

CHAPTER 11

ANATOMY, MECHANISM AND ANTHROPOLOGY. NICOLAS STENO'S READING OF *L'HOMME*

In Delphine Antoine-Mahut and Stephen Gaukroger, *Descartes' Treatise on Man and its Reception*, Cham, Springer, 2016, p. 175-192. [version avant correction sur épreuves]

ABSTRACT

Nicolas Steno's criticism of *L'Homme* played a major role in the early reception of Cartesianism: from the late 1660s, the *Discourse on the Anatomy of the Brain* has never ceased being used in order to discredit Descartes's philosophy. And yet, the anatomical works of Nicolas Steno are themselves informed by Cartesian method. This paradox has led to the depiction of Steno either as a repentant Cartesian or a non-Cartesian mechanist. In this paper, I clarify such problematic labels by studying the different kinds of relationships between anthropology and anatomy that *L'Homme* may have used to justify. In particular, I show how Descartes' clock analogy was used to defend two different conceptions of the articulation between anatomical observations and functional hypotheses respectively in La Forge and in Steno.

KEYWORDS

Steno, anatomy, mechanism, functions

11.1 Introduction

Cartesian anatomy is often the object of two contradictory judgments.¹ On the one hand, the anatomical considerations of *L'Homme* are regarded as fanciful and disconnected from what

* raphaelae.andrault@ens-lyon.fr

¹ I use the following abbreviations: DESCARTES: Ariew = *Philosophical Essays and Correspondence*, ed. R. Ariew (Indianapolis/Cambridge: Hackett, 2000). AT = *Œuvres de Descartes*, ed. C. Adam and P. Tannery, new presentation by B. Rochot and P. Costabel (Paris: Vrin-CNRS, 1964-1974). *Discours* = Nicolas Sténon, *Discours sur l'anatomie du cerveau*

can be observed in anatomical theaters. On the other hand, this treatise is supposed to have promoted the description of organs as the unique cause [p. 176] of the functions of the human body. In other words, Descartes is depicted both as someone who would have dealt negligently with the anatomical science of the human body, and as someone who would have given an explanatory value to anatomy itself. One can read these two kinds of claims for instance in Kurt Sprengel's *Versuch einer Pragmatischen Geschichte der Arzneikunde* published in 1801: the resourceful hypotheses of Descartes allowed scientists to exclude occult qualities and to focus attention on the structure of the parts of the human body, while at the same time it must be recognized that Descartes' theory undermined the sense of observation.² One can find also this twofold judgement in Jacques Roger's *Les sciences de la vie dans la pensée française du XVIII^e siècle* first published in 1963. Roger sharply criticizes the Cartesian use of unverifiable hypotheses while considering that Descartes's conception of life stimulated anatomical research: since for Descartes everything was a matter of shapes and motions, it was essential to discover the shapes of organs.³ Georges Canguilhem's famous reading of the implications of the 'mechanism' in the life sciences reinforces this twofold judgement. His view was that Cartesian analogies between living bodies and machines allows one to deduce biological functions from anatomical forms, while at the same time imposing a rigid and erroneous conception of the dynamical functioning of living organisms: 'It may thus be said that [Descartes substituted] mechanism for the organism.'⁴ Canguilhem then invokes Nicolas Steno's *Discourse on the anatomy of the brain* (1669) to emphasize the distance between Descartes' man and 'the man of the anatomist,' i.e. the man of nature.

As a matter of fact, Steno's reading of *L'Homme*, and, even more so, the early reception of Steno's *Discourse*, support a complex relationship with Cartesian epistemology. A careful reading of Steno's ambiguous judgment on Descartes permits us to clarify both the role played by anatomy in Cartesian anthropology and the medical implications of the mechanist analogy between man and machine. In this chapter, I examine first Steno's reading of *L'Homme* and its early reception. Then, I show in what sense Steno's critique of Descartes'

(Paris: Robert de Ninville, 1669). *Epistolae* = N. Steno, *Epistolae et epistolae ad eum datae, quas cum proemiis ac notis Germanice scriptis edidit*, ed. G. Scherz (Copenhagen: A. Busck 1952). Gaukroger = Descartes, *The World and Other Writings*, trans. and ed. by Stephen Gaukroger (Cambridge: Cambridge University Press, 2004). Maquet = *Nicolaus Steno: Biography and Original Papers of a 17th Century Scientist*, ed. T. Kardel and P. Maquet (Berlin: Springer, 2013).

² K. Sprengel, *Versuch einer Pragmatischen Geschichte der Arzneikunde. Vierter Theil* (Halle: bei Johann Jacob Gebauer, 1801), 379.

³ J. Roger, *Les sciences de la vie dans la pensée française du XVIII^e siècle. La génération des animaux de Descartes à l'Encyclopédie* (Paris: Armand Colin, 1993), 169, 207.

⁴ G. Canguilhem, 'Machine and organism', *Knowledge of life*, ed. P. Marrati and T. Meyers, trans. S. Geroulanos and D. Ginsburg (New York: Fordham University Press, 2008), 75-97, 86.

anthropology may be partly based on Descartes' analogy between living bodies and clocks. Finally, by comparing La Forge and Steno, I explain how contradictory claims on the role ascribed to anatomy by Descartes or by the so-called 'mechanists' come from two different interpretations of the machine analogy. [p 177]

11.2. Steno's critique of Descartes and its early reception

No sooner had the Latin translation of *L'Homme* been published, than a certain number of letters and accounts of dissections raised questions about the relevance of Descartes' descriptions or the accuracy of Schuyl's diagrams. Such a reception testifies that Descartes' book constituted an important event for those who practiced anatomy in Europa at the time. To be sure, before the publication of *L'Homme*, the anatomy of the brain proposed in Descartes' *Passions de l'âme* was already being discussed by anatomists – for instance in the third version of the *Institutiones anatomicae* by Thomas Bartholin.⁵ But during 1662 a number of new discussions were triggered. In August 1662, Nicolas Steno (Niels Stensen) mentions the publication of *De Homine*, where 'there are some not inelegant figures.' He conceded that 'they have proceeded from a clever brain,' but he doubted 'whether such images can be seen in any brain.'⁶ In March 1663, Steno reiterated his judgment. He seemed first to take Descartes's anatomy of the brain seriously, since he was ready to consider the 'pineal gland' in the middle of the brain as the seat of the soul. His own dissections disabused him all the same. Mentioning his dissections of a head of horse, he explained:

The size of the pineal gland was conspicuous enough but its colour was blackish externally, internally grey marked by many dark spots so that everyone may say that black bile does not leave intact even the seat of the soul. [...] Certainly, the more I open brains, either of other animals or of birds of various kinds, the less the structure of the brain of animals thought out by the noble *Descartes*, most ingenious and otherwise very appropriate to the explanation of animal actions, seems to fit animals.⁷

During his Parisian stay in 1665, the public dissections that Steno performed nearly every day, either at the Faculté de médecine or in Thévenot's salon, disseminated his negative

⁵ Thomas Bartholin (ed.), *Anatomia ex Caspari Bartholini parentis Institutionibus, omniumque recentiorum & propriis observationibus tertium ad sanguinis circulationem reformatam, cum iconibus novis accuratissimis* (Lugdunum Batavorum: Franciscum Hackius 1651), 336-337. Beside, Descartes' conception of the movements of the heart, and more broadly, Descartes' physiology, were already discussed in the late 1630 (on the basis of the *Discours de la méthode*, 1637). See on this point Annie Bitbol-Hespériès, 'Cartesian Physiology', in S. Gaukroger, J. Schuster and J. Sutton (eds), *Descartes' Natural Philosophy* (London/New York: Routledge, 2000), 374.

