen proved relatively easy to implement. But the fact that I measured, in quick succession, many different people of a different weight made the weighing process feel laborious. I constantly had to work with the counterweight in order to first determine the starting point for each individual and then to return the counterweight to that same customized position for the second measurement. During the phases when the test persons entered and exited the chair, I had to exercise caution to prevent the counterweight from rising or dropping down in an uncontrolled manner. This required attention on the part of the test persons, too. For their first measurements, an assistant was on hand to help them into and out of the chair, although with a little practice this can easily be done alone. Furthermore, despite having fitted the beam with an extensible component, I was unable to cover the entire weight range of the children and heavy adults among the test persons. By contrast, reading the chair's distance from the floor was unproblematic.

These observations allow some further conclusions to be drawn regarding Sanctorius's weighing procedures. If his claim to have weighed more than ten thousand people is true, he must have encountered problems similar to my own during the Long Night of Sciences. Although there can be little doubt that he had an assistant who was much better trained and more familiar with the handling of a steelyard than I, the frequent moving of the counterweight still must have been exhausting and time-consuming; and all the more so, given that the mechanism was hidden behind a false ceiling. But at the same time, this detail might have been useful. When the weighing chair was not in use, the counterweight could simply sit on the ceiling; and when a person entered or left the chair, it would move only a little; thus, the danger of its uncontrolled movement was greatly limited. Still, Sanctorius needed to instruct every single test person on how to properly enter, leave, and sit on the chair ideally, in an always identical manner. Their level of cooperation and skill would thus influence the measurements and affect the comparability of the measurements gained from the various individuals. To cover a broad range of weights, Sanctorius probably used different counterweights and might have also worked with various suspension hooks. But if several people with differing weights used the chair consecutively, the individual adjustment of the weighing chair would be quite complex and time-consuming. In this regard, the inclusion of the descent of the chair in the measurements might not have been so practical, since one had to work a lot with the counterweight and the hidden steelyard anyway. Contrary to me, Sanctorius most certainly worked with a calibrated steelyard and it is therefore conceivable that he used the steelyard exclusively in the classic way, when observing differences in weight in many people. However, the weighing procedures that I undertook during the exhibition were still far removed from the observations that Sanctorius described in his work *De statica medicina*. To further approximate his experimental practice, I took the replica home with me.

Reenacting the Weighing Procedures When reenacting the weighing procedures of Sanctorius, I had to consider the different parameters that the Venetian physician allegedly included in his measurement of insensible perspiration. Following his reinterpretation of the doctrine of the six non-natural things, he tried to examine the effect of climate, sleep, exercise, coitus, and even states of mind on the excretion of the *perspiratio insensibilis* (Sect. 3.3). In an attempt to find out if it is truly possible to take into account all of these parameters in the weighing procedure, I decided to commence a test series in which I myself would be the guinea pig. This required that I meticulously record my food intake, my tangible and intangible excretions, my sleep patterns, the weather, and my mood in the intervals between the measurements. I weighed myself before and after eating and drinking, before and after going to the toilet, before and after exercise, before and after sleeping, and whenever something occurred that might potentially influence my physiology.[85]

As this suggests, my imitation of Sanctorius's procedures demanded a high level of self-discipline and a regular and uniform lifestyle, always within reach of the weighing chair. I needed to develop an intimacy with the balance akin to that which some people share with their smartphones or fitness trackers. The big difference, however, was that while "wearable technology" can easily be transported, I had to stay close to the weighing chair, to make sure that no change took place unnoticed. I could not simply go out and meet friends, but had to invite them to my flat. When I did so, they became direct witnesses of my weighing procedures, which provoked mixed reactions: sometimes interest, always astonishment, and occasionally perplexity or even amusement. My regular sports activities had to be adapted, too. No longer could I go to the gym for longer periods of time, since I was not supposed to drink or go to the toilet without monitoring any changes in my weight before and afterwards. Moreover, I had to work from home, without the constant exchange with colleagues, or the technical facilities of my usual working environment. In short: experimenting with the weighing chair entailed inflexibility, isolation, and a complete orientation of daily life toward the requirements of the weighing procedures.

[85] For a brief description of a pilot phase of the reenactment of Sanctorius's weighing procedures, see: Hollerbach 2018: 141 f.

Due to these constraints, I only stayed the course for two days. For another four days, I confined myself to measuring how much I perspired when asleep at night.

My experience over the six-day test period unveiled an important dimension of the Sanctorian weighing procedures: the problematic status of living beings in an experiment. In her study on nutritional physiological experiments in the nineteenth century, Elizabeth Neswald pointed out some important characteristics when experimenting with living beings, as opposed to with inorganic objects (Neswald 2011). There is, for example, a large variability not only among different individuals, but also in a single individual at different times. Hence, even if I recorded intangible bodily losses, it was difficult to determine whether these were caused by my mood or the weather. How did I know which parameter caused which effect, or whether they influenced my body simultaneously? Without the help of statistical methods, one would need to considerably scale up the weighing procedures in order to at least detect some tendencies. Contrary to inorganic objects, living beings can be standardized and manipulated only to a limited extent. They have individual needs, interests, preferences, and boundaries. Hence, the test persons actively participate in experiments and thereby add a new dimension to the interaction already at work between the experimenter and her instruments. As Neswald suggests, the success of any physiological experiment depends on the level of cooperation between the different actors, human/animal and material (Neswald 2011: 61 f.). In my case, the situation was unique because I conducted experiments on myself.

