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Giovan Battista Della Porta's construction of pneumatic phenomena and his use of recipes as heuristic tools

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SPECIAL ISSUE
The creative power of experimentation: Bacon and Della Porta

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Abstract

In this paper, I suggest that research results from the history and philosophy of modern science provide a valuable methodological contribution for investigating early modern experimental philosophy and employ them to reassess the contribution of Giovan Battista Della Porta to its development. In modern science, the production of experimental knowledge is dependent on a complex array of communication strategies involving verbal terminology, diagrams, standardized instruments, and measurement units. Historians and philosophers have investigated the constitutive connection between such strategies and the phenomena scientists study in laboratories, showing how the two often co-evolved during the 19th and 20th centuries. Della Porta took an important first step towards the development of such methods by transforming the traditional recipe format into a strategy for mutually connecting, conceptualizing, and sharing observations made in experiments involving similar, but not identical, instruments and procedures. I use as a case study the changing manner in which he used recipes for presenting and connecting a number of pneumatic experiences from the first edition of *Natural Magic* (1558) until his meteorology treatise *On Transmutations of Air* (1610). In modern terms, those experiences can be interpreted as demonstrating the air's expansion and contraction with heat or pressure. However, today's notions of air pressure, density, and volume did not exist around 1600 and the verbal, visual, and quantitative means of expressing them had yet to be created. Della Porta did not create the modern notions, but he contributed to their emergence in a substantial way with his discussions of those pneumatic experiences. Della Porta's innovation may be described as the creation of a new epistemic genre, but it was not of a purely literary character, since the recipes also shaped the instruments and procedures they described, transforming them into new means of knowledge production in experimental philosophy.

KEYWORDS
construction of phenomena, Giovan Battista Della Porta, pneumatics, recipes

1 | INTRODUCTION

Diverse concepts and practices of experiment are today recognized as a core element of the natural sciences. There is no single, specific function fulfilled by experimentation within scientific research, but historians and philosophers generally agree that experimental practices are epistemically independent from theoretical ones and are not simply means of delivering raw material for reflections or of testing conceptual hypothesis.[1] In particular, it is recognized that experiments can modify and expand conceptual frameworks, or even create new ones. In this context, techniques for representing and manipulating experiences play a very important role.

These research results were achieved by investigating the experimental practices of modern and contemporary science, and they have yet to be systematically employed to analyse the writings on experiment by Renaissance scholars. Thus, these writings are often approached by focussing on the more abstract cultural or philosophical issues, such as notions of "matter" or "wonders," the relationship of the text to the Aristotelian or alchemical traditions, the literary techniques employed by the authors, or the way in which experiments could come to be seen as epistemically relevant. The present contribution aims to demonstrate the productivity of an approach more sensitive to the complex interface between experiments and texts, which can open up new perspectives on the investigation of early modern experimentation. I will do so by discussing the changing way in which Giovan Battista Della Porta presented and interpreted one specific experience in his writings, starting from his first published work, the first edition of *Natural Magic* (1558), and finishing with his meteorology treatise *On Transmutations of Air* (1610), which was printed only a few years before the author's death.[2] The experience, which I refer to as an "inverted glass experiment," involves a vase of transparent glass, some water, and some air.[3] In today's terms, the experience can be seen as demonstrating how air expands and contracts with heat and cold and that, when expanding, it is capable of exercising pressure on a water surface, pushing it down. As is often the case with experiments from the 16th and early 17th centuries, today's conceptualization appears so simple and straightforward that it is tempting to think of

[1]Seminal studies on this topic include Franklin (1989); Galison (1997); Rheinberger (1997); Steinle (2016).
[2]The first edition of *Natural Magic* comprised four books (Della Porta, 1558/1560), and was later expanded into a 20-book edition (Della Porta, 1589/1597). The treatise *On Transmutations of Air* was published in 1610, although it had probably been ready for some time, waiting for the approval of the Church (Della Porta, 1610/2000).
[3]I introduced the term "inverted glass experiment" in Borrelli (2008b).

the experiences in terms of the discovery of pre-existing natural phenomena.[4] When looking in this way at Della Porta's discussion of the inverted glass experiment, one may interpret his later descriptions at least partially in today's terms, and so receive the impression that Della Porta was taking a first glimpse at phenomena later explored more competently by other authors, such as Evangelista Torricelli or Francis Bacon.

However, when using a methodological approach developed on the basis of later, more complex case studies on electromagnetism, particle physics or molecular biology, one can see that today's notions not only of air pressure, but also of air density and volume are anything but trivial, and that no verbal, visual, or quantitative terminology that could express them existed around 1600.[5] Indeed, as I argue in the following pages, these notions and the means to express them emerged from a process of instrument-aided construction of phenomena, of which Della Porta's discussions of the inverted glass experiment constituted a very important step. In other words, Della Porta simultaneously developed new concepts and new verbal—and later, also visual and quantitative—strategies to express them. It was a construction of knowledge about nature that was possible only with the help both of new instruments and procedures and of new ways of fixing them in writing, both for the experimenters and for the general public. The conceptual structures that Della Porta developed to express new and old pneumatic experiences in writing were different from the modern ones, and are often difficult to grasp today, as in the example of the "consistency" of air discussed below. However, this fact does not detract from their historical role as a basis for further developments, and their complexity can be regarded as evidence of the difficulty of the task Della Porta faced.

The knowledge produced in Della Porta's experiments was not linked to common experiences, such as that heavy bodies fall to the ground or that water boils when heated, but to quite singular ones, which could only be brought about with the help of specific objects and by following predetermined procedures. As a result, Della Porta often made use of the recipe format, which had been employed also in learned texts to fix in writing and communicate procedural knowledge since antiquity. When I use the term "recipe," I refer not only to short and simple "how to" texts, but also to long, elaborate instructions on how to build instruments and perform experiences.[6] In Della Porta's more scholarly writings, and partly also in the second edition of *Natural Magic*, recipes were at times enriched by or embedded in learned discussions, but they still remained recipes, whose key feature—as far as the topic studied here is concerned—was to address the reader as a potential experimenter and creator of an effect that is rarely or never experienced in everyday life. The recipe format had become well-established in the 16th century as the standard form used in "books of secrets" to present readers with more or less realistic instructions on how to produce extraordinary effects. Della Porta started his writing career within that tradition, and recipes remained for him a privileged means for expressing experimental knowledge throughout his life. In his later works, he developed the format by systematically employing the same terminology across a series of recipes, thus allowing him to connect them into a coherent whole and giving rise to more complex textual creations, which combined the hierarchical structure of a classical treatise with the parallel one of a book of secrets. In the case study discussed below, the result of these efforts was an innovative framework for conceptualizing experiences involving air.

The structure of this paper is as follows: In the next two sections, I briefly introduce Della Porta's work, as well as his notion of natural magic and how it related to the use of recipes. In the following chapter, after some general remarks on the connection between representation strategies and knowledge construction, I focus on the function of recipes in the creation of phenomena and in the formation of new concepts. After that, I sketch the different ways in which air and its properties could be viewed in the late 16th and early 17th centuries, and then explain how, in that historical-epistemological context, Della Porta's pneumatic writings might be regarded as attempts to provide a new and comprehensive conceptualization of a broad range of experiences and observations involving the rarefaction and condensation of air. I support these theses with analyses of texts from the first and second editions of

[4]For a discussion of this effect in the case of optics, see Borrelli (2014; 2017).