⁶ Steno to Bartholin, Leiden, 26 August 1662, in *Epistolae*, 163; trans. in Maquet, 433.

⁷ Steno to Bartholin, Leiden, 5 March 1663, in *Epistolae*, 172; trans. in Maquet, 445.

judgment regarding the Cartesian account of the brain's anatomy. Jean Chapelain, a staunch Gassendist, declared:

Stensen the Dane has performed the most marvelous experiments ever in this field. He has even forced the obstinate and dogmatic Cartesians to admit the error of their leader with regard to the gland of the brain and its function [...], on which he based all the operations of the reasonable soul.⁸

[p 178]

Other accounts show that Steno's dissecting skill was then famous among Parisian scientific circles. For instance, the French scholar André Graindorge claimed that public dissections performed by Steno were 'all the rage.'⁹ It partly explains the success of the *Discours sur l'anatomie du cerveau* that Steno pronounced in 1665, in the salon of the polymath Melchisédec Thévenot, who published the short text in 1669.¹⁰ If the *Discours* does not deal exclusively with Cartesian anatomy, it does quote the French edition of *L'Homme*, and calls the 'pineal gland' the 'most famous anatomical question' of 'this century.' Steno rejects Descartes' hypotheses by showing that the gland is not at the entry of the concavities of the brain, that it cannot move from side to side without breaking apart, that it is not surrounded by arteries and, lastly, that it is not located where the animal spirits, i.e. those subtle particles stemmed from the blood and responsible for the sensory-motor actions, are supposed to come from.¹¹ All these refutations are fundamental to the assessment of Descartes' anthropology.¹² For instance, all the explanations that Descartes gave to psychophysical functions such as sensory perception, voluntary motion or attentiveness are directly or indirectly contingent

⁸ Letter to Huet, 6 April 1665, in Chapelain, *Lettres*, ed. T. de Laroque, Paris: Imprimerie Nationale 1883, II, p. 393, note 3; trans. in *Nicolaus Steno's Lecture on the anatomy of the brain*, ed. and trans. by G. Scherz (Hafniae: A. Busck, 1965), 70.

⁹ Graindorge to Huet, 5 mai 1665, in L. Tolmer, *Pierre-Daniel Huet, humaniste physicien* (Bayeux: Colas 1949), 330; trans. by Ole Peter Grell, 'Between Anatomy and Religion: The Conversions to Catholicism of the Two Danish Anatomists Nicolas Steno and Jacob Winsløw,' in O. P. Grell and A. Cunningham (eds.), *Medicine and Religion in Enlightenment Europe* (Aldeshot: Ashgate 2007), 205-221, 213: 'This afternoon we saw the eye of a horse. To tell you the truth, compared with him [Steno] we are only apprentices. [...] He is always dissecting. He has an unbelievable patience and through practice he has gained a unique expertise.'

¹⁰ On the circumstances, the audience of the *Discourse* and its publication, see our introduction in *Discours sur l'anatomie du cerveau*, ed. R. Andrault (Paris: Classiques Garnier, 2009), 15-19.

¹¹ *L'Homme*, AT IX, 179; trans. in Gaukroger, 152: 'Consider also that gland H. is composed of very soft matter which is not joined to or part of the substance of the brain but attached only to certain little arteries whose membranes are somewhat relaxed and pliant, and that it is kept in balance as it were by the flow of blood which the heat of the heart drives in its direction; so that very little is required to make it incline or lean, whether a little or a great deal, whether to this side or to that, and so to make the spirits that issue from it proceed to particular regions of the brain rather than others.' See also Steno, *Discours*, 15-16, where Steno quotes five statements that he finds decisive in *L'Homme*, and 20-21, where he dismisses those statements; trans. in Maquet, 512-513.

¹² See *Discours*, 2; trans. in Maquet, 513: 'The hypothesis of the arteries gathered around the gland and rising to the great channel is a matter of no little consequence for the system of Mr Descartes since the separation of the spirits and their movement depends on it. However, if you believe your eyes, you will find that it is only a collection of veins.'

upon the various inclinations of the gland H, i.e. the pineal gland.¹³ If this tiny gland [p 179] cannot be inclined freely side to side, the entire cerebral physiology that Descartes propounded in the *Passions de l'âme* and in *L'Homme* is challenged. It is thus not surprising that in the *Ethics* Spinoza uses Steno's arguments to dismiss the union of soul and body conceived by Descartes, adding, to his refutation of the idea of an interaction between something corporeal and something incorporeal, that 'his gland is not to be found located in the middle of the brain in such a way that it can be driven about so easily and in so many ways, nor do all nerves extend as far as the cavities of the brain.'¹⁴ Such a polemical use of Steno's anatomical refutation will remain constant. A decade after the *Discourse*, Steno himself, in a letter to Leibniz, will mention the anatomical 'error' of Descartes on the organization of the muscles as a reason not to agree with Cartesian metaphysics:

I considered the system of Mr Descartes as infallible [...]. I chose a leg of a little rabbit which I had dissected a short time before. The first muscle which I tested revealed to me the first step of the structure of the muscle which so far nobody had known and which demolished the whole system of Mr Descartes. [...] [If those gentlemen] have deceived themselves in material things which are accessible to the senses, what certitude can they give me against a similar deception if they deal with God and the soul.¹⁵

Later on, Leibniz will use such a judgment to dismiss Descartes' authority in matter of experimental science.¹⁶ In this way, the dissections performed by Steno were used to discredit Cartesian anthropology as a whole.

11.3. The man of Descartes and the man of the anatomists

What, however, are the real implications of the criticism that the man depicted by Descartes in *L'Homme* does not correspond to the man observed by the anatomists? Descartes himself

¹³ See for instance *L'Homme*, AT XI, 183-184; trans. in Gaukroger, 155: 'And when a soul has been put in this machine, this will allow it to sense various objects by means of the same organs, disposed in the same way, and without anything at all changing except the position of the gland [...]. Now suppose that gland leans a little further forward, in such a way that points *n* and *o* on its surface are at the places marked *i* and *k*, and that as a consequence it is from them that the spirits entering and issue: the soul would sense what is at *n* and what is at *o* by means of the same hands without them being changed in any way.'