Once a helper brought the steelyard into a balanced position for my weight, I could use the weighing chair all by myself. I just needed a ladder on which the counterweight could sit when I was not using the instrument, a small stool to help me enter the chair, and my smartphone to film the ruler attached to a chair leg to indicate the descent of the chair. Knowing the distance from the chair to the floor for my initial weight, I was able to detect weight changes by measuring the descent of the chair: 1 mm on the ruler corresponded to 100 g.[86] As this implies, the experimental situation was quite different from the previous ones. The replica entered into my private life and I interacted with the instrument on an immediate level—without any spectators or the assistance of fellow researchers. However, the struggles to discipline my behavior and to adapt my daily routine to the requirements of the weighing procedures affected my body and therefore also the outcome of the experiments. I experienced firsthand what Neswald meant when she wrote that the needs and constraints of the test persons in nutritional physiological experiments forced the researchers to modify their experiments, to shorten their planned duration, to prepare for new variables, and to accept the imprecision that resulted from these changes (Neswald 2011: 69). Although I was both the experimenter and test person in one, and was thus highly motivated to conclude the experiments successfully, my body signaled resistance. The isolation and

[86] Before I started the experiments, I again tested the proportionality and precision of the instrument by simulating weight changes through adding weights to the person seated in the chair. This showed that the chair descending by 1 mm corresponded to 100 g of weight change. However, the measurements were still prone to inaccuracies when working with very small weight changes, due to the difficulty of, for example, always adopting the exact same posture.

loss of freedom that the weighing procedures entailed were difficult for me to cope with. I had never before experienced such constraints in my daily life and quickly reached the point where I found them unbearable.

My “resistance” was more psychological than physical. Given that the weighing procedures structured every aspect of my life, I thought about them nonstop. Knowing that I had to weigh myself whenever I did something that possibly influenced my physiology, I had to train myself to recognize the situations requiring me to sit on the weighing chair. But this resulted in a certain bias that impacted my behavior. Even though the weighing itself was easy to conduct, I found myself trying to limit the weighing procedures as much as possible. Usually, I drink small amounts of water very often throughout the day. During the experiments, I tried to switch to drinking larger amounts of water only a few times a day. Similarly, I stopped eating snacks throughout the day and ate only three larger meals daily instead. Thus, also here, my behavior actively shaped the experimental practice and the outcome of the weighing procedures. My emotions and my mind influenced the way I dealt with the artificial experimental situation and made me deviate from my “normal” routines. As Neswald aptly put it with regard to nutritional physiological experiments in the nineteenth century: “normality, the normal metabolism, could only be studied under normal conditions, which, however, ran counter to the conditions of the experiment” (Neswald 2011: 73). Already during the whole reconstruction process, I had become fluent in handling the instrument in order to realize my research agenda. And yet, it turned out that I was not prepared for the dictates that the instrument imposed on me once it was installed next to my bedroom. This was, indeed, a very instructive experience.

As previously mentioned, the aim of my experiments was not to verify Sanctorius’s exact results, but to develop an understanding of his method. The calculations for my *perspiratio insensibilis* were intended to give me a general idea of how Sanctorius’s weighing practice might have looked; they did not provide reliable data to verify Sanctorius’s measurements. In order to reach a certain comparability between the present-day procedures and those undertaken by Sanctorius, one needs far more than a functional replica. In order to conduct the experiments in an identical climate to that of the historical setting, one would have to feed the test persons a Renaissance diet and move the weighing chair to Venice. But even if such measures were taken, problems like the different physiologies of early-modern and present-day individuals would remain. Here again, the fact that the experiments were physiological and undertaken with living beings complicates matters. Yet, despite these limitations, the observations made during my reenactment of Sanctorius’s weighing procedures may be reinterpreted in order to gain a better understanding of his work.

7.5.4 The Weighing Procedures of Sanctorius

Just like the experiments that I conducted with my replica, Sanctorius’s weighing procedures and their outcome were actively shaped by his test persons. Hence, in order to be successful he had to find cooperative and suitable research subjects. My experience during the experiments on myself revealed that the use of the Sanctorian chair must have been very demanding, requiring participants to put themselves wholly at the service of the experiment. Moreover, Sanctorius had to find people who were ready to closely follow his instructions and thus to interact not only with the instrument, but with the physician, too. Since the weighing chair most probably stood in Sanctorius's house, they had to stay there at the least for the duration of the weighing procedures. This shows that there must have been a high level of intimacy between the experimenter Sanctorius and his research subjects. He would monitor every visit to the toilet, every bite they ingested, and even any sexual activity. At the Long Night of Sciences, I could easily tell if a person did not comply with my request and went to the bathroom between measurements. But, of course, I was very hesitant to address their cheating or carelessness, since most people are not too eager to talk openly about their excretions.