[5]See, on electromagnetism, Steinle (2016); on particle physics, Galison (1997); on molecular biology, Rheinberger (1997).

[6]On the recipe form, see Pomata (2013) and the references therein. Further below I discuss how my analysis relates to that literature.

Natural Magic (*Magia naturalis*, 1558 and 1589), from the Italian version of the *Three Books on Pneumatics* (*Tre libri de' spiritali*, 1606), and from the meteorological treatise *On Transmutations of Air* (*De aeris transmutationibus*, 1610).[7]

2 | DELLA PORTA'S WRITINGS AND HIS CONCEPT OF NATURAL MAGIC

The name of Giovan Battista Della Porta was well-known to the learned public of his time, well beyond his native town of Naples.[8] Born to an impoverished noble family around 1535, Della Porta was taught privately and travelled Europe as a young man, spending time at different Italian and European courts. Later in his life, he lived mainly in Naples, where he died in 1615. Della Porta achieved fame initially with the first edition of *Natural Magic*, which was published in 1558 and quickly reprinted and translated from the Latin original into many other languages.[9] This work conformed to the tradition of books of secrets, which was very popular in Italy at the time. They were collections of short chapters, mostly in recipe form, that reported knowledge originating from ancient and medieval authors and contemporary artisans.[10] In fact, in the Italian language of the time, the term "*secreto*" could also mean a formula or recipe that had previously been transmitted only by word of mouth and was being written down for the first time.[11] Della Porta's *Natural Magic* contained recipes from ancient and medieval sources of various kinds, but also included much original material derived either from Della Porta's own fantasies and experiences, or from those of persons in his circle of friends, who were often mentioned in his writings. The topics treated in the volume were very varied, as we shall see, but they corresponded to Della Porta's broad interests and capabilities. In 1589, he published a second, much expanded version of *Natural Magic*, in which the material from the first edition was reprinted, at times in slightly altered form, and complemented with new experiences, new topics, and some additional learned discussions.[12] While working on the second edition of *Natural Magic*, Della Porta was also experimenting and reading both older and newer literature on many topics. During the late 16th and early 17th centuries, he published a series of monographs devoted to subjects that had been treated in shorter form in *Natural Magic*. For the purposes of this paper, the treatises of interest are those *On Pneumatics*, published in 1601 in Latin and then in 1606 in an expanded Italian edition, and the one on meteorology, *On Transformations of Air*, which appeared in print in 1610.[13]

Before discussing Della Porta's pneumatic experiments, however, a few words must be said about his relationship with another, equally successful literary and philosophical tradition of his age: treatises of "natural magic." Natural magic is a term that had emerged in the 15th century in parallel with the increasing criminalization by Church and state of ritualized practices aimed at enlisting the help of occult powers to produce effects relevant to worldly life.[14] These practices were usually subsumed by those opposing them under the general term "magic," but some of the authors interested in them strove to introduce a distinction between a natural magic that only harnessed the forces of nature and a black, demonic magic that instead relied on the invocation of holy or unholy powers—angels and demons. On this basis, they argued that only the latter should be forbidden, although in practice the distinction remained quite vague. Eventually, the term was appropriated by philosophers, who gave their own diverging characterizations of what "natural magic" was, and to what extent it did or did not involve commerce with demonic powers. In *Natural Magic*, Della Porta combined ideas from earlier authors, especially Marsilio Ficino and Agrippa von Nettesheim, to expound the distinction between allowed and forbidden magic, which was of great relevance for his

[7]For my analysis I have used either the original Latin or Italian text, in the modern critical edition (Della Porta, 1606/2008b; 1610/2000) or, when such an edition does not exist, in early modern ones (Della Porta, 1558/1560; 1589/1597). To my knowledge, no translations exist for the meteorological and pneumatic treatises, and *Natural Magic* was translated into various languages during the 16th and 17th centuries, but the English translations given in this paper are my own.

[8]The following discussion of Della Porta's life and works is based on Eamon (1994; 2017).

[9]Della Porta (1558/1560). On the reception of *Natural Magic* and other works by Giovan Battista Della Porta, see Balbiani (1999).

[10]Eamon (1994).

[11]Byrne (2017, p. 687).

[12]Della Porta (1589/1597).

[13]Della Porta (1601/2008a; 1606/2008b; 1610/2000).

[14]Labouvie & Neugebauer-Wölk (2016).

constant struggle against ecclesiastic censorship and the Inquisition.[15] He was well aware of the Church's increasing persecution of writers on natural magic, which led to Giordano Bruno being burned at the stake in 1600 and Tommaso Campanella enduring torture and decades of imprisonment.[16]

Perhaps also because of this, when writing on natural magic, Della Porta left out the mystical and religious connotations present in Ficino and Agrippa, and instead underscored the role of experimental practice in the natural-magical endeavour, explaining how the primary goal of a magus was to substitute himself to nature in finding a way to produce given effects. Della Porta's *Natural Magic* was so successful that in many ways it redefined that term, (re) connecting it to experimental practices, in contrast to authors like Ficino, Bruno, or Campanella. Other than those and other authors of his time, Della Porta did not investigate nature from the background of any predetermined conceptual framework, and was also not interested in formulating a new one.[17] Even in his more learned writings he rarely employed the usual structure of a natural philosophical treatise, where general principles are first stated and then applied. Instead, he followed a bottom-up approach, presenting chosen facets of nature through specific human perceptions (and in some cases even emotions), then showing how these human reactions—and, as such, the phenomenon—could be reproduced by the natural magician, who in this way could both entertain his public and learn about nature. Yet Della Porta was not in principle averse to broader theoretical statements. In his treatise on meteorology, for example, there is a central tenet stated at the beginning that provides the basis for all meteorological explanations: the activity of air and its ability to transform into all possible weather manifestations.[18] In that case, too, however, little or no details are provided as to how the transmutations of air occur, and the actual explanatory work in the treatise is usually done by elaborate recipes demonstrating how the activity of air and its transformations can be brought about in experiments. One may say that Della Porta did not attempt to refer to one specific theory of nature, but was happy to make use of elements from very different schools of thought when he believed them appropriate to the case at hand.

3 | DELLA PORTA'S USE OF THE RECIPE FORMAT

The earliest recipe relevant for the current topic appeared in the first edition of *Natural Magic*, and it states:

> One should prepare a vase with a very long neck (the longer the neck is, the more marvellous [the experiment]), made out of glass and transparent, so that through it you shall see the water rise. The vase must be filled completely with boiling water (or alternatively its bottom should be brought near to a fire), so that it will all become very hot, then immediately, lest it cool down, it must be turned upside down and put with its mouth in the water, and it will absorb it all in itself. The explorers of the nature of things say that it is in this way that water is drawn up and absorbed by the rays of the sun from the caves of the earth in mountains, so that water springs originate.[19]

This short, simple text was included also in the second edition of *Natural Magic* alongside longer, more refined recipes, and it is easy to dismiss it as having little relevance for the development of experimental philosophy. In fact, although later recipes on pneumatics were more elaborate, all of them, when interpreted in today's terms, can be seen as describing quite simple applications of the same physical phenomenon: the variations of volume and pressure

[15]Tarrant (2013); Zambelli (2004).

[16]On Della Porta and the Inquisition, see Tarrant (2013).

[17]For more details on this topic, see Borrelli (2011).

