"Of the Octave the Relation 2:1": How an Exemplary Case of Formal Causation Turned Against the Neo-Aristotelians

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In this paper, I address how music theory, generally, and the case of the octave more specifically, played an instrumental and under-appreciated role in the development of 17th century mechanization of sensory perception. In particular, I argue that investigation into the causes of the octave, Aristotle's chosen example of a formal cause, and other musical intervals like it served to undermine the Neo-Aristotelian framework, while also providing key evidence in support of a mechanistic account of sensory perception. I begin by discussing how the case of the octave was understood in Scholastic Neo-Aristotelian philosophy and how this framework was applied in 16th century music theory. Following this, I show how developments in music theory and acoustics challenged the status of formal causes and real qualities in this Neo-Aristotelian framework. Finally, I show how these developments provided a much-needed detailed, empirically supported example of the mechanistic-style metaphysics of sensory perception that was prevalent in the Early Modern period, focusing primarily on Descartes.

Keywords: Formal causation; sensory qualities; Descartes; Early Modern mechanism; musical consonance

1. Introduction

In the *Physics* and *Metaphysics*, Aristotle lays out four kinds of causes and provides examples of each. Bronze and silver are offered as examples of the material causes of artefacts, the father as an example of the efficient cause of the child, and health as an example of the final cause of walking. These examples are, by and large, helpful, and comprehensible. However, his example of the formal cause is arguably neither of these: "the form or the archetype, i.e. the definition of the essence, and its genera, are called causes (e.g. of the octave the relation of 2:1, and generally number) …" (*Physics* 194b27-194b29). He is referring here to the proportion or ratio between string lengths required to produce an octave and, more generally, that such production of any musical interval (i.e. two pitches sounding simultaneously) will involve a ratio specific to the interval in question.[1] My aim in this paper is not to address directly Aristotle's views on Ancient Greek music theory, formal causation, or his understanding of how the ratio of 2:1 exemplifies it. Rather, my purpose will be to show how this case turned out to be instrumental in challenging the Neo-Aristotelian framework of later centuries. I will argue that this case played a significant role in the banishment of real qualities and the transformation of formal causation into a description of material, efficient interactions. To argue for this claim, I will focus on how developments in music theory served to challenge the 2:1 ratio's role in the Neo-Aristotelian framework, while simultaneously providing significant support for a mechanist-style metaphysics of sensory perception that did not rely on real qualities. While these discoveries have been noted in the history

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[1] For instance, the ratio for the perfect fifth is 3:2, and that for the perfect fourth is 4:3. These two intervals, along with the octave, were those generally considered 'consonant', or pleasant-sounding, in Antiquity. However, every musical interval has an associated ratio, which was historically understood to refer to the proportion between string lengths producing the interval in question. This ratio is now understood to correspond to the proportion between the frequencies of the two notes that make up the interval in question. The discovery of these ratios is often attributed to Pythagoras, and the theory that attaches whole-number ratios to musical intervals was well-known throughout Ancient Greece, although the explanatory significance of the ratios was debated for centuries.

of science and musicology literature, their significance, especially regarding metaphysics and philosophy of perception, has been largely overlooked by historians of philosophy.[2]

I will begin by discussing formal causation and the metaphysics of sound in Scholastic Neo-Aristotelian philosophy and its intersection with 16th century music theory. Following this, I will show how developments in music theory and acoustics challenged the Neo-Aristotelian explanation of the octave and other musical intervals. Finally, I will show how these developments were incorporated to support a mechanistic-style metaphysics of sensory perception that was prevalent in the Early Modern period, evidenced especially in Descartes.[3] My goal will be to show that the case of musical consonance both weakened the Scholastic Neo-Aristotelian framework, as well as provided a strong example that contributed much-needed empirical support for the mathematically quantifiable mechanization of sensory perception.

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[2] Notable exceptions include de Buzon, "La perception des objets musicaux" and "The *Compendium Musicae*", and Jorgensen, "Descartes on Music". For a thorough discussions of the reciprocal relationship between Early Modern music and science in the history of science literature, see Cohen, *Quantifying Music*; Drake, "Renaissance Music"; and Gouk, *Music, Science, and Natural Magic*. My account differs from these in that it focuses on how the musical ratios were treated in the Neo-Aristotelian tradition. While these authors make mention of this, they do not dedicate much discussion to it. In addition to making this feature the focus of my paper, I also will focus primarily on the philosophical elements of the discussion, such as the significance of the musical ratios for developments in fundamental ontology and the metaphysics of sensory perception.