So, who might the persons have been, willing not only to adapt their whole lifestyle to the weighing procedures, but also to let Sanctorius control and monitor their excretions? Based on my research, I think that Sanctorius could have conducted long-term measurements only with people from his immediate environment, probably with colleagues or friends. As Neswald has pointed out, for a willingness to subject oneself to the constraints of physiological experiments, it is very helpful to have an interest in, and an understanding of the research involved (Neswald 2011: 70 f.). Another possibility would be that Sanctorius paid people to sit on his chair. But given the intimacy and diligence required of the test person, I do not consider this very likely. Another, in my opinion, far more plausible scenario, is that Sanctorius used no one but himself to make long-term measurements; yet, he nonetheless issued an open invitation to sit on the chair to all and sundry who visited him at home. He accordingly was faced with the great variability of his test persons and all the challenges this involved, such as the need to frequently adjust the steelyard (Sect. 7.5.3). At any rate, the results that Sanctorius presented in the *De statica medicina* imply that it was mostly middle-aged men who helped him test the weighing chair, since he scarcely made a reference to age or gender (Sects. 3.3.5 and 4.1.2). It is also conceivable that Sanctorius avoided the problems connected with weighing many different people by conducting more experiments on himself than he cared to admit. As my experience with the replica showed, taking measurements is much easier when only one person uses the chair. The counterweight needs then be put in position once only, after which it is possible to work solely with the descent of the chair, without further need of assistance. What is more, in the course of his research, Sanctorius certainly developed great skill in using the chair properly, skill he could not expect of other test persons. In addition to this, he must have been highly motivated to conduct the measurements successfully and diligently. Yet, even though his willpower and stamina were perhaps greater than mine, it is doubtful whether he strictly observed his insensible perspiration in connection with the various measuring parameters, the six non-natural things, over a long period of time. Furthermore, if it is true that he conducted a lot of experiments on himself, then he must have faced the difficulty of translating his very individual measurements into more generally valid statements.

Along with the issues relating to Sanctorius's test persons came the problem of including the many different parameters in his measurements. In Sect. 3.3, I have analyzed how deeply embedded in traditional Galenic medicine was Sanctorius's

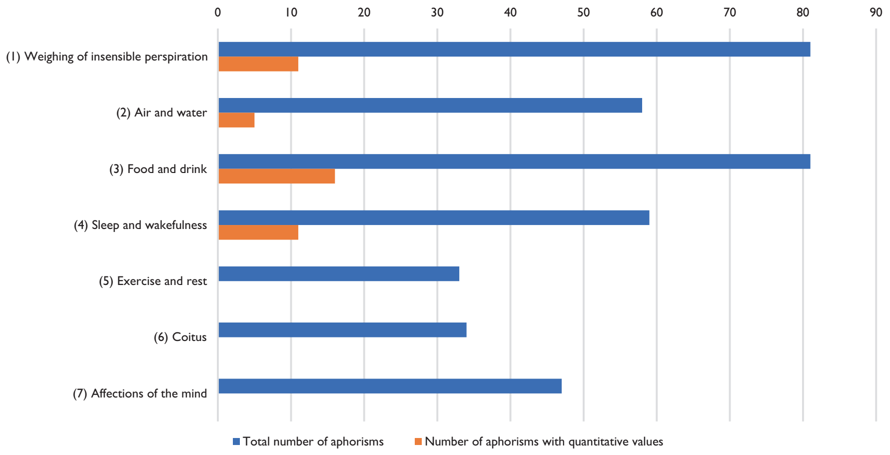

Fig. 7.32 The mention of quantitative values in the first edition of the *De statica medicina* (Sanctorius 1614)

reinterpretation of the doctrine of the six non-natural things. Perusal of the *De statica medicina* shows that Sanctorius often complemented his measurements of insensible perspiration with qualitative conclusions and general observations that he made during the weighing experiments, or that he knew of from the medical literature. Interestingly, he only specified precise quantities in the first four sections, whereas he confined himself to more general and rather qualitative statements in sections V to VII. As the diagram illustrates (Fig. 7.32), even in those sections in which Sanctorius mentioned quantitative values, he did so in only a small proportion of the aphorisms overall. This is especially remarkable with regard to the first section which, as its title says, deals with the weighing of insensible perspiration. Contrary to what one might expect, Sanctorius mentioned quantitative values in fewer aphorisms in this section than in the section on food and drink.

Looking at the 1634 edition of the *De statica medicina*, to which Sanctorius added 108 aphorisms, it is striking that none of them contains any quantitative value, except for one aphorism in the section on food and drink; yet, this refers to an assumed quantity of ingested food rather than to a measurement of insensible perspiration (Sanctorius 1634: 40r).

That being said, against the backdrop of my experiences during the reenactment of Sanctorius's weighing procedures, these observations no longer seem so surprising. In fact, they must be taken as an indication of Sanctorius's ability (or inability) to measure certain parameters. My experiments with the reconstruction have shown that it is not complicated to apply the weighing procedures to food and drink, as their quantities can be controlled and monitored relatively easy. Hence, this was most certainly the case for Sanctorius, too, and he therefore was able to specify in this section the most quantitative values. Consequently, the prominent place of food and drink in the *De statica medicina* cannot be explained solely by the great contemporary demand for dietary guidance, but also by Sanctorius's ability to quite easily measure this non-natural factor. But how did his weighing chair precisely indicate weight changes that were directly connected to his test person's mood? How could Sanctorius possibly have included all the six non-natural factors in his measurements and considered them in conjunction with each other? Since I failed to achieve this in my experiments on myself, it is most probable that Sanctorius actually also had difficulties in doing so.