[18]For a discussion of Della Porta's meteorological treatise, see Borrelli (2011).

[19]"Longissimi colli paretur vas, et quo longius fuerit, eo mirabilius, vitreum vero, et pellucidum, ut ascendentem perspicies aquam, hoc bullientis aquae expletur, et ubi totum efferbuerit, vel igni fundum admoveto, illico, ne frigescat, inverso ore aquam tangat, et intro totam absorbeat. Sic naturae rerum exploratores Solis radiis aquam hauriri, et absorberi aiunt, e terrae concavis locis in montibus, unde fontanea efficitur scaturigo." (Della Porta, 1558/1560, p. 59r).

of a mass of air constrained between the walls of a (usually glass) vessel and a surface of water. By changing either the temperature of the air or the pressure acting on it, it is possible to generate a motion of the water, such as a slow raising of its level, or a sudden jet. This paper will consider the following examples of these experiments:

- The recipe for raising water quoted above (Book 2 of *Natural Magic* [1558]);
- Two recipes for raising water and two for producing jets of water (Book 19 of *Natural Magic* [1589]);
- One recipe for "measuring into how many parts of thinner air one ounce of air in its consistency can dissolve" (Book 3 of the Italian version of the treatise *On Pneumatics* [1606]);
- One recipe for "measuring" the expansion of air (as above), and to demonstrate the creation of wind (Book 1 of *On Transformations of Air* [1610]).

The effects described in these recipes were not a novelty at the time and were not discovered by Della Porta, so that his texts might appear to be at best light-hearted—and at worst rambling—attempts to show off with rather trivial knowledge. Indeed, the gap often present in Della Porta's writings between his general claims and the fragmentary character of the experiences described has provided the basis for criticisms of him as an enthusiastic but disorganized amateur who was more interested in impressing and entertaining his audience than in investigating nature.[20] But the picture changes when one takes into account that, however well-known these and similar pneumatic experience were at the time, there still did not exist any generally accepted framework for conceptualizing them. Della Porta's role in the history of early modern natural philosophy can best be appreciated when aware that the construction of knowledge about nature is not identical with the development of theoretical frameworks, and that experimentation cannot be separated from its representation and circulation, just as there are no clear-cut distinctions between a "descriptive" and an "explanatory" language.[21]

As will be discussed more in detail in the next section, even in modern science "phenomena" and "facts" are not something naturally given that scientists discover, but are constructed through experiments and their representations. Modern scientists have a very broad arsenal of well-established experimental and representational strategies at their disposal, while Renaissance experimentalists were only barely starting to develop methods of performing, recording, and circulating their experiences. While the history of experimentation has traditionally been written with a focus on the development of instruments and experimental methodologies, recent studies have highlighted how the task of finding means of representing and communicating experiences was also extremely difficult, and involved the development of rhetoric strategies comprising texts, images, numbers, and tables, standardized instruments and procedures, as well as the emergence of institutions empowered to validate the various strategies of knowledge construction. From this perspective, the use of the recipe format no longer appears as yet another proof of how naive and old-fashioned Della Porta was, but is instead a feature to be understood in view of the premises and goals of his work.

The recipe was a form of writing going back to ancient times and found most often in artisanal, alchemical, and medical texts.[22] Many of the experiences collected in *Natural Magic* and in Della Porta's later works had been transmitted primarily in recipe form until then, while others were being fixed in writing for the first time. Moreover, some ancient and late ancient writings employed by Della Porta as sources, such as the *Pneumatics* by Hero of Alexandria, also employed the recipe format to describe apparatuses and experiences; although, in those cases, the "recipes" were longer and more accurate. Thus, in Della Porta's time, recipes were not just a well-established strategy for fixing in writing practical experimental knowledge on the structure and functioning of more or less complex apparatuses, but in fact were often the only strategy available. The difficulty of finding means of communication to express

[20]For examples, see Grmek (1990); Kodera (2015); Piccari (2007, pp. 52–53). For discussions of bias against Della Porta regarding optics, see Borrelli (2014; 2017).
[21]For in-depth discussions of these topics, see Franklin (1989); Galison (1997); Gooding, Pinch, & Schaffer (1989); Gooding (1990); Hacking (1983); Latour & Woolgar (1986); Licoppe (1996); Lynch & Woolgar (1990); Shapin & Shaffer (1985); Steinle (2016).
[22]Pomata (2013).

practical knowledge in the Middle Ages and Renaissance has been discussed in depth by Pamela Smith, who convincingly argued that the expression in literary forms of tacit knowledge, which had been transmitted through non-verbal channels until then, could not be separated by the development of an "artisan epistemology" that she regards as exemplified by the writings of Paracelsus.[23] While Smith has discussed in detail the links and tensions between bodily and textual practices of knowledge production, and in particular the role of recipes, the more literary side of the matter has been the subject of various investigations by Gianna Pomata, who has focused mostly on medicine and pharmacology.[24] Pomata suggested that medical and pharmaceutical recipes of the late medieval and early modern periods should be regarded as a new "epistemic genre," that is, a literary genre that is also "the vehicle of cognitive project" and is "shaped by it."[25] Pomata has written extensively on "epistemic genres," underscoring their cognitive functions. Nonetheless, her analyses largely remain within the scope of literary studies, essentially regarding epistemic genres as a subspecies of literary genres and comparing different epistemic genres that appeared in early modern medicine, such as "recipe," "*experimentum*," or "case narrative."[26] This structural perspective does not allow much space for specific investigations into how knowledge was produced or transformed in the process, but provides a fruitful framework when connected with the aforementioned studies on the interplay between experimentation and communication, such as Steven Shapin's and Simon Schaffer's (1985) analysis of the rhetorical practices of "fact" construction in early modern England, which allowed readers to be "virtual witnesses" of the experiments described; Bruno Latour and Steve Woolgar's (1986) notion of "inscriptions"; or David Gooding's (1990) discussion of the social and epistemological dimensions of experimentation.[27] Although all these studies address very disparate issues with diverse methodologies and within radically different cultural and historical contexts, they have inspired my claim that it is necessary to link the "literary" and the "practical" perspective when trying to analyse Della Porta's writings and their relevance for the history of experimental natural philosophy.

Finally, an important factor to be considered is that experiences discussed by Della Porta were not of the common, everyday kind that was traditionally employed in natural philosophical discussions. In an analysis of the rhetorical strategies employed by Galileo Galilei to present his experiences on falling bodies, Peter Dear noted that Galileo described his quite singular experiments on bodies falling along inclined planes in such a way as to make them look like the universally known experiences accepted as evidence in the Aristotelian tradition.[28] To do this, Galileo erased the experimenter and the context of the experience. Della Porta, on the other hand, took the opposite approach, employing the how-to format of recipes to underscore the singularity of the experiences, while at the same time presenting them as evidence that any reader could, at least in principle, check by himself.