[3] I understand this to refer to a family of theories, all of which endorse the view that the physical world can be explained entirely in terms of efficient causal interactions between extended bodies and their geometrical properties.

2. Forms, Qualities, and 16th Century Music Theory

2.1 Neo-Aristotelian formal causes & the case of sound

We've seen Aristotle's own comments on the 2:1 proportion above, but what will be important for us is how this case was understood by Neo-Aristotelians. A natural place to start is with Aquinas. In his commentary on the *Physics* he writes,

> …A cause is said to be the species and exemplar. This is called a cause insofar as it is the quidditative nature [*ratio*] of the thing, for this is that through which we know of each thing 'what it is'… [Aristotle] gives as an example that harmony [*consonantia*] of music which is called the octave. The form of an octave is a proportion of the double, which is a relation of two to one. For musical harmonies are constituted by the application of numerical proportions to sounds as to matter (*Commentaria in octo libros Physicorum* II, Lectio 5, 179).[4]

Here, Aquinas tells us that a formal cause refers to the form of the thing in question, with 'form' being synonymized with 'species,' 'exemplar,' and 'quiddative nature'. These refer to the definitive characteristic of a thing: that which makes it what it is. So, in the example of the octave, the ratio of 2:1 is what makes the interval an octave, as opposed another interval, like a fifth or a fourth. Aquinas then adds that musical consonances or harmonies are constituted by a combination of numerical proportion as form and 'sounds' as matter. To understand this, we must consider some details of the Neo-Aristotelian understanding of sound.

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[4] The term that is translated here as "harmony" is "*consonantia*". This will be important for linking Aquinas' treatment of the octave with Zarlino's below, whose use of the same term is translated as "consonance".

The metaphysics of sound is somewhat anomalous in this context.[5] Generally speaking, sound was understood as a real quality, or an irreducibly qualitative feature of reality.[6] This means that, along with other sensible qualities, its reality was seen as on a par with that of substance.[7] We

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[5] For a thorough treatment of sound in Scholastic philosophy, see Pasnau, "Sensible Qualities" – the work in this section of the paper is indebted to Pasnau's examination of this topic. It should be noted, however, that while Pasnau suggests that the quality of sound might have been particularly susceptible to mechanization, here I am arguing explicitly that musical sounds, with their clear mathematical quantifiability, were particularly significant in motivating this broader shift.

[6] In the past few decades, there has been a significant amount of scholarly attention paid to representing the diversity of viewpoints in Scholastic philosophy. For instance, see Ariew, *Descartes*; Ariew & Greene, "Cartesian Destiny"; Mercer, "Vitality and Importance"; Pasnau, *Metaphysical Themes*; Schmitt, *Aristotle and the Renaissance*; Schmutz, "L'heritage des subtils"; and Thijssen, "Some Reflections"; and for an overview of approaches, see Edwards, "Aristotelianism, Descartes, and Hobbes". Jacob Schmutz's *Scholasticon* website also provides a wealth of information (http://www.scholasticon.fr/). I do not have the space to represent this diversity of views here. Rather, I will give a gloss on the kind of stance that is most relevant to the claims I wish to present in this paper. I am not committed to claiming that my account catalogues the representative view in Neo-Aristotelianism, nor am I committed to the claim that there is even such a 'representative view' available. The account I present here is meant only to reflect the views of some prominent Scholastic philosophers, emphasizing those commitments that 17th century mechanists took themselves to be arguing against.

[7] See Suarez, *De Anima (DA)*, III.2.1-2, where he asserts that the qualities perceived by the external senses are "real beings" and in *DA* III.19.1: "…sound is a sensible quality coming from a violent

might ask why it is that Scholastic theorists posit the existence of real qualities. The reason that is often put forth is their resistance to other kinds of explanation, expressed here by Ockham:

> To determine when a quality should be construed as a thing distinct from substance and when not, one can employ the following test: predicables which, while incapable of being truly applied to one thing at the same time, can successively hold true of an object merely as the result of a local motion, need not be construed as signifying distinct things. 'Curved' and 'straight', for example, can be successively affirmed of one and the same thing merely as the result of a local motion… But it is different in the case of terms like 'whiteness', 'blackness', heat', and 'cold'. For it is not simply because a thing or its parts undergo local motion that the thing becomes hot or cold. Consequently, these terms designate things distinct from substance (Ockham, *Summa logicae* I.55.20-35, in Loux 1998: 178).

Ockham's point is that there seem to be certain qualities, like shape, that can be explained in terms of local