¹⁴ *Ethics*, part. 5, preface, trans. S. Shirley, in Spinoza, *Complete Works*, ed. M. L. Morgan (Indianapolis/Cambridge: Hackett 2002), 365. On the interest of Spinoza for the public dissections of the brain performed by Steno in Leiden, see Pina Totaro, 'Ho certi amici in Ollandia': Stensen and Spinoza – science verso faith,' in K. Ascani, H. Kermit, and G. Skytte (eds.), *Niccolo Stenone. Anatomista, geologo, vescovo* (Rome: L'Erma 2002), 27-38. For a more detailed account on this use of Steno's anatomy in Spinoza, see Raphaële Andrault, *La vie selon la raison. Physiologie et métaphysique chez Spinoza et Leibniz* (Paris: Champion, 2014), 308.

¹⁵ Steno to Leibniz, 1677, in *Epistolae*, II, 367-368; trans. in Maquet, 94.

¹⁶ Leibniz to Nicaise, 1692, in *Die Philosophischen Schriften von Gottfried Wilhelm Leibniz*, ed. Gerhardt (Hildesheim/New York: Georg Olms 1978), vol. IV, 348.

pointed out the hypothetic status of his ‘man.’ His aim was not to give a complete physiology of the human body. The *Treatise* aimed rather at showing that it is possible to account for the behavior of a living body without mentioning any occult quality, vegetable power or sensitive soul. In order to do so, Descartes propounded plausible bodily causes of observed effects and functions. By definition, these causes put forward by Descartes are parts and movements that are not [p. 180] described in handbooks of anatomy; they are rather invisible components, internal fluids or unobservable movements of the anatomical parts which are shown in anatomical theaters. For instance, regarding the explanations of cerebral functions, Descartes remarks:

[The] functions that we are concerned with here do not depend at all on the external shape of the visible parts which the anatomists distinguish in the substance of the brain and in its concavities, but solely on three factors, namely, the spirits that come from the heart, the pores of the brain through which they pass, and the way in which the spirits are distributed in these pores.¹⁷

To be sure, anatomy plays an important role in Descartes’ anthropology. First, the explanations of the different functions of the human body should take into account the thin consensus view on the anatomical composition of the human body: we can assume that the hypotheses propounded by Descartes cannot contradict anatomical knowledge.¹⁸ Second, and more generally, anatomy illustrates the possibility of accounting for complex functions, such as nutrition, voluntary motion or even cognitive attention, through *explanantia* that are as simple and as corporeal as mechanical processes observed in machines:

[The] ignorance of anatomy and mechanics has contributed to [this belief that the soul is the principle behind all our movements], for in considering only the exterior of the human body, we never imagined that it had enough organs or springs in it to move itself in all the different ways in which we see it move.¹⁹

According to Descartes, anatomy suggests a model of economical explanation, where the causes are homogeneous to the effects while being simpler than them.²⁰ Third, occasionally, in the *Discours de la méthode*, the anatomical structure seems to constitute by itself the cause of physiological functions. It is the case for the circulation of the blood, a central function of

¹⁷ *L’Homme*, AT XI, 166; trans. in Gaukroger, 140.

¹⁸ See *L’Homme*, AT XI, 121; trans. in Gaukroger, 99-100.

¹⁹ *La description du corps humain*, AT XI, 224; trans. in Gaukroger, 170.

²⁰ On the principle of economy in the explanation, see *L’Homme*, AT XI, 201 (nature acts always by the most easy and simple ways); see also *Principes de la philosophie*, IXb, 319-320: the *explanans* must be simpler than the *explanandum* and conceived on the model of the things one can feel.

the animal body that seems to depend only on the different shapes of the parts of the heart and blood vessels:

[This movement of the blood] which I have just been explaining follows just as necessarily from the mere disposition of the organs that can be seen in the heart by the naked eye, and from the heart that can be felt with the fingers, and from the nature of blood, which can be known through observation, as does the movement of a clock from the force, placement, and shape of its counterweights and wheels.²¹

[p. 181] But it remains the case that anatomy does not constitute by itself the unique source of the explanations proposed by Descartes.²² To put it briefly, one should not confuse the way Descartes presents his physiological explanations (the *modus exponendi*), which in the case of the heart perfectly illustrates the possible deduction from anatomical structures to biological functions, with the *modus inveniendi* that Descartes really adopted in order to elaborate his physiology: most of the time the empirical data provided directly by anatomical observations corresponds rather in Descartes to phenomenal effects than to underlying causes.²³

It is precisely what La Forge's remarks on *L'Homme* suggests in a passage where he comments on Descartes' statement according to which the functions of the brain do not depend on 'the external shape of the visible parts which the anatomists distinguish in the substance of the brain:'

There is nothing truer than what Monsieur Descartes claims here, since we see that it is impossible to explain, nor to account for any functions of the brain, by the sole conformation of its sensible parts; what clearly demonstrates that [such a conformation] is not sufficient, and that it is necessary to seek another cause, which goes beyond what we feel.²⁴

For La Forge, it is necessary to resort to conjectures on the invisible parts of the human body to explain how it functions. In this matter, hypothetical-deductive reasoning is legitimate and

²¹ *Discours de la méthode*, AT VI, 49-50; trans. in Ariew, 69.

²² For instance Descartes mentions the 'common experience of surgeons' to prove the circulation of the blood: 'He [Harvey] proves this very effectively from the common experience of surgeons, who, on binding an arm moderately tightly above the spot where they open the vein, cause the blood to flow out in even greater abundance than if they had not bound the arm at all.' Beside this point, a lot of readings, experiments and analogies underlie Descartes' descriptions and explanations. On the anatomical knowledge of Descartes, see Annie Bitbol-Hesperies, 'Cartesian Physiology', 349-382.

²³ We cannot develop this point here. For a discussion of the idea of 'anatomical deduction' on which Canguilhem bases his critique of Descartes' mechanism, see our book *La raison des corps. Mécanisme et sciences médicales* (1664-1716), Paris, Vrin, 2016, chap. 1.