4 | RECIPES AND THE CREATION OF PHENOMENA

Seen through the lenses of a presentist perspective, the recipes by Della Porta analysed in the present article concern the phenomenon of rarefaction and condensation of air, a subject that initially might not seem to present many conceptual difficulties, since the statement that air can expand and contract was essentially undisputed in the Renaissance. However, this statement should not be confused with the refined conceptual structure that is today inextricably associated to the phenomenon of air contraction and expansion, a structure that comprises notions such as elasticity, pressure, or temperature, none of which existed in Della Porta's time—and some of which would only emerge centuries later. The modern conceptual structure emerged from a long process of performing, representing, and connecting experiences of which Della Porta's writing represent a small, early, but nonetheless crucial part; and

[23]Smith (2004).
[24]Pomata (2013; 2014) .
[25]Pomata (2013, p. 134).
[26]Pomata (2013).
[27]Shapin & Schaffer (1985); Latour & Woolgar (1986); Gooding (1990).
[28]Dear (1991).

a key element in this process was the recipe format, which Della Porta developed into a refined heuristic tool in the course of his writings. The Neapolitan philosopher did more than simply collect instructions for producing various experimental effects: a careful analysis of the development of his writings shows how he systematically strove to set side-by-side procedures that were similar in their structures, involved apparatuses, or results, and he also aimed to describe them with the same terms and formulations. As a result, the various experiences could be regarded as individual instances of a more general pattern of natural events or, as we would say today, as different manifestations of the same natural phenomenon, such as the expansion and contraction of air. One feature I will underscore in my analysis of the development of Della Porta's pneumatic recipes is how initially, in the text quoted above, air was not even mentioned, while later on it would become the main and explicit focus of the recipes. In this way, the epistemic function of the texts changed, although the practical steps to be performed remained the same. What was initially a rather haphazard collection of individual recipes with little in common became in the new, more systematic description a series of instances demonstrating different manifestations of the same phenomenon: changes in the "consistency" of air. It is this shift I am speaking of when I state that Della Porta was using recipes to construct a new phenomenon.

In his seminal work on the epistemology of experimentation, *Representing and Intervening*, Ian Hacking wrote that, due to the theory-dominated view of modern science, we tend to think of phenomena as regularities following from the laws of nature, which are "out there" to be discovered experimentally. However, he continued, this view neglects the human work and technological premises needed to create scientific phenomena in the laboratory, when in nature only complexity is to be found: "In nature there is just complexity, which we are remarkably able to analyze. We do so by distinguishing, in the mind, numerous different laws. We do so, by presenting, in the laboratory, pure, isolated, phenomena."[29] While Hacking underscored the epistemic relevance of "representing and intervening" in laboratory practices, historians and sociologists of science noted how the experimental creation of phenomena as "scientific facts" also relied on strategies employed for circulating the knowledge produced in experiments.[30] Natural-philosophical reflections like those in the Aristotelian tradition usually emerged in verbal form and could therefore circulate and establish their authority most easily through written texts. However, this was not the case for knowledge emerging primarily from experimentation, for whose communication practitioners had to rely on combinations of words, images, and diagrams, and which could usually be replicated only (if at all) by employing exact copies of the instruments involved. In the last decades, research has shown how instruments, procedures, and their descriptions and depictions could function as representations for new notions, for example in the study of electromagnetism, thermodynamics, and the life sciences.[31] These and other studies have underscored the epistemic role of representation in experimental practices in the combined tasks of conceptualizing experience and establishing the result as authoritative fact. Using a later term, these descriptions may be tentatively characterized as providing "operational definitions" of concepts, as opposed to top-down definitions based on pre-existing notions. Operational definitions are not expressed in terms of pre-existing conceptual frameworks, but are rather based on descriptions of apparatuses and procedure, such as describing how to build and gauge a thermometer and then defining "temperature" as the quantity measured with it, as is done in today's metrology.[32] In this way, the representation of experimental practices and theories may lead to conceptual innovations that complement, modify, or replace existing theoretical structures.

Friedrich Steinle has suggested the term "exploratory experimentation" to denote the experimental activities that are not driven by pre-established theoretical frameworks, but are nonetheless characterized by a strong

[29]Hacking (1983, pp. 225, 226).
[30]Coopmans, Woolgar, Lynch, & Vertesi (2014); Fleck (1935); Latour & Woolgar (1986); Licoppe (1996); Shapin & Schaffer (1985); Lynch & Woolgar (1990).
[31]On electromagnetism, see Gooding (1990) and Steinle (2002: 2016); on thermodynamics, see Wise (1988); on the life sciences, see Müller-Wille & Rheinberger (2007).
[32]Fischer & Fellmuth (2005).

epistemic drive which may result in the emergence of new conceptual structures.[33] In his essay on "Experiment in the History and Philosophy of Science," Steinle wrote:

> Far from being a mindless playing around with an apparatus, exploratory experimentation may well be characterized by definite guidelines and epistemic goals. The most prominent characteristic of the experimental procedure is the systematic variation of experimental parameters. The first aim here is to find out which of the various parameters affect the effect in question, and which of them are essential. Closely connected, there is the central goal of formulating empirical regularities about these dependencies and correlations. Typically they have the form of "if–then" propositions, where both the if- and the then-clauses refer to the empirical level. In many cases, however, the attempt to formulate regularities requires the revision of existing concepts and categories, and the formation of new ones, which allow a stable and general formulation of the experimental results. It is here, in the realm of concept-formation, where exploratory experimentation has its most unique power and importance.[34]

Steinle developed his notion of exploratory experimentation in the study of 19th-century electromagnetism, but it might also provide a guide for studying Della Porta's writings as early attempts to construct an epistemic genre fitting to the practices of exploratory experimentation of new fields, such as the properties of air. The notion of exploratory experimentation has been successfully employed by Dana Jalobeanu to investigate the experiments of Francis Bacon, by Laura Georgescu in her study of William Gilbert, and by myself with regard to Della Porta's writings on optics, and I believe that a similar, if less clear-cut development can be discerned in Della Porta's pneumatic writings.[35] While he may not have achieved much in terms of conceptual frameworks, Della Porta provided a very important template with his writings for later authors wishing to record and communicate their experiences. It was not by chance that the recipe format was reflected upon by Francis Bacon and was still employed in the *Transactions of the Royal Society* in the late 17th century, and that *Natural Magic* remained a much-read text long after the death of its author.[36]

5 | AIR AND ITS PROPERTIES IN DELLA PORTA'S TIME

In the Renaissance there was no coherent, generally accepted notion of air: the Latin term "*aer*," and the corresponding ones in other languages (*aria*, *aere* in Italian; *air* in French; air in English; *Luft* in German) were traditionally associated with one of the four elements constituting the core of much of ancient natural philosophy, and in particular of Aristotelian physics.[37] However, even the original Aristotelian scheme did not offer a precise characterization of air, which like the other elements was presented both as a material substance (atmospheric air) and as a more abstract principle, which could be present, but was not necessarily manifest in all material bodies. Some air-like substances, like water vapour, could be regarded as "air," thereby making it possible to conceptualize evaporation in terms of the transmutation of water into air. At the same time, "vapours" and "exhalations" distinct from air were assumed to provide the basis for weather phenomena. The four-element scheme had been taken over and adapted by late ancient and medieval authors writing in Greek, Latin, or Arabic, adding to the variety of features which air could or not possess. In the Renaissance, this picture was further complicated by the rediscovery of the Stoic tradition, in which atmospheric air was regarded as a manifestation of a unique principle ("*pneuma*") giving life to whole

[33] Steinle (2016).
[34] Steinle (2002, p. 419).
[35] Borrelli (2014; 2017) ; Georgescu (2017); Jalobeanu (2015).
[36] Pastorino (2020); Dear (1985).
[37] For a more detailed discussion of the notion of air in the Renaissance, see Borrelli (2008a).