In view of the lack of numerical values in the section on the influence of mood on insensible perspiration, for example, it can be assumed that Sanctorius was unable to determine any. When reenacting the experiments, I often found it hard to tell what emotions I had or what mood I was in. Furthermore, these were also influenced by the many constraints that the experimental situation imposed on my daily life. For the chair to measure my "affections of the mind," I would have had to use the weighing chair as soon as I recognized a mood change, to determine how this was affecting my weight and the excretion of the *perspiratio insensibilis*. While it was already very difficult for me to somehow detect a mood change in myself, especially under the artificial circumstances of the experiment, it was nigh on impossible to isolate its impact from that of the other parameters simultaneously influencing my physiology. For example, if I rested for a longer period of time and then noticed a mood change, was it the mood change, or the long rest, or a combination of both factors that was responsible for the weight change I measured with the replica chair? Adding to these difficulties, if Sanctorius did experiment not on himself, but on test persons, he would have had to completely rely on their own assessment of their mood and emotions, and on their diligence in using the weighing chair in relation to them. Thus, in all likelihood, it was issues such as these that made Sanctorius confine himself in this section of the *De statica medicina* to outlining general tendencies, for example that some emotions provoke weight loss, whereas others provoke weight gain (Sect. 3.3.6). Regarding the section on coitus, it might also have been issues of privacy and shame that prevented him from arriving at quantitative measuring results. On a more general level, the scarce references to precise quantities in the *De statica medicina* could imply that Sanctorius did not conduct as many experiments as he claimed. My experience with the replica revealed that both, the weighing of many different people over a short period of time, and long-term measurements with one person only, each bring difficulties of their own.

All things considered, it is most probable that Sanctorius tinkered with different factors until he found the most practical combination of design, measuring method, test duration, and test person. The research with the reconstruction strongly implies that he, just like me, varied the number of research subjects, the duration of the weighing procedures, the counterweights, the length of the balance beam, and his measuring methods. Whenever possible, he tried to include the six non-natural factors in his measurements, but certainly struggled, as I did, to consider all of them simultaneously. His mention or omission of quantitative values in the different sections of the *De statica medicina* reflect these struggles. Moreover, given the problems that I faced in the reenactment of the weighing procedures, Sanctorius's claim that he conducted the experiments with more than ten thousand people and over a time span of around thirty years seems highly exaggerated.

7.5.5 Measuring Respiration

In the following, I shall take up a specific aspect which does not directly relate to the preceding paragraphs, but is still important to consider in the context of Sanctorius's measurements of insensible perspiration. As explained in Sect. 3.2.4, according to the Venetian physician, *perspiratio insensibilis* resulted not only from the digestive activities of the body, but also from respiration. In the *De statica medicina*, he specified a quantity of daily respiration, which suggests that he differentiated between the two different forms of insensible perspiration in his weighing procedures. Furthermore, Sanctorius also described a way in which he arrived at this quantity, which can be interpreted as a measuring method rather than only as a simple quantitative reference, because he included it in one of his static aphorisms. However, the method which Sanctorius allegedly used to measure breathing is far from clear. He simply stated that "the drops on a mirror placed in front of the mouth" indicated that the daily respiration usually amounted to about half a pound (Sanctorius 1614: 2r).[87] It seems thus that Sanctorius placed a mirror on a balance in order to weigh the water drops on its surface caused by breathing. Given that it would be impossible to conduct such a measurement over a period of one whole day, Sanctorius most likely determined the amount of respiration for a shorter period and projected the result for the whole day. For this purpose, he might have used his pocket watch type of *pulsilogium*, which he also employed to register the duration of his observations with the thermoscopes. Or he used one of his dial type *pulsilogia*, with which he claimed to be able to measure the respiration cycle. Yet, since the water drops on the mirror would quickly evaporate, Sanctorius must have worked with very brief periods of time. This, in turn, would result in exceedingly small quantities measured, since the value that he determined for the daily amount of respiration was only half a pound.[88] Hence, it is quite questionable how Sanctorius actually conducted his measurements of breathing and how he arrived at a quantity for daily respiration. What is more, as mentioned above, it is unclear why he did not refer to his hygrometers in this context (Sect. 7.4.4). Still, some valuable clues to Sanctorius's dealing with respiration as an origin of insensible perspiration can be found in the medical tradition.

Sanctorius upheld the Galenic conception that insensible perspiration resulted from the respiratory and digestive activities of the body. In her analysis of Galen's notions of perspiration, Armelle Debru has argued that the function of respiration, oral as well as cutaneous, was, according to Galen, only qualitative, namely to balance body heat.[89] Contrary to this, *perspiratio insensibilis*, which resulted from the digestive process, fulfilled a quantitative function. Being a bodily evacuation, just

[87] "Perspiratio insensibilis … fit per respirationem per os factam, quae unica die ad selibram circiter ascendere solet; hoc enim indicant guttae in speculo, si ori apponatur." See: Sanctorius 1614: 2r.