²⁴ La Forge, 'Remarques sur le *Traité de l'Homme*', in *L'homme* (Paris: Charles Angot, 1664), 287: 'il n'y a rien de plus vray que ce que dit icy Monsieur Descartes, puis que nous voyons que l'on ne peut expliquer, ny rendre raison, d'aucune des fonctions du cerveau, par la seule conformation de ses parties sensibles; Ce qui monstre clairement qu'elle n'est pas suffisante, & qu'il en faut chercher une autre cause, qui ne tombe pas sous les sens.'

does not rule out the relevance of the physiological explanations propounded.²⁵ Both the remarks on *L'Homme* and his own *Traité de l'esprit humain*, published soon after, suggest that La Forge granted a very limited role to anatomy. First, as La Forge held, the anatomy of dead bodies dissected in anatomical theaters does not necessarily correspond to the exact configuration of internal [p. 182] organs and fluids in a living body.²⁶ Second, cerebral actions that Descartes explained in his *Treatise* are allegedly caused by invisible parts such as animal-spirits and pores, which precisely go beyond the limits of anatomical observations. Consequently, Descartes' physiology cannot be refuted simply by invoking anatomical observations that contradict it: Descartes' automaton depicted in *L'homme* is not supposed to resemble the corpses observed in anatomical theaters and described in anatomical handbooks, since a certain number of parts and springs of this automaton by definition escape the power of observation that limits anatomical knowledge. The idea that Descartes' man is not the man observed by the anatomists could thus be read in a favorable light.

Steno's reading of *L'Homme* agrees with La Forge's view on one point: Descartes' machine described in *L'Homme* does not pretend correspond to the man described by anatomists. But such a common assumption leads Steno to a completely conflicting view regarding the relevance of Descartes' physiology and the role of anatomy: Steno regarded *L'Homme* as an interesting modelling only, not as the plausible and useful reconstruction of the most hidden parts of the human body:

As far as Mr Descartes is concerned, he knew too well the shortcomings of the description that we have of man to explain his true structure. Therefore, he does not undertake to do that in his *Traité de l'homme* but he explains to us a machine that would of everything men are able to do. [...]

Mr Descartes thus must not be condemned if his system of the brain is not strictly in agreement with experience.²⁷

²⁵ See also Descartes, *Principes de la philosophie*, part. IV, art. 201, AT IXb, 324; trans. in Ariew, 269: 'But it seems to me to be doing great wrong to human reason if we do not consider that knowledge goes beyond what we see.'

²⁶ *Treatise on the Human Mind*, ed. and trans. by Desmond Clarke (Dordrecht: Springer 1997), 153: 'Thirdly to their objection [i.e. the objections made by anatomists like Steno against Descartes' anatomy of the brain] that this gland cannot move, I reply that if they can convince us that all the parts of a living animal brain are as compacted as those of the head of a dead calf, their objection may be acceptable and we would possibly agree with it. But there is no reason to believe that is the case while the animal is alive...' Such a statement may be based on Descartes, *Description du corps humain*, AT XI, 224; trans. in Gaukroger, 170: 'And we have been confirmed in this error in judging that dead bodies have the same organs as living ones, for they lack nothing but the soul...'

²⁷ *Discours*, 13; trans. in Maquet, 511: 'The excellence of his mind which principally appears in his *Traité de l'homme* covers the errors of his hypotheses. We see that very skilled anatomists such as Vesalius and others could not avoid making similar errors. If these great gentlemen who spent most of their lives in dissections have been forgiven their errors, why would you be less indulgent to Mr Descartes who has spent his time very happily on other speculations?'

Steno gives a very specific role to Descartes's treatise. According to him, *L'Homme* is not uninteresting in itself, but it should not be read as a medical book and should not be seen as a solid basis for the emergent modern human physiology:

I should have been content to admire [this treatise] with some other people as the description of a nice machine all of his invention, if I had not met many people who take it quite differently and who want to present it as an exact report of that which is deeply concealed in the recesses of the human body. Since these people do not agree with the very evident demonstrations of Mr Sylvius, who has often showed that the description of Mr Descartes is not in agreement with the dissection of the bodies which it describes, I must, without reporting here all this system, point out some places where, I am sure, if they want, they will see clearly and acknowledge a big difference between the machine which Mr Descartes [p. 183] has imagined and that which we see when we make the anatomy of human bodies.²⁸

The anthropological interest of *L'Homme* seems thus rather limited. On this point, Steno and La Forge differ radically. Yet, they both defended their views by using the clock analogy.

11.4. Steno and La Forge: two opposite understandings of the clock analogy

When Steno points out the epistemological interest of Descartes' undertaking, he describes it as a 'mechanical' explanation:

Nobody else [other than Descartes] has explained mechanically all the actions of man and principally those of the brain. The others describe man himself. Mr Descartes speaks only of a machine, which however, lets us see the insufficiency of what the others teach and lets us know a method of looking for the functions of the other parts of the body as evidently as he demonstrates the parts of the machine of his man, which nobody has done before him.²⁹

Nowhere in Steno's texts there is a true definition of 'mechanical' or 'mechanism.' Moreover, it is well-known that there was no consensus about the meaning of this notion among his contemporaries.³⁰ Sometimes, 'mechanical' meant strictly an explanation based on the shapes and movements of small corpuscles, or, to put it in Boyle's words, an explanation based on 'motions and other affections of the minute particle of matters' that 'are obvious and very

²⁸ *Discours*, 14; trans. in Maquet, 511.

²⁹ *Discours*, 13; trans. in Maquet, 511.

³⁰ See for instance A. Gabbey, 'What was 'Mechanical' about *The Mechanical Philosophy*?' in C. P. Palmerino and J. M. M. H. Thijssen (eds.), *The reception of the Galilean Science of Motion in Seventeenth-Century Europe* (Dordrecht: Kluwer Academic Publishers, 2004), 11-23, and S. Roux and D. Garber, 'introduction', in S. Roux and D. Garber (eds.), *The Mechanization of Natural Philosophy* (Dordrecht/Heidelberg/New York/London: Springer, 2013), xi.

powerful in Mechanical Engines.³¹ Sometimes ‘mechanism’ implies only the thesis that ‘whatever comes about in matter arises from the prior state of matter, according to the laws of change,’³² if we [p. 184] stick to Leibniz’s own mechanism. In this last case, a mechanical explanation does not necessarily identify itself with a corpuscular explanation. Leibniz regarded with harshness the corpuscular explanations proposed by Descartes in *L’Homme*, but he propounded all the same a natural philosophy that he described himself as ‘mechanical’ or true to the ‘mechanism.’ This natural philosophy is based on local motions, but did not seek to explain growth and nutrition by putting forward the various shapes of tiny corpuscles or the fitting between the shape of the particles of the secreted fluid and the shape of the pores of the secreting gland according to the modelling of the sieve.