cosmos. In this worldview, air was endowed with the power of moving itself and other bodies not only in a purely external, mechanical sense, but also by conferring on them some kind of inner life, by analogy to its role in supporting animal life. The action of heat was seen as enhancing the moving power of air and was linked to the notion that the Sun was the origin of all life and motion. In turn, discourses on the moving power of (fiery) air fit well with the development and increasing epistemic value of technological apparatuses that involved atmospheric air in some way, such as wind charts for navigation, pneumatic machines, windmills, or cooling and airing systems for ovens. Further input to Renaissance discussions about air was provided by the treatise *Pneumatics* by Hero of Alexandria (1st century CE).[38] In the late middle ages, Hero's text had already been circulating in manuscript form in its Greek original, and from the 15th century onward it was translated into Latin by Italian humanists. In 1575, the Latin translation of the *Pneumatics* by Federico Commandino was printed, leading to a much wider reception of this work in Europe. Hero's text was primarily devoted to descriptions of pneumatic apparatuses, but also presented a conceptualization of experiences with air based on the idea that it contains interstitial vacua, which stood in contrast to the Aristotelian doctrine and sparked much debate on the possible existence of vacuum.

For our subject it is important to note that, when Della Porta was writing, increasingly complex pneumatic apparatuses were being built whose workings could not be explained by any general conceptual framework so far, challenging both practitioners and philosophers to develop new approaches on how to think about air and its properties. As discussed above, from today's point of view, the experiences that attracted the attention of Renaissance philosophers and experimenters are due to "phenomena" (in Hacking's sense), which are described in terms of air properties like pressure, temperature, or density. These notions all emerged later than 1600, including also the apparently straightforward notion of air "density," that is, mass divided by volume. Renaissance scholars and practitioners had no reason to see these experiences as manifestations of the properties of air; indeed, many of them were conceptualized in terms of nature's horror of the void. Moreover, air was passive in the Aristotelian scheme, and possessed no moving power of its own. The Aristotelian explanation of wind was based on dry exhalations coming up from the earth and flowing through the air, at times also sweeping air along. In short, in the Aristotelian framework not even wind was moving air, so that describing an experience in terms of the activity of air was no straightforward observational statement but constituted an interpretive step. Finally, it must be considered that the experiences studied by early modern authors also included meteorological observations, which even today cannot usually be described in terms of simple laboratory thermodynamics. To better understand the difficulties of the task facing early modern authors in their discussions of air, it may be helpful to recall that the concepts of "dense" and "rare" remained problematic even beyond the Renaissance period, as they were closely linked to the question of vacuum and the issue of the quantification of matter.[39]

In conclusion, when analysing Della Porta's writings on the rare and the dense in air, it is necessary to keep in mind that he was not "discovering" the pure phenomena we know today, but rather contributing to the very early stages of their creation, both with his experimental activity and with his methods for representing it. I do not mean that we should look in Della Porta's writings for some "embryonic" versions of today's notions, but rather try and grasp those (admittedly vague) conceptual structures that emerged from his descriptions of experiences, and in doing so appreciate the methodology he was developing. In his monograph on early modern mechanics, Domenico Bertoloni Meli introduced the term "thinking with objects" to characterize a modus operandi in which simple instruments (such as the lever or the pendulum) and their descriptions were employed as a means of representing and conceptualizing more complex ones (such as bodies moving along curved paths).[40] Analysing Della Porta's passages on the rarefaction and condensation of air, one may to some extent see them as attempts to conceptualize experiences by tentatively grouping and comparing them in such a way as to "think" of one in terms of the other, isolating the simplest one and using it to operationally shape new notions like "rarefaction" and "condensation." Della Porta was

[38]On the reception of Hero's *Pneumatics* among Italian humanists, see Laird (2017); Trabucco (2010). On its reception among both philosophers and engineers, see Valleriani (2007).
[39]Manzo (2016).
[40]Bertoloni Meli (2006).

looking for common patterns among different experiences, and recipes provided the necessary means for collecting and comparing procedures and observations in a flexible, accurate way, without employing philosophically loaded terms such as those belonging to the Aristotelian or alchemical traditions. Whether or not the results of this process appear "correct" in terms of today's conceptual frameworks, the methodology elaborated by Della Porta may be seen as having contributed to the development of "experimental histories" and laboratory notebooks.

6 | THE RARE AND THE DENSE IN THE TWO EDITIONS OF *NATURAL MAGIC* (1558; 1589)

The inverted glass experiment first appeared in Book 2 of the first edition of *Natural Magic*, after a series of experiences concerning plants and fruits, fire, cryptography, and water and wine. The experiment was one of "a few mechanical experiments."[41] These experiences had little or no relation to each other, as they discussed the kite, things floating in the air, a trick with paper strips, how a candle can burn underwater, and, finally, how to raise water with an inverted vase and a vase generating wind (the *aeolipila*). As shown above, Della Porta's earliest recipe for raising water with the inverted vase was not particularly elaborate:

> One should prepare a vase with a very long neck (the longer the neck is, the more marvellous [the experiment]), made out of glass and transparent, so that you shall see through it the water rise. The vase must be filled completely with boiling water (or alternatively its bottom should be brought near to a fire), so that it will become all very hot, then immediately, lest it cool down, it must be turned upside down and put with its mouth in the water, and it will absorb it all in itself. The explorers of the nature of things say that it is in this way that water is drawn up and absorbed by the rays of the sun from the caves of the earth in mountains, so that water springs originate.[42]

This passage represents the earliest known instance of the thermal expansion and contraction of air being demonstrated using a transparent glass vessel, while an analogous experience performed with the help of an animal bladder was already present in Hero's *Pneumatics*.[43] In all probability, Della Porta did not invent the experiment, but he certainly contributed to making it known in wider circles. Of particular interest here is that, although we conceive this experience as being about air, air is not mentioned at all: it is only the rising water that is made visible through the glass, while air is only implicitly present for those who are already aware of its relevance as the "empty" space left within the glass above the water—a space which becomes larger and smaller during the experience. The final sentence related, but stopped short of endorsing, the Aristotelian explanation of the experience, and there is little doubt that the wording of the recipe framed the experiment as having nothing to do with air. It is impossible to know whether Della Porta accepted this explanation at the time, or was already thinking about this experience in terms of air expanding and contracting, but the latter was certainly the case in 1589, when the second edition of *Natural Magic* appeared. In that work, the entirety of Book 19 was devoted to pneumatic experiments, and in it Della Porta reported experiments by Hero with a few additions by himself. As discussed above, this expansion of the subject can be understood in the context of both the reception of Commandino's Latin translation of Hero's work and the increasing number of new pneumatic devices in civil and military engineering. Here, I focus on Chapter 3, which began with the words: "Now let us go on to related, but different experiments, also of pneumatic character, which

[41]"de mechanicis quibusdam experimentis," Della Porta (1558/1560, Book 2, Ch. 13).

[42]"Longissimi colli paretur vas, et quo longius fuerit, eo mirabilius, vitreum vero, et pellucidum, ut ascendentem perspicies aquam, hoc bullientis aquae expletur, et ubi totum efferbuerit, vel igni fundum admoveto, illico, ne frigescat, inverso ore aquam tangat, et intro totam absorbeat. Sic naturae rerum exploratores Solis radiis aquam hauriri, et absorberi aiunt, e terrae concavis locis in montibus, unde fontanea efficitur scaturigo" (Della Porta, 1558/1560, p. 59r).