[88] If calculated on the basis of Venetian *oncia sottile*, half a pound corresponds to 150 g (Sect. 5.4.2, fn. 39).

[89] According to Armelle Debru, Galen did not include oral respiration, but only cutaneous respiration in his concept of perspiration (Debru 1996: 183–7).

like urine or feces, it entailed a material loss. However, as Debru has further outlined, Galen did not strictly differentiate between the two forms of insensible perspiration, but sometimes confounded them in his works (Debru 1996: 153–91). This might explain why Sanctorius did not explicitly refer to cutaneous respiration in the context of insensible perspiration, and why respiration, more generally, played no major part in his weighing procedures, since he referred only in one aphorism to oral respiration and to a dubious method of weighing it. At the same time, however, the fact that Sanctorius included this aphorism in the *De statica medicina* implies that he departed from the Galenic teachings according to which the measurement of the quantity of inhaled air and exhaled matter was not only impossible, but also unimportant, owing to the exclusively qualitative function of respiration. It seems then that Sanctorius, unlike Galen, considered important the quantity of respiration, as a form of insensible perspiration, but struggled to measure it.

Interestingly, in the second half of the sixteenth century, Girolamo Cardano had already tried to quantify "inspired" air. In his commentary on the Hippocratic treatise *Nutriment*, the same work in which he examined the quantitative relation between pulse and respiration (Sect. 7.2.2), he stated that "we inspire daily eight hundred amphoras" (Cardano 1574: dedication).[90] But here, too, Cardano gave no information on how he determined this amount and whether he used an instrument to do so. It is intriguing that he indicated the quantity of respiration in amphoras, an ancient Roman unit of capacity, especially used for liquid products. Since one amphora is equivalent to about 27.84 liters, the amount that Cardano mentioned is extremely high. While his measurement of inhaled air thus raises more questions than answers and shall not be discussed here in any detail, it is still worth mentioning that Cardano had dealt with the quantity of respiration in a medical-dietetic context, before Sanctorius did (Encyclopaedia Britannica 2018).

7.5.6 The Sanctorian Chair: A Multifunctional Instrument?

With his weighing chair, Sanctorius repurposed a long-established instrument. Although the balance is one of the oldest measuring instruments, Sanctorius's seventeenth-century scale was the first to be applied to humans.[91] My reassessment of the original source materials in the light of the experience gained through reconstructing the Sanctorian chair and replicating the weighing experiments taught me how this novel application of the steelyard raises challenges for the instrument's mechanical design. It also widened my perspective on the great variety of its

[90] "… singulis diebus haurimus mensura mensa DCCC. Amphoras aeris Italicas: …." See: Cardano 1574: dedication.

[91] According to Robens, et al., weighing people was a practice during the witch trials held in Europe between the fifteenth and eighteenth centuries (2014: 470). This was not related to medical considerations, however, but to the identification of witches. Since witches were supposed to fly on brooms, they were expected to be light. A person who weighed less than circa 50 kg was thought to be able to fly. A witch trial of this sort took place in the Netherlands (near Oudewater) in 1545.

potential applications. Different measuring methods can be applied that directly affect the design, the functioning, and the precision of the weighing chair. Although my research does not allow me to unambiguously define the measuring method Sanctorius used, it has shown that this method is not as self-evident as has commonly been assumed.

On the basis of my research, it can be assumed that Sanctorius most likely used some variation on the measuring methods mentioned above. He used both the steelyard concealed behind the ceiling and at least two reference points made on the bottom of the chair. Even though the original illustration of the weighing chair gives no clear indication of a scale at the base of the chair or on the wood panel behind it, scaling would have been necessary at these two reference points. In short, Sanctorius had to translate weight into a distance. He thus worked with proportions as well as with exact quantities. Whether the pointers, nails, or pegs at the base of the chair served to indicate these reference points to stabilize the chair, or both, cannot be ascertained using the available sources.

The aphorisms of the *De statica medicina* and the description of the Sanctorian chair imply that the instrument had two functions. On the one hand, it was used as a research tool to monitor variations in the production of *perspiratio insensibilis*; on the other, it helped to determine and maintain an ideal body weight. The measuring methods might have varied in correspondence with these two functions. Based on my experiences with the reconstruction, it seems likely that Sanctorius used the steelyard in the traditional way, especially in the initial phase of his experiments, when he tried to define the healthy quantity of insensible perspiration. In this connection, he most probably observed weight changes in many different people over shorter periods of time. As soon as he managed to stabilize this quantity, he could determine the ideal body weight for individual persons and determine the healthy amount of food and drink that they should ingest. To this end, he might have used the descent of the chair as an indication of changes in weight, as described in the *Commentary on Avicenna*. My own experiments have shown that this would have enabled individuals, even laymen, to use the chair on their own, without any need of an assistant to move the counterweight along the longer arm of the weighing chair. In this regard, the weighing chair would not have been meant for use by multiple individuals, but only by one person; the beam of the steelyard would therefore be balanced only once, for that person's respective weight. Due to the rather easy measuring method and the narrow focus on keeping an ideal weight, it is indeed conceivable that Sanctorius tested this second type of use of his steelyard over a longer time span, most certainly on himself. This fits with his suggestion that the beam of the steelyard be hidden above the ceiling to obviate the astonishment of guests, to whom the weighing device might have looked ridiculous. It implies—as did the longer quote in Sect. 7.5.1—that Sanctorius may have conceived of the chair for use by a larger public, to regulate their eating habits.[92]

[92] Lucia Dacome has also pointed out the possibility that Sanctorius's proposal to hide the beam of the weighing chair above the ceiling implies that he may have conceived the chair for a larger public, beyond the community of physicians. See: Dacome 2001: 476.