In accordance with Descartes’ epistemological principles, Steno’s natural science never refers to occult entities or invisible powers that would be irreducible to the local motions of corporeal parts.³³ But Steno does not present this postulate as ‘mechanical.’ In addition, if we stick to Steno’s *Discours*, ‘mechanical’ refers very generally to the evidence and clarity of the theories that presuppose that the human bodies is as decomposable as a machine: ‘Descartes ... lets us know a method of looking for the functions of the other parts of the body as evidently as he demonstrates the parts of the machine of his man, which nobody has done before him’. In the anatomical vocabulary of Steno, the word ‘demonstrate’ refers to the visual and public display of a bodily part during the process of dissecting or experimenting. Hence, the machine provides an analytical model according to which the complex behavior of a machine is explained by means of the arrangement of its observable components. Steno uses himself the analogy between the brain and a machine to indicate the necessity to base every functional explanation on the exhaustive description of bodily parts under consideration:

There are two ways only to arrive at the knowledge of a machine, one that the master who made it discloses us its artifice, the other to take it to pieces to the last spring and to examine all these separately and together [...]. The brain being indeed a machine, we must not hope to find its artifice through other ways than those which are used to find the artifice of the other machines. It thus

³¹ R. Boyle, ‘Some Specimens of an Attempt to make Chymical experiments useful to Illustrate the Notions of the Corpuscular Philosophy’, in *The works*, eds. Michael Hunter and Edward B. Davis (London: Pickering & Chatto, 1999-2000), 2, 87.

³² Leibniz, *The Leibniz-Stahl Controversy* (New Haven: Yale University Press, forthcoming), ed. and trans. F. Duchesneau and J. Smith, *Animadversiones*, §2, where Leibniz adds: ‘And this is what is meant, or ought to be meant, by those who say that all things in bodies can be explained mechanically.’ See also: ‘Leibniz’s Exception to Exception XXI’ (‘While I state that all things happen in the body mechanically, I do not thereby dwell on the exquisite figures of the pores, but in this instance I grant a greater part to motions than to figures.’)

³³ See Steno, *De Solido intra Solidum naturaliter contento dissertationis Prodromus* (Florentiae: ex Typographia sub signo Stellae, 1669), 10-11

remains to do what we would do for any other machine; I mean to dismantle it piece by piece and to consider what these can do separately and together.³⁴

And later on in the *Discours sur l'anatomie du cerveau*:

I did not anything so far of the functions of the parts, nor of the actions called animal because it is impossible to explain the movements occurring through a machine if the artifice of its parts is not known.³⁵

The comparison between an organ and a machine conceived on the model of a clock indicates that the description of parts is a necessary condition for understanding the functioning of the whole.

Negatively, this analogy means that one should suspend all hypotheses about the explanation of an action if one cannot accurately describe the real figures and situations [p. 185] of the components of the machine performing this action. That is why, regarding the brain, Steno recommends as a first matter to consider ‘the description of the parts, in which one must determine what is true and certain to be able to distinguish that from propositions which are false or uncertain.’³⁶ Plausible structures of the small parts of the human body are not considered as a sufficient basis for functional explanations. Steno takes up Descartes’ arguments in the *Discours de la méthode* according to which there are several possible ways of producing a single effect, but to better oppose Descartes’ reasoning in *L’Homme*:

These are the true means of knowing the artifice of a machine and, however most people have believed that they had better guessed it than it was easy to see it by examining it closely with one’s senses. They were content with observing its movements and, on these observations alone, they have built systems which they presented as truths when they have believed that they were able thus to explain all the effects which had come to their knowledge. They did not consider that one thing can be explained in different ways and that only the senses can assure us that the idea which we have formed about it is consistent with nature.³⁷

Both authors agree on the fact that experiments are needed for knowing which cause, among all the possible causes, has really produced the observed effect.³⁸ But for Steno, it means that

³⁴ *Discours*, 32; trans. in Maquet, 516.

³⁵ *Discours*, 53; trans. in Maquet, 521.

³⁶ *Ibid.*, p. 518.

³⁷ *Discours*, 32; trans. Maquet, 516.

³⁸ *Discours de la méthode*, VI, AT V, 65; trans. in Ariew, 76: ‘But I must also admit that the power of nature is so ample and so vast, and these principles are so simple and so general, that I notice hardly any particular effect without at once knowing that it can be deduced in many different ways from them, and that ordinarily my greatest difficulty is to find in which of these ways it depends on them. For, to this end, I know of no other expedient at all except to search once more for some experiments which are such that their outcomes are not the same, if it is in one of these ways rather than in another that one ought to explain the outcome.’

one should wait for a more advanced state of knowledge before propounding functional hypotheses: assertions that are not firmly based on observations are regarded by Steno as useless and deceptive. In this respect, Cartesian physiology would just be a premature theory – not a useful modelling and program.

Positively, the machine analogy mentioned by Steno implies making anatomy a true experimental science, and not only a point of departure on which one can build a conjectural physiology. But in order to make anatomy such a solid and essential science, it is however necessary to reform it, and notably to develop technical innovations and new experimental procedures.³⁹ For instance, Steno recommends inventing a circular saw that could rotate on a fixed axis, or a liquor that would dissolve [p. 186] bones, in order to observe the brain more easily:⁴⁰ at the time being, the methods of dissecting, and particularly the violence required to remove the brain from the cranial cavity, damaged the brain and altered the organization of the cerebral parts.

The decisive role that Steno ascribed to anatomy by using the machine analogy thus implies a certain understanding of the word ‘anatomy.’ In particular, ‘anatomy’ requires dissections, experimentations, vivisections, compared anatomy, pathological anatomy and embryological anatomy.⁴¹ Such a broad meaning of the term is not peculiar to Steno. In the early modern period, anatomy often included local excisions or techniques such as infiltration of wax or colored ink in the vessels. The division between anatomy and physiology did not correspond to the division between, on the one hand, a descriptive science of observable structures (anatomy), and, on the other hand, a science of the functions of living beings (physiology).⁴² The study of what we would call today a ‘function’ (respiration, reproduction and so on) is

³⁹ Steno considers also institutional reforms and a modification of the taxonomy, see *Discours*, 35; trans. Maquet, 517: ‘The boundaries between these two professions have been so poorly marked that true knowledge of the machine of the human body, which was most necessary, is neglected as not being in the province of anatomy nor of that of the physician nor of the surgeon. I say that to make researches which would teach us the truth requires a man entirely, a man who has nothing else to do. Even the one who makes profession of anatomy is not suited to that since he is compelled to carry out public demonstrations that prevent him from engaging in this application ...’

⁴⁰ See for instance *Discours*, 45; trans. in Maquet, 519-520.

⁴¹ See for instance *Discours*, 54; trans. in Maquet, 521.