[43]Borrelli (2008b).

derive from the reason of air, in which way it becomes expanded and contracted, rarefied by fire and condensed by cold."[44]

In contrast to the treatment of it in 1558, air here took centre stage in the description and in the conceptualization of the effect. It should be noted that, as anticipated in the previous section, Della Porta did not speak of "density" or "volume" of air, but described acts performed by it, like expanding and contracting or rarefying and condensing because of heat and cold. Significantly, the two processes are described in different terms, and for Della Porta, as will be shown, they are not as equivalent as they might appear to us. However, the first experience described in this chapter was the same one already present in the first edition of *Natural Magic*, and it appeared unchanged—that is, without air being mentioned. Nonetheless, the context in which it was now embedded gave it a new meaning, since air was explicitly mentioned in the following recipes. Later in the same chapter, a recipe showed how the expansion of air could be used to produce a jet of water, both by compressing or by heating it:

> If you want to produce a high jet of water, fill a vase with air by blowing into it as strong as you can. As soon as you move away from the mouth of the vase, turn it down, so that water flows into it and closes the path of the air. Since the air wants to come out, it will project the water high up. If you want to make the jet of water without the attraction of the air: heat up a bit the bottom of the vase, since the air, once rarefied, will desire a larger space, and trying to break out it will project out the water.[45]

In this passage, two different recipes for obtaining the same effect were set side by side: in the first one, air was mechanically compressed, in the second one it was thermally rarefied, and in both cases the result was air pushing a water jet out of a vase. Through the juxtaposition of the two recipes, the water jet no longer appear as merely a one-off joke, but also as the result of a natural occurrence that would manifest itself when certain conditions were met—air developing moving power. Although the immediately visible features of the experience only involved water, the recipe-like text also "described" what could not be seen: the air "desiring" ("*quarens*," "*quaerit*") to expand or rarefy when compressed or heated. Air and its moving power took centre stage, while the acts of blowing into the vase or heating it represented the conditions under which the phenomenon manifested itself. The representational—or, perhaps better, medial—strategy allowed him to construct a phenomenon that lay behind what could immediately be experienced with the senses, and to suggest it as the cause of the manifest effects without having to spell out general principles.[46] Della Porta used the term "desire" to characterize the behaviour of the air; this term connects to an idea of desires and fears of inanimate bodies that Della Porta certainly did not invent, and it has been suggested that Della Porta might have been inspired by the writings of Bernardino Telesio.[47] Della Porta did not quote Telesio, but this is hardly surprising, given that at the time Telesio's writings were on the *Index Librorum Phohibitorum*, the list of books forbidden by the Church. However, Della Porta did not use this term primarily to embed the experiences in a Telesian framework, but rather because it fit those aspects of the experience which he wished to highlight, and which would come to constitute the pivotal feature of his conceptualization of air's motion. At the same time, however, the employment of that language brought with it conceptual implications, and in fact the animistic, Stoic framework became an important element in the meteorology of Della Porta and other authors of the early 17th century.[48] Further below, Della Porta explained how heated air could be used to raise water, an experience which, from our

[44]"Nunc ad cognata sed varia experimenta transeamus, etiam pneumatica, ex aeris ratione exorientia, quomodo dilatetur at comprimatur, igni rarescat et densetur frigore" (Della Porta, 1589/1597, p. 635).

[45]"Quum aquam eminus vis iaculari, vas aere reple, insufflando quam vehementissime poteris, mox ab ore recedens, inclina os vasis, ut aqua in os currat, et obex aeri fiat, nam aer foras erumpere quaerens, aquam eminus iaculatur. Si vero sine aeris attractione vis aquam eminus proiicere: calefacito paulisper vasis fundum: nam aere rarefacto, ampliorem locum quaerit, et interrumpere querens, aquam foris expellit" (Della Porta, 1589/1597, pp. 635–636).

[46]Following Wise (1988), among others, I employ the terms "medium" and "medial" to underscore how, in this case, no clear-cut distinction is possible between form and content, or representation and represented thing. This meaning of these terms is linked especially to Marshall McLuhan's work, but is common in media theory today (McLuhan, 1965).

[47]Borrelli (2019); Trabucco (2016, p. 229).

[48]Borrelli (2008a).

point of view, describes the same phenomenon as the pneumatic recipe in the *Natural Magic* of 1558. The reader should put a vase on top of a tower with a pipe connecting it to the water below, and then the following would happen:

> The upper vase must be made hot by the sun or by fire, so that the air which is contained inside it should rarefy and escape out, so that we shall see the water moved by bubbles. As soon as the sun goes away, when the vase cools down, the air condenses and, when the air in the vase is not enough to fill it, the water will enter and move upwards.[49]

Here both rarefaction and condensation of air took place, and were described in terms of the air either expanding or failing to do so despite having space at its disposition. Once more, a recipe-like text let the reader "virtually witness" the "fact" that (invisible) air, under the effect of heat or cold, would change its behaviour with respect to occupying space.[50] Della Porta did not explain why this was so, and the recipe format was the ideal vehicle to convey to the reader his interpretation of the experience without having to introduce any general principles of how air did or did not move. The "fact" that air wishes to expand and contract was being created. Further below, Della Porta presented other experiences involving air moving water were collected, strengthening the operationally defined idea of air's moving power.

7 | AIR AND ITS "CONSISTENCY" IN THE ITALIAN VERSION OF *ON PNEUMATICS* (1606) AND IN *ON TRANSMUTATIONS OF AIR* (1610)

Pneumatics was one of the topics to which Della Porta devoted an individual, more scholarly treatise. In 1601, the treatise *On Pneumatics* appeared, a text inspired by Hero's *Pneumatics* and by contemporary discussions on pneumatic machines. Its first book was devoted to discussing the vacuum and the workings of siphons, while the other two were collections of recipe-like texts describing pneumatic and hydraulic machines and experiences, some of them taken from Hero and some of them new. It is not possible to discuss here in detail the relationship between Hero's *Pneumatics* and Della Porta's work, which has already been thoroughly analysed by Oreste Trabucco, but it is important to note that the recipes I focus on are not among those taken from Hero.[51]

Other than the pneumatic chapters of *Natural Magic*, Della Porta's *On Pneumatics* also addresses theoretical issues and, in particular, in Book 1, Chapter 8 he briefly expressed his own ideas of what caused siphons to work. After relating the opinions of ancient writers, he reported Girolamo Cardano's theory that siphons worked not because of the *horror vacui*, but because air had a horror of being rarefied and therefore pulled water up from below. In fact, Della Porta stated, air did pull water up, but the reason was not a horror of the vacuum or of rarefaction, but rather the air's desire of "conservation of its own essence" ("*suae essentiae conservatio*"), because of which air strove to remain as unified in itself as possible, since "conservation obtains in unity" ("*conservatio fit in unitatem*"):

> But the cause of the marvellous happening is neither vacuum, nor the fear of vacuum, nor rarefaction, nor continuity, but rather a higher reason, and that is the conservation of the own essence; it is inborn

[49]"Calefiat vas superius vel Sole, vel igne, nam aer, qui in alvo continetur, rarefit, et foras prolabitur, unde aquam in bullas tumere videbimus, mox absentia solis, ubi vas refigescit, aer condensatur et quum non sufficiat inclusus aer vacuum replere, accersitur aqua et ascendit supra" (Della Porta, 1589/1597, pp. 636–637).