In this context, it is important to keep in mind that Sanctorius published the description and illustration of the Sanctorian chair eleven years after the *De statica medicina*. Based on the insights I gained during my research, I have come to imagine a possible chronological use of the instrument, which might reflect the development of Sanctorius's research during these years. After beginning with the aim of determining the quantity of the *perspiratio insensibilis* within the frame of contemporary dietetic medicine, he might have realized that the chair not only helped the physician to monitor changes in weight and, on this basis, to issue rules of health, but also offered an opportunity to find and maintain an ideal weight. Of importance here, certainly, is the fact that the weighing procedures could be applied with relative ease to food and drink, as my own experience with the reconstruction has shown. In order to make the chair accessible to laymen, Sanctorius might have adapted the design and measuring method with regard to this newly discovered function and published both in his *Commentary on Avicenna*.[93] The great contemporary demand for health handbooks, especially food guides, and the general awareness of the importance of regulating food intake in quantitative terms (Sect. 5.1) most certainly played their part, too. With his weighing chair, Sanctorius was able to offer dietary guidance not only in the form of written advice, as in the *De statica medicina*, but also in the form of an instrument. He enabled his audience to conduct by themselves weighing procedures that allowed them to monitor their weight—without the help of a physician. As mentioned before (Sect. 5.1), dietetics in the Renaissance became a field in which laypeople—and not only physicians—might gain a certain level of authority and this propelled their efforts to regulate personal hygiene. In all likelihood, Sanctorius's weighing chair was a response to this trend.

However, it should not be forgotten that Sanctorius presented the illustration and description of the weighing chair in a lengthy medical commentary addressed, in Latin, to an audience within the university realm. Outside of this context, the work was reserved to learned physicians, scholars, or other well-educated persons fluent in Latin. Furthermore, in order to copy the Sanctorian chair, prospective weight watchers would have needed money, materials, equipment, and technical support.

7.5.7 The Reception of the Sanctorian Chair—A Few Thoughts

Without aiming to provide a detailed history of the reception of the Sanctorian chair, I will focus rather in the following on those aspects that I consider relevant to the present study. Despite the great success of the *De statica medicina* and the popularity of the weighing chair, Sanctorius repeatedly stated that he anticipated criticism

[93] In their paper (Valleriani and Pearl 2017), Matteo Valleriani and Yifat-Sara Pearl highlight the use of images as low-threshold educational tools, particularly in scientific texts, since this makes knowledge accessible to wider audiences.

of his novel quantitative approach. In the dedication to the *De statica medicina*, he wrote that he had long reflected on whether or not to publish the treatise. He was worried about its reception by "ignorant and malevolent people, who either disapprove of the novelty, or do not understand the subtleties" of static art (Sanctorius 1614: dedication).[94] In the preface to the *De statica medicina*, he similarly warned that people usually tried to suppress novelties because of envy, instead of advancing them through studies. He further explained that he expected that "many, not only among the vulgar, but also among the learned, … will rise up against this new art and will heavily inveigh against it" (Sanctorius 1614: Ad lectorem).[95] Moreover, in the dedication in the *Commentary on Avicenna*, he emphasized that many people did not accept his "new and extraordinary way of dealing with medical theory" and that he was therefore in need of a most learned and most celebrated patron—whom he found namely in Ferdinando Gonzaga (1587–1626), Duke of Mantua and of Montferrat (Sanctorius 1625: dedication).[96] In the dedication in the *Commentary on Hippocrates*, he referred to his static medicine, explaining that he hoped to promote longevity with it. According to him, matters as important as longevity depended solely on the "patronage of truth." But given that truth was in itself troublesome and the origin of hatred, he required the support of the "greatest man," who was, in this case, the Duke of Urbino, Francesco Maria II della Rovere (1549–1631) (Sanctorius 1629: dedication).

Of course, issues of authority, legitimation, and credibility were a common concern of scholars at the time, as they are still today, and it is anything but unusual that Sanctorius glowingly praised his patrons. Furthermore, citations similar to those by the Venetian physician can be found, for example, in the works of William Gilbert (1544–1603), Francis Bacon (1561–1626), and Galileo Galilei. They reflect a general attitude among the scholars of the sixteenth and seventeenth century, their sense of the dawning of a new era in which anyone who did not approve of their innovations could rightly be attacked as a backward ignoramus. Sanctorius's recurrent mention and anticipation of criticism is therefore remarkable and even more so considering that, at the time when he published the *De statica medicina*, he already held one of the most prestigious positions at the University of Padua—the chair for medical theory. The other two works in which he referred to others' disapproval, the *Commentary on Avicenna* and the *Commentary on Hippocrates*, were both published after the *De statica medicina*, when Sanctorius had already resigned his professorship. Apparently, his innovative approach to physiology and to the teaching of

94 "… ex una parte erat imperitorum, & malevolorum hominum magna acies, qui vel nova improbantes, vel subtilia non intelligentes, hanc artem, divinam licet, damnaturi essent: …." See: Sanctorius 1614: dedication.