⁴² See on this point Andrew Cunningham, ‘The pen and the sword: recovering the disciplinary identity of physiology and anatomy before 1800. Old Physiology – the Pen’, *Studies in History and Philosophy of Biological and Biomedical Sciences*, 33 (2002), 631-665; ‘Old Anatomy – the Sword’, *Studies in History and Philosophy of Biological and Biomedical Sciences*, 34 (2003), 51-76. Physiology corresponds to a systematic discourse on the whole animal or human health body, while anatomy corresponds to the experimental knowledge on such or such aspect of this body.

not detailed in physiological treatises, but in anatomical accounts: it is in books named ‘anatomy of...’ that functions or uses of organs are first studied.⁴³

Hence, the machine analogy used by Steno in order to promote anatomy does not suggest that observing the structures of the main parts of the body would be sufficient for understanding the functioning of the whole: 1) according to Steno, it is necessary – not sufficient – to observe the structures of the parts to understand precisely the way the functions are performed; 2) the functions are assimilated with the observable effects of the machine, or at least the effects that the anatomist seeks to explain – not with the *terminus ad quem* of the anatomical demonstrations;⁴⁴ 3) the observations that Steno considers essential to the explanation of the whole are not limited to the direct observation of its most coarse components; they include more complex procedures and experiments, more subtle divisions of the parts, several public demonstrations according to different methods of dissection, targeted excisions and even deductions from pathological and compared anatomy. The components of the machine that Steno deems necessary to know experimentally are not necessarily solid parts visible to the naked eye: they may be also fluids or more subtle components. [p. 187]

Strikingly enough, La Forge’s *Remarques*, in which he seeks to defend Descartes’ ‘man’, are underlain by a totally different conception of anatomy. The machine analogy is also used in order to indicate the scientific place that one should give to the direct observation of the bodily components, but in an exact opposite way. For La Forge, the different wheels of the clock are perceptible by our senses, when the inner parts of the human bodies are not. As a result, it may suffice to observe the shape and situation of the wheels in order to understand how the clock indicates the hours, when, in the case of the human body, we are compelled to resort to rational hypotheses about the structure of invisible parts:

I believe that one will not deny that, if, by the sole inspection of the conformation of every perceptible part, one could conceive how everything that is observed in the human body is accomplished, in the same manner as one clearly understand in which manner every movement of a clock is accomplished when one has examined the shape and the situations of all its wheels, one

⁴³ For a distinction between function (*functio*) and use (*usus*), see Bartholin, *Anatomia reformata*, 2-3. To put it briefly, ‘function’ is more general (respiration is a function, generation too), while ‘use’ means only what an organ or such structural aspect of this organ do, or help to do (for instance a motion).

⁴⁴ For instance Steno discovered the existence of the canal parotid in investigating on the saliva and the way the glands produced the saliva. The first element in the *modus inveniendi* was thus the apparent function and not the anatomical structure.

would never have guessed that there were in the human body a quantity of things that are not perceived in any way by our senses.⁴⁵

There ‘is a lot of things in the human Body that our senses do not perceive in any way’.⁴⁶ For those reasons, it is not only irrelevant to dismiss Descartes’s anthropology with anatomical observations, but it is also inappropriate to pretend explain more generally the functioning of the human body by means of anatomy. La Forge emphasizes the clear separation between the invisible causes invoked by philosophers and the exterior figures observable by anatomists: according to him there is no more connection between the figures observed by anatomists and the functions executed by the human body than between the exterior structure of the clock and its capacity to indicate the hours. And indeed, the apparent structure that it is observable by anatomists can be changed in various manners without altering the function of the clock:

The author [Descartes] does not say simply that these functions do not depend on the figure of the parts and on those of the cavities of the brain; otherwise he would contradict himself, since our body, being regarded as deprived from a reasonable soul that would be united to it, is nothing more than an Automaton, of which every movement depend on the conformation of its parts. But he claims that these [functions] do not depend on the figure that may [p. 188] be observed by the senses. As if a clockmaker said that the power according to which a watch indicates the time does not come from its outwards shape, all the more so because it may be changed in thousand ways without stopping to produce the same effect.⁴⁷

In sum, for Steno the analogy between the body and a machine suggests an analytical model for explaining the actions of the human body: it is legitimate to consider the human body as a machine than one can and should dismantle if one wants to explain the way it functions. For La Forge, it is impossible to explain the functioning of the human body by the mere observation of its components as it is the case for the clock, since most often the key components of the human body are precisely not observable. In both cases however, for La

⁴⁵ ‘Remarques de Louis de La Forge’, in *L’homme de René Descartes et un Traité de la formation du fœtus du même auteur, avec les remarques de Louis de la Forge* (Paris: Charles Angot, 1664), 171- 408, 215: ‘Je crois que l’on ne niera pas non plus, que si par la seule inspection de la conformation de toutes les parties sensibles, nous pouvions concevoir comment se fait tout ce qui se remarque dans le Corps humain, de la même façon que l’on comprend clairement de quelle manière se font tous les mouvements d’une horloge quand on a examiné la figure et la situation de toutes ses roues, on n’aurait jamais supposé qu’il y a quantité de choses dans le Corps de l’homme que les sens n’aperçoivent en aucune façon.’

⁴⁶ Ibid., 216: ‘Ce n’est pourtant pas que [ces hypothèses] soient fausses à cause que les sens n’en découvrent rien ; nous serions bien ignorants si nous devions douter de tout ce que nous ne voyons point.’

⁴⁷ Ibid., 287: ‘L’Auteur ne dit pas simplement, que ces fonctions ne dependent point de la figure des parties & de celles des cavités du cerveau, autrement il se contrediroit; car nostre corps, estant consideré comme n’ayant point d’Ame raisonnable qui luy soit unie, n’est rien autre chose qu’un Automate, de qui tous les mouvemens dependent de la conformation de ses parties: Mais il declare qu’elles ne dependent pas de la figure extérieure qui peut tomber sous les sens; Comme si un horloger disoit que ce n’est pas de la forme extérieur d’une montre, que vient le pouvoir qu’elle a de monstrer les heures, d’autant qu’elle peut ester change en mille façons, sans qu’elle cesse d’avoir le mesme effet.’

Forge and Steno, the image of the machine is not used in order to model some definite physiological process, but, far more generally, to demonstrate or invalidate the relevance of the autopsy of a human body for the explanation of its living functioning.⁴⁸ The analogy allows one to promote a certain kind of connection between the different branches of medical sciences or between the different parts of natural philosophy.