[50]I use here the term "virtual witnessing" to suggest that Della Porta's recipe style may have provided a template for Boyle's methods of reporting experiments, but I certainly do not claim that Della Porta's practices are comparable to those discussed by Shapin & Schaffer (1985), as the cultural and institutional contexts were very different.

[51]Trabucco (2010, pp. 129–144; 2016), as well as the edition of *On Pneumatics* (Della Porta, 1601/2008a). Trabucco follows earlier scholars in criticizing Della Porta's lack of an overarching theoretical framework, although he defends Della Porta against the accusation of being a mere phantasist (Trabucco 2010, p. 144).

> in a nature to conserve its own continued existence in its whole unity. And continued existence consists in the conservation of one's own essence, and conservation obtains through the unity of the self, and unity obtains through connection, contact and mutual link of own extremes. And such a powerful connection ties [the extremes] together is such a way that, rather than letting a separation happen, anything will be suffered, and any thing strange and unusual may happen.[52]

Della Porta did not offer further explanations of his idea of the air's "essence" and its conservation, but rather demonstrated his views by describing two experiences in terms of the air's desire for conserving unity; once again, the recipe format was the most fitting one for presenting and supporting his interpretation of natural order. In 1606, an Italian version of the work appeared, translated by Giovanni Scrivani, who also added some new experiences he had seen Della Porta perform.[53] Among the new material was a description of how to operationally quantify the rarefaction of air. The experience was described in Book 3, Chapter 7, the first part of which explained how to quantify the expansion of water when it evaporates. In the second part of the chapter, water evaporation provided the template for "measuring into how many parts of thinner air one ounce of air in its consistency can dissolve."[54] The set-up for this second measurement was a familiar one:

> Vase A will have its mouth in vase B, flat and full of water. Vase [A] will be full of air, which in its consistency shall be more or less thick according to place and season. Then bring a vase full of fire near the body of the vase A: the air, immediately heated up, starts to become more subtle and, once is it made more subtle, it wants more space and, trying to escape, comes out of the water, and one will see the water boil, which is a sign that the air is escaping. The more the air heats up, the more intensely the water boils, but, once the air has become most thin, the water will stop boiling. At that point, remove the vase with fire in it from the belly of A, and the air, cooling down, will become thicker and desire less space and, not having any way to fill the vase because its mouth is under water, will attract the water from the vase, and one shall see the water rise up with great fury, to fill all of the vase, leaving empty only that part where the air lies, reduced back to the nature it had in the beginning …. Once the water has stopped rising, mark with pen and ink on the outside of the glass the level of the water surface. Afterwards, letting out all the water from the vase, take another vase and fill the first one with water until it reaches the line you marked with ink. Then measure that quantity of water, and count how many times it has to be taken to fill the whole vase: that is the number of times by which a portion of air, taken at first in its consistence, shall enlarge when it is made more subtle by fire, and from here great secrets take their origin.[55]

This recipe-like text not only presented the activity of invisible air to the readers, but also showed how to quantify it. But what was being measured here? We would describe it as a change of volume, yet Della Porta never spoke

[52]"Sed mirabilium operationum causam ipse: non vacuum, non vacui metus, non rarefactio, non continuatio, sed altior ratio sit, scilicet suae essentiae conservatio; ita naturae ingenitum est sui perennitatem in totius unitate conservare. Nam cum perpetuitas consistat in suae essentiae conservationie, et conservatio fit per sui unitatem, et unitas fit ex nexu, contactu et mutuo suorum extremorum complexu; et tanta continuatione sibi mutuo convinciuntur, ut, priusquam ad eorum sparationem veniatur, quodvis potius patiatur, quodvis mirum et insolitum effciat" (Della Porta, 1601/2008a, p. 15).

[53]Della Porta (1606/2008b).

[54]Della Porta (1606/2008b, pp. 144–145).

[55]"[S]ia il vaso A, questo habbi la bocca dentro un vaso B, piano, pieno di acqua, il qual vaso sarà pieno di aria, grosso nella sua consistenza, più, e meno, secondo il luogo, e la stagione. Poi accostarete un vaso pieno di fuoco al corpo del vaso in A, e l'aria subito riscaldandosi, si andarà sottigliando, e fatta più sottile, vuole più gran luogo, e cercando uscir fuori, verrà fuori dell'acqua, e si vedrà l'acqua bollire, che è segno che l'aria fugge, e quando si andrà più riscaldando, l'acqua più boglierà, ma essendo ridotta tenuissima, l'acqua non boglierà più, all'hora rimovete il vaso del fuoco dal ventre A, e l'aria rinfrescandosi, s'andrà ingrossando, e vuol minor luogo, e non havendo come riempir il vano del vaso, perchè ha la bocca sotto l'acqua, tirerà à se l'acqua dal vaso, e si vedrà salir l'acqua su con gran furia, e riempir tutto il vaso, lasciando vacua quella parte, dove sta l'aria ridotta già nella sua natura di prima …. Fermata cha sarà l'acqua, voi con una penna, et inchiostro segnarete fuori il vetro l'estrema superficie dell'acqua, poi lasciando uscir fuori tutta l'acqua della carrafa, all'hora con un'altro vaso porrete tanta acqua in detta carrafa, finchè riempirete infin al segno della linea notata con inchiostro: all'hora misurarete quell'acqua, e quante volte quell'acqua riempirà tutta la carrafa, tante volte una parte di aria nella sua consistenza si ampliarà, essendo attenuata dal caldo, e di qua nascono grandissimi segreti" (Della Porta, 1606/2008b, pp. 144–145).

of the space occupied by air, and employed water volume only as a means to measure the "number of parts" of subtler air in which a given quantity of air "in its consistency" dissolved, much like the space occupied by water in a "clepshydra" could be a means to measure time. Della Porta's operational quantification of the transition of water into air and of air into thinner air might be connected to the idea, discussed by Cardano, that processes of transmutation and of rarefaction and condensation always happened according to definite proportions that depend on the bodies involved.[56] However, Della Porta made here no reference to Cardano, although, as noted above, he referred to him in an earlier part of the treatise. The only property that Della Porta ascribed to air was its "consistency," and it was this property that was associated with a number that we might describe as an expansion factor. In his later meteorological treatise *On Transformations of Air*, Della Porta presented the same recipe in Book 1, Chapter 16, underlining how the result of the measure depended both on air and on the way the measure was performed, demonstrating that he was aware that the number obtained was only indicative if the measure was performed in a controlled, standardized way:

> It is worth noticing that this experience never obtains in the same way, since sometimes the air contained in the vase is thicker, for example when the vase has been in a cold, humid place, and sometimes it is finer, if it was kept in dry places. And one part of thicker air will dissolve in a larger quantity of air. Moreover, if the fire is moved closer to the belly of the vase, the rarefaction of the air will be greater; if it is moved to it with less intensity, the air will rarefy less, and we observed that it will lose approximately one part in 60.[57]

Here, Della Porta seemed more interested in how the number varied with variations in the conditions of the experience than in the number itself, a fact that reminds us of the practices of exploratory experimentation described by Steinle, where the systematic performance of a certain experimental procedure served to individuate and isolate features of nature to be further explored. I would like to suggest that from Della Porta's increasingly elaborate recipes a notion was emerging: the "consistency" of air. Consistency might be understood as that property which air, according to Della Porta, wanted to "conserve," and which determined how much it would mechanically or thermally expand or contract. Changes in consistency were certainly transformations along the rare–dense scale, but it can hardly be interpreted as weight divided by volume, not only because that would involve a notion of weight of air which not found in Della Porta's text, but also because consistency had a dynamic character that made it important in Della Porta's meteorology. In fact, immediately after the previous passage, he added:

> Now let us fit to our aims what we have explained above. We have to know that the Sun, as it circles the Earth and hits it with its rays, gives rise through reflection to a large amount of heat, so that the air heats up and becomes thinner, takes up a larger space and moves upwards, to the right and left, and all around. And having achieved a monstrous dimension and not able to contain itself any more, it approaches the air nearby and pushes it away, and the air pushed away fights with the other near itself, and the vanquished is compressed and gives way, and occupies space near the winner, and goes where a weaker opposition invites it and where it finds some vacuum, as long as the air which has become larger pushes it.[58]

[56]Manzo (2016).