95 "… scio multos non solum vulgares, sed etiam ex literatorum censu, … contra artem hanc novam insurrecturos, eamque graviter detracturos esse, …." See: ibid. The English translation is taken from: Sanctorius and D. 1676: Sanctorius to the reader.

96 "… hic novus, & propemodum inusitatus stylus tractandi Theoricam …." See: Sanctorius 1625: dedication.

theoria was controversially received. But being a recognized physician and an (emeritus) medical professor, why was Sanctorius so worried about criticism?

The answer certainly lies in part in his rivalry with Ippolito Obizzi. As mentioned earlier (Sect. 3.1, fn. 2), only one year after the appearance of the *De statica medicina*, Obizzi published a violent attack on the work (Obizzi 1615). In fact, already in a letter (*epistola*) dated July 1613, the physician from Ferrara had criticized Sanctorius's first book *Methodi vitandorum errorum* (Obizzi 1618: 25–32). Hence, Obizzi's objections were not exclusively directed against static medicine and Sanctorius was most probably aware of his critic before he published the *De statica medicina*. It is conceivable that personal motives, unknown to us today, were involved in the dispute, too (Grmek 1952: 10, 37; Sanctorius and Ongaro 2001: 40 f.).

However, in my opinion, Sanctorius's worries about criticism cannot be explained solely by Obizzi's attacks. It seems to me that they equally stemmed from a more general skepticism about his novel quantitative approach to physiology, which Sanctorius claimed to detect in his contemporaries, both educated and uneducated, as the citations above show. Since physiology, as a university subject, was a highly theoretical discipline at the time, Sanctorius's introduction of mechanical procedures into this field of medicine was most likely perceived as particularly radical. Accordingly, Sanctorius feared the mockery of his colleagues, and anticipated his patients' irritation upon being confronted with a huge steelyard, installed in the middle of their physician's living room. It was to mitigate this irritation that he hid the beam of his weighing chair behind a false ceiling. Interestingly, the illustration of Sanctorius's *lectus artificiosus* (Fig. 4.15) shows that the crank mechanism, serving to lift and lower the bed, was likewise concealed by a false ceiling. Even though Sanctorius did not comment on this in his description of the device, it can be assumed that, here again, he wanted to hide this novel and unorthodox feature of the instrument. Hence, Sanctorius's introduction of mechanical devices and procedures known from other contexts into the world of medical practice was not uncontroversial. In order to give a pair of scales a medical identity, Sanctorius had not only to materially adapt the device, but also to build trust in his new medical technology. Hiding the mechanism of the device was his attempt to integrate the Sanctorian chair as smoothly as possible into the domestic sphere and, more generally, into people's lives.

Putting ourselves in Sanctorius's shoes, for a moment, let's consider how he might have sold his weighing chair to a colleague or friend, without needing to rhetorically defend his novel approach. Perhaps he would have explained that, given the relevance to health of maintaining an ideal balance between ingestion and excretion, it was of the utmost importance to observe this balance in quantitative terms; and that the physician could now do so, for the first time ever, thanks to his, Sanctorius's, newly invented weighing chair. He might have uttered his conviction that most diseases resulted from hindered or blocked insensible perspiration—a physiological process which was no longer obscure, but detectable, with his instrument; and the weighing procedures he had devised would allow his colleague or friend to make a better diagnosis, prognosis, and treatment. In addition, Sanctorius would most certainly have pointed out the second purpose of his weighing chair: to define and monitor a person's ideal weight. In this regard, he probably emphasized that the weighing chair would enable everyone to keep track of their own weight. To put this in a nutshell, if Sanctorius were to advertise his instrument on today's market, he might use a slogan like: "The Sanctorian Chair—Creating Healthier and Longer Lives!" Of course, this is only playful speculation, yet it allows us to see the instrument in a new light.

Whatever words Sanctorius used to promote his weighing chair, it is difficult to ascertain how successfully he did so. Testimonies of people who built their own versions of the Sanctorian chair and imitated the weighing procedures date only from the late seventeenth century and especially, the eighteenth century, while little is known to us of the instrument's earlier reception.[97] The available sources show that, over the course of the eighteenth century, Sanctorius's weighing chair drew mixed reactions and that its two functions were hotly debated (Dacome 2001: 475). Who should use the Sanctorian chair? Was it designed for medical or lay practice? With the primary sources at hand, I still cannot unambiguously answer these questions. However, the methodological approach of replication enabled me to find a possible connection between the different functions of the Sanctorian chair and its design and measuring methods. During my research, I developed a new understanding of the mechanical and practical knowledge involved in Sanctorius's weighing procedures—an understanding that I could hardly have developed on the basis of the written sources alone.