11.5. Conclusion: *mechanism* and *anatomy* as polysemic labellings

Those two uses of the comparison between the clock and the human body in La Forge and Steno imply two opposite understandings of the notion of visibility and of the role of observations. By means of the machine analogy, La Forge points out the opposition between what is inside the body and remains invisible and what is outside and observable. The underlying idea is that the inside of human body will always escape our powers of observation. Accordingly, anatomy cannot display the hidden causes of the observed effects; it can only display some intermediary effects.⁴⁹ On the contrary, according to Steno's understanding of the machine analogy [p. 189], the inside is always likely to be rendered observable by the new techniques and the dexterity of the observers: regarding bodily structures, the inside and the outside are relative notions. The aim of dissections is precisely to push back the limits of the experimental analysis.⁵⁰ For him there is not an insurmountable separation between the main organs observed by the anatomist at first sight and the unseen internal mechanisms according to which these organs move and function together. Hence, it is not wrong to say that the machine analogy promotes an epistemological model according to which the intelligibility of corporeal phenomena is contingent upon their visibility. As Guénancia put it, 'the machine is by excellence the example of the integral visibility to which science is supposed to reduce all natural phenomena.'⁵¹ But the conceptions of this visibility may vary widely. This visibility may just be a model of intelligibility, and in this case one may then conceive of small unobservable components, like Descartes did in *L'Homme*. Or

⁴⁸ About this distinction, see S. Roux, 'Quelles machines pour quels animaux? Jacques Rohault, Claude Perrault, Giovanni Alfonso Borelli', in A. Gaillard, J.-Y. Goffi, B. Roukhomovsky and S. Roux (eds.), *L'automate. Machine, métaphore, modèle, merveille* (Pessac: Presses universitaires de Bordeaux, 2013), 69-113.

⁴⁹ See C. Salomon-Bayet, *L'institution de la science et l'expérience du vivant* (Paris: Flammarion, 1978), 180-181: 'la dissection ne donne pas la raison des faits de surface, elle donne une autre série de faits constatés à un autre niveau.'

⁵⁰ Steno mentions sometimes the '*analysis sensibus*', see the *Elementorum Myologiae Specimen seu Musculi* description (Florentiae: ex Typographia sub signo Stellae, 1667), 4.

⁵¹ P. Guénancia, 'La signification de la technique dans le *Discours de la méthode*', in H. Méchoulan (ed.), *Problématique et réception du Discours de la méthode et des Essais* (Paris: Vrin, 1988), 213-223, 215. See also C. Wilson, *The invisible world: Early Modern Philosophy and the Invention of the Microscope* (Princeton: Princeton University Press, 1995), 113.

this visibility may be an experimental requirement that implies to really observe the components put forward, like Steno recommended. Those two opposite understandings of the intelligibility of the human body and of the machine analogy may be seen however as two readings of only one Cartesian claim: the claim that the different functions of the human body ‘follow naturally from the disposition of its organs alone.’⁵² Indeed, on this last point, La Forge and Steno would agree. But this agreement indicates nothing specific about the way we have access to the disposition of the organs (experimentally or by conjectures?), or about what we can call an organ (just the main organs, the most subtle parts and fluids or the unobservable corpuscles mentioned by Descartes?).

These two concurrent readings of Descartes precisely gave rise to two different understandings of the specificity of mechanism in respect to anatomy. The first understanding, following La Forge, identifies medical mechanism with the hypothetical reconstitution of hidden structures and movements.⁵³ The other understanding associates mechanism with an analytical method that experimentally brings back the functioning of a whole to the description of its various components.⁵⁴ [p. 190] It seems to us that these two conceptions of what defines Cartesian mechanism and its relationship to anatomy are often not distinguished. This would explain the contradictory claims about the place of anatomy in Descartes’ natural philosophy that we mentioned in introduction.

Accordingly, Steno’s *Discourse* may be seen as a mechanist manifesto only if one interprets ‘mechanist’ as ‘analytical’ and finds decisive the very occurrence of the machine analogy. But this machine analogy was very common and sometimes used to defend opposite claims. In the late seventeenth century, there was neither agreement on the exact definition and role of anatomy, nor on the exact implications of the general comparison between the human body and a clock. Accordingly, it does not seem relevant to relate the so-called biological ‘mechanism’ with a certain epistemological priority granted to anatomy understood as the mere description of bodily structures.

⁵² Descartes, *L’homme*, AT XI, 202.

⁵³ Claude Perrault adopts for instance this kind of epistemological model. See *Œuvres de physique et de mécanique de Mrs. C. & P. Perrault, de l’académie royale des sciences et de l’académie française* (Amsterdam: chez J.-F. Bernard, 1727), vol. IV, 513: the dissection displays only the outside of the organs; conjectures and reflections are needed to go further (orig. ‘La dissection, qui présente à l’œil la composition et la structure artificieuse de toutes les parties des organes, n’en fait voir, pour ainsi dire, que le dehors. Pour être instruit autant qu’il est possible, de ce qui se fait dans les organes, il faut entrer plus avant, et passer outre, si l’on peut, par l’entremise des conjectures et des réflexions que les différents phénomènes peuvent fournir’).

⁵⁴ It is the kind of mechanism that epistemologists identify today in R. Cummins’ understanding of the notion of ‘function’ (see ‘Functional Analysis’, *Journal of Philosophy*, 1975, 72, 741-764).

Bibliography

Andrault, Raphaële, 'Mathématiser l'anatomie: la myologie de Stensen,' in *Early Science and Medicine*, vol. 15, n° 4-5, 2010, p. 505-536.

Andrault, Raphaële, *La vie selon la raison. Physiologie et métaphysique chez Spinoza et Leibniz*, Paris: Champion 2014.

Ariew, Roger, *Descartes and the First Cartesians*, Oxford: Oxford University Press 2014.

Bartholin, Thomas, *Anatomia ex Caspari Bartholini parentis Institutionibus, omniumque recentiorum et propriis observationibus, tertium ad sanguinis circulationem reformata, cum iconibus novis accuratissimis*, Lugdunum Batavorum: Franciscum Hackium 1651.

Bartholin, Thomas, *Anatome ex omnium veterum recentiorumque observationibus imprimis Institutionibus b. m. parentis Harvejanam, et vasa lymphatica quartum renovata*, Lugdunum Batavorum: ex Officina Hackiana 1673.

Bitbol-Hespériès, Annie, 'Cartesian Physiology', in S. Gaukroger, J. Schuster and J. Sutton (eds), *Descartes' Natural Philosophy*, New York: Routledge, 2000

Brown, Harcourt, *Scientific Organization in Seventeenth-Century France (1620-1680)*, Baltimore: William & Wilkins Cie 1934.

Canguilhem, George, 'Machine and organism', *Knowledge of life*, ed. P. Marrati and T. Meyers, trans. S. Geroulanos and D. Ginsburg, New York: Fordham University Press, 2008.

Chapelain, Jean, *Lettres*, ed. T. de Laroque, Paris: Imprimerie Nationale, 1883.

Cummins, Robert, 'Functional Analysis', *Journal of Philosophy*, 1975, 72, 741-764

Cunningham, Andrew, 'The pen and the sword: recovering the disciplinary identity of physiology and anatomy before 1800. Old Physiology – the Pen', *Studies in History and Philosophy of Biological and Biomedical Sciences*, 33 (2002), 631-665.

Cunningham, Andrew, 'Old Anatomy – the Sword', *Studies in History and Philosophy of Biological and Biomedical Sciences*, 34 (2003), 51-76.