[57]"Hoc animadversione dignum est experimentum nunquam eodem modo succedere, nam aliquando aer vase contentus crassior erit, utpote si vas locis frigidis, humidisque steterit, aliquando aridior, si siccis, et pars una crassi aeris in maiorem aeris soluti quantitatem se solverit. Praeterea si ignis vehementeior vasis ventri admoveatur, maior erit aeris resolutio, si remissior minus resolventur observabivimus vix sexagesimam parte reliquisse"(Della Porta, 1610/2000, pp. 44–45).

[58]"Ut ea igitur quae prius declaravimus ad intentionem nostram accomodemus. Sciendum quod Sol dum terram circumibit, et verticalibus suis radiis eam verberat calorem ingentem ex reflexione gignit, unde is aerem excalefaciendum attenuat, hic in vastum locum se explicans superna petit, dextra sinistrave et circumquaque, sic immani mole exauctus nex sui capax proximum sibi aerem facessit, disploditque hic displosus cum altero sibi propinquo colluctatur, hic victus comprimitur, ceditque locum proximus victoris occupat, et ubi debilior exitus invitat, et aliquid reperit vacui, se recipit, et id usque donec amplior factus aer vehementius impellit" (Della Porta, 1610/2000, p. 45).

The consistency of air according to location and season and its (now quantifiable) reaction to solar heat were thus notions designed to provide an explanation of seasonal and local winds patterns, which Della Porta, following an idea expressed by Telesio, had in an earlier section linked to the yearly progress of the Sun along the Zodiac and the corresponding change in the inclination with which the Sun's rays hit the surface of the Earth at a given location.[59] By experimentally showing how the reaction of air to solar heat also depends on changing local conditions, Della Porta could explain why there was more variety in meteorological phenomena than in astronomical motion.

It makes little sense to try and interpret the consistency of air in terms of later notions, but I believe that the procedure through which it tentatively emerged was a methodological template for later experimentalists on pneumatics and thermodynamics. At the core of Della Porta's methodology was not only experimentation, but also—as we have seen in the above example—the innovative employment and development of the recipe format. Depending on the conceptual framework, the inverted glass experiment could equally be seen as an experiment about air expansion or about the way in which heat makes water rise. It was through the bottom-up approach allowed by the recipe format that the former interpretation could emerge, despite the fact that Della Porta had no new general conceptual framework to offer. Among those who took up Della Porta's methods and results we may count Francis Bacon, who transformed the inverted glass experiment into an instrument, the weatherglass (*vitrum calendare*), to be systematically employed in experiments, and who, like Della Porta, associated rarefaction and condensation with the desire of bodies to maintain their “consistency.”[60]

8 | CONCLUSION

In this paper I have applied results from historical-epistemological research on modern and contemporary science to the analysis of Della Porta's pneumatic recipes, arguing for a reassessment of his often underappreciated contribution to the development of experimental philosophy in the late Renaissance.

A key feature of modern science is the sharing of experimental knowledge, which is only possible thanks to complex arrays of verbal terminology, images, formulas, diagrams, standardized instruments, and units of measurement. These and other strategies are not passive forms for storing and circulating experimental results; they are necessary to allow the connection and conceptualization of experiments performed at different times and places and under varying conditions, and thus to construct from them experimental knowledge. Using a terminology introduced in a previous section, one may refer to them as media without which no experimental knowledge in modern scientific sense could exist. None of these strategies existed in the Renaissance, but they started to emerge when historical actors began systematically sharing reflections based on instrument-aided experiences. To do so, Renaissance experimenters needed a means to present to their readers the results of their work, which did not concern the common experiences that traditionally constituted the basis of natural-philosophical discussions, but rather singular, often unexpected events brought about with special tools and procedures. Performing an experience was not in itself an act of knowledge production. Knowledge came into existence only after the experimenters fixed in words, images, or numbers the way the experiment had been performed and what was considered to be its result. Very different knowledge could be produced by the same performance, depending on the way it was recorded and communicated. Recipes provided a means of fulfilling these functions, and constituted a premise for the later development of more refined strategies for constructing shared experimental knowledge.[61] Della Porta was among the earliest authors to systematically employ recipes toward this aim, perfecting their use in the course of his long career as a natural magician.

With the help of experiments and their recipe-like descriptions, Della Porta could transform the concept of air. In late Renaissance texts, the term “air” could be employed and defined in many diverging ways according to the

[59]Borrelli (2019, pp. 82–84). In this case, too, Della Porta made no reference to Telesio.
[60]Jalobeanu (2015, pp. 261–272); Manzo (2016, pp. 107–108).
[61]See, for example, Shapin & Schaffer (1985).

background, goals, and worldviews of the writers, who could be engineers describing pumps and fountains, or scholars expounding or criticizing the conceptual frameworks of Aristotelian or alchemical philosophy. In this context, Della Porta took on a special position in that he employed that term neither as a predefined explanatory tool nor as an everyday, purely descriptive word for discussing pneumatic devices. For Della Porta, “air” was an object of investigation, and his modus operandi was to choose and connect a broad range of experiences, providing a bottom-up (re)conceptualization of them in terms of an innovative, operationally defined notion of “air” that was characterized by certain properties and behaviour under different conditions. In particular, thanks to a skilful grouping of recipes, the different manifestations of air's desire to maintain its “consistency” were displayed.

The recipe format was a key heuristic tool of Della Porta's modus operandi. In his hands, that traditional literary form was gradually transformed into a new written means of knowledge production. In the terminology introduced by Gianna Pomata, one might claim that the transformed recipes became a new epistemic genre.[62] However, although Pomata's discussion is very helpful in analysing Della Porta's writing, it is my contention that Della Porta's innovation was not a purely literary one, but rather functioned in connection with instrument-aided experimental practices. Della Porta's literary techniques were closely linked to the experimental set-ups he employed, and in turn allowed the latter, once described in a systematic way, to become new strategies of knowledge production that could be deployed in new contexts. For example, the inverted glass experiment with air and water described by Della Porta provided a template for experiences later performed (or at least recorded) by Francis Bacon in the *Sylva sylvarum*. In the terminology introduced by Dana Jalobeanu, one may say that Della Porta's recipes deployed their full potential when enacted and appropriated by later readers of *Natural Magic*.[63]

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[62] Pomata (2013; 2014).

[63] Jalobeanu (2020).

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