In conclusion, while we can be sure that Sanctorius did build his weighing chair, questions still remain regarding how he actually used it. My experience with the reconstruction has shown that it is possible to measure very small quantities with a steelyard the size of the Sanctorian chair. Moreover, my own experimentation revealed that the instrument can easily be used by just one person, when the distance from the chair to the floor is to be measured. Other issues remain open, however. It is, for example, still unclear how Sanctorius dealt with the problem of including all of the six non-natural factors in his quantitative observations, or how he handled the high variability of his test persons and their influence on his weighing procedures. Furthermore, we do not know how he coped with the constraints that the experiments imposed on the test person and how this affected his weighing practice. This notwithstanding, I think there is no reason to doubt that Sanctorius actually measured the quantities to which he referred in the *De statica medicina* with an instrument that was at least similar to the one depicted in the *Commentary on Avicenna*. But his claims regarding the duration, range, and frequency of the weighing procedures are a different matter. As my experience with the reconstruction has demonstrated, it is highly questionable that he conducted his experiments over a period of thirty years. The many travels he undertook in the late sixteenth century—the time

[97] Ippolito Obizzi claimed that Sanctorius's friend Hieronymus Thebaldus used the Sanctorian chair and that the weighing procedures made him ill (Obizzi 1615: 24). Given that I was unable to find any other reference to Thebaldus's use of the instrument and that Obizzi was an opponent of both Sanctorius and Thebaldus, this statement must be taken with a grain of salt. On the quarrels between Obizzi and Thebaldus, see: Sanctorius 1625: 82.

when he allegedly started using his weighing chair—reinforce this assumption (Sect. 2.2). Similarly, Sanctorius certainly exaggerated when he wrote in his letter to Galileo Galilei that he had observed the insensible perspiration of more than ten thousand subjects (Sanctorius 1902). Indeed, as Evan Ragland has shown, it was common at the time to invoke a rhetorically large number of trials to substantiate new claims. Galileo himself claimed to have repeated experiments "one hundred times" and the physician and anatomist Gabriele Falloppia reported that he had tested a prophylaxis against the French disease "in a thousand and one hundred men" (Ragland 2017: 515).

In the same letter to Galileo, Sanctorius mentioned that the famous scholar was among the subjects who had sat in his weighing chair. Would Galileo not have protested, had this been untrue? Would Sanctorius's Venetian circle of friends, the *Ridotto Morosini*, not have been suspicious, had Sanctorius never showed them his device? And what about Sanctorius's many pupils at the University of Padua, whom he introduced his static observations to? In view of Sanctorius's renown and his large network of friends, one can imagine that it would hardly have gone unnoticed, had his static medicine been mere rhetoric. Still, it is striking that none of Sanctorius's students, friends, or colleagues seems to have written about the original weighing chair and Sanctorius's presentation of it. While there are such reports on his thermoscope and *pulsilogium*, there is no known evidence of this regarding the Sanctorian chair. From a preliminary perspective, it seems therefore that the instrument sparked enthusiasm only later, toward the end of the seventeenth century. Although Sanctorius's anticipation of criticism was certainly in part rhetorical, it might also reflect his immediate contemporaries' hesitant reception of his static experiments. Apparently, they were not prepared to install a Sanctorian chair in their homes.

7.5.8 Sanctorius's Measuring Instruments in Context

In the foregoing paragraphs, I have examined Sanctorius's measuring instruments from a broad perspective, analyzing their development and use in various contexts—theoretical, social, practical. This has revealed their deep integration into Galenic medicine and made clear that they can only be understood within such framework. Sanctorius's interest in, and receptivity to contemporary technological developments came to the fore, as illustrated by his use of a pendulum for his *pulsilogia*, for example, or his attempt, inspired by the practical hydraulics of his day, to measure the *impetus* of water currents. Moreover, the chapter has shown that his socio-intellectual milieu in Padua and Venice, most importantly, the *Ridotto Morosini*, brought him into contact with distinguished scholars and aristocrats and gave him a platform to discuss the latest technological and intellectual trends. The meetings in the *palazzo* on the Grand Canal certainly spurred him in his use of quantification and measurements—they were fertile ground in which to develop and test new ideas. Although I could often not unambiguously clarify how Sanctorius's measuring instruments were related to earlier similar ideas, such as those of

Cardano, it was hopefully instructive to highlight that these ideas did arise independently of Sanctorius. Ultimately, however, it was he who applied these ideas, concepts, instruments, and techniques to medical practice. And this is not at all trivial. As my reconstruction of his most famous instrument, the weighing chair, has clearly illustrated, the path from the intellectual conception of an instrument to its actual application in research and practice is often long, and surely was, in the case of Sanctorius, since he applied his measuring instruments to human physiology. Therefore, caution is advised, if analyzing Sanctorius's devices solely on the basis of his written and pictorial accounts of them, without further inquiry into his making and doing. In any event, Sanctorius's strong interest in practical technologies, especially mechanics, was anything but ordinary for a Renaissance physician. With his innovation of various measuring instruments, whether he actually used all of them or not, he opened up new perspectives—in medicine and beyond.

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