Descartes, René, *De Homine, figuris et latinitate donatus a Florentio Schuyl*, Lugdunum Batavorum: Petrum Leffen & Franciscum Moyardum 1662.

Descartes, René, *L'homme de René Descartes et un Traité de la formation du fœtus du même auteur, avec les remarques de Louis de la Forge*, Paris: Charles Angot 1664.

Descartes, René, *Œuvres*, ed. C. Adam and P. Tannery, new presentation by B. Rochot and P. Costabel, Vrin-CNRS 1964-1974.

Descartes, René, *Philosophical Essays and Correspondence*, ed. R. Ariew, Indianapolis/Cambridge: Hackett, 2000.

Descartes, *The World and Other Writings*, trans. and ed. by S. Gaukroger, Cambridge: Cambridge University Press, 2004. [p. 191]

Journal des savants, I (1665-6), ed. De Houdeville, Amsterdam: Pierre Le Grand 1685.

Gabbey, Alan ‘What was ‘Mechanical’ about *The Mechanical Philosophy*?’ in C. P. Palmerino and J. M. M. H. Thijssen (eds.), *The reception of the Galilean Science of Motion in Seventeenth-Century Europe*, Dordrecht: Kluwer Academic Publishers, 2004, 11-23.

Gaukroger, Stephen, Schuster, John and Sutton, John (eds), *Descartes’ Natural Philosophy*, New York: Routledge, 2000.

Gaukroger, Stephen, ‘The resources of a mechanist physiology and the problem of goal-directed processes’, in S. Gaukroger, J. Schuster and J. Sutton (eds), *Descartes’ Natural Philosophy*, New York: Routledge, 2000, 383-400.

Grell, Ole Peter, ‘Between Anatomy and Religion: The Conversions to Catholicism of the Two Danish Anatomists Nicolas Steno and Jacob Winsløw,’ in O. P. Grell and A. Cunningham (eds.), *Medicine and Religion in Enlightenment Europe*, Aldeshot: Ashgate 2007, p. 205-21.

Guénancia, Pierre, ‘La signification de la technique dans le *Discours de la méthode*’, in H. Méchoulan (ed.), *Problématique et réception du Discours de la méthode et des Essais*, Paris: Vrin, 1988, 213-223

Huygens, Christiaan, *Œuvres complètes*, ed. Société hollandaise des Sciences, Den Haag: Martinus Nijhoff, 1880-1950.

La Forge, Louis de, *Traité de l’esprit de l’homme et de ses facultés et fonctions et de son union avec le corps suivant les principes de René Descartes*, Paris: Theodor Girard, 1666.

La Forge, Louis de, *Treatise on the Human Mind*, ed. and trans. Desmond Clarke, Dordrecht: Springer, 1997.

Leibniz, Gottfried Wilhelm, *Sämtliche Schriften und Briefe*, Berlin: Akademie-Verlag, 1923–.

Perrault, Claude, *Œuvres de physique et de mécanique de Mrs. C. & P. Perrault, de l’académie royale des sciences et de l’académie française*, Amsterdam: chez J.-F. Bernard, 1727.

- Roger, Jacques, *Les sciences de la vie dans la pensée française du XVIII^e siècle. La génération des animaux de Descartes à l'Encyclopédie*, Paris: Armand Colin, 1993.
- Roux, Sophie, 'Was there a Cartesian Experimentalism in 1660s France?', in Mihnea Dobre and Tammy Nyden (eds.), *Cartesian Empiricisms*, Dordrecht: Springer 2013, 47-88.
- Roux, Sophie and Garber, Daniel, 'introduction', in S. Roux and D. Garber (eds.), *The Mechanization of Natural Philosophy*, Dordrecht: Springer, 2013.
- Roux, Sophie, 'Quelles machines pour quels animaux? Jacques Rohault, Claude Perrault, Giovanni Alfonso Borelli', in A. Gaillard, J.-Y. Goffi, B. Roukhomovsky and S. Roux (eds.), *L'automate. Machine, métaphore, modèle, merveille*, Pessac: Presses universitaires de Bordeaux, 2013.
- Salomon-Bayet, Claire, *L'institution de la science et l'expérience du vivant*, Paris: Flammarion, 1978.
- Schiller, Joseph and Théodoridès, Jean, 'Sténon et les milieux scientifiques parisiens,' in Gustav Scherz (ed.), *Steno and Brain Research in the Seventeenth Century*, Oxford: Pergamon Press 1968, p. 155-67.
- Spinoza, Benedict, *Complete Works*, ed. M. L. Morgan, trans. S. Shirley, Indianapolis/Cambridge: Hackett 2002.
- Sprengel, Kurt, *Versuch einer Pragmatischen Geschichte der Arzneikunde. Vierter Theil*, Halle: bei Johann Jacob Gebauer, 1801.
- Steno, Nicolas, *Elementorum Myologiae Specimen seu Musculi descriptio*, Florentiae: ex Typographia sub signo Stellae 1667.
- Steno, Nicolas, *Discours sur l'anatomie du cerveau*, Paris: Robert de Ninville, 1669.
- Steno, Nicolas, *De Solido intra Solidum naturaliter contento dissertationis Prodromus*, Florentiae: ex Typographia sub signo Stellae, 1669
- Steno, Nicolas, *Opera theologica*, ed. K. Larsen & G. Scherz, Hafniae: A. Busck, 1944.
- Steno, Nicolas, *Epistolae et epistolae ad eum datae, quas cum promonia ac notis germanice scriptis*, ed. G. Scherz, Hafniae: A. Busck, 1952.
- Steno, Nicolas, *Lecture on the Anatomy of the Brain*, ed. G. Scherz, Hafniae: A. Busck 1965.
- Steno, Nicolas, *Chaos-manuscript, Copenhagen 1659, complete edition*, ed. and trans. by A. Ziggelaar, Copenhagen: Munksgaard 1997.
- Steno, Nicolas, *Discours sur l'anatomie du cerveau*, ed. R. Andrault, Paris: Classiques Garnier 2009.
- Steno, Nicolas, *Nicolaus Steno: Biography and Original Papers of a 17th Century Scientist*, ed. T. Kardel and P. Maquet, Berlin: Springer 2013.

Tolmer, Léon Joseph Auguste Louis, *Pierre-Daniel Huet, humaniste physicien*, Bayeux: Colas 1949. [p. 192]

Totaro, Pina, ‘Ho certi amici in Ollandia’: Stensen and Spinoza – science verso faith,’ in K. Ascani, H. Kermit, and G. Skytte (eds.), *Niccolo Stenone. Anatomista, geologo, vescovo*, Rome: L’Erma 2002, p. 27–38.

Wilson, Catherine, *The invisible world: Early Modern Philosophy and the Invention of the Microscope*, Princeton: Princeton University Press, 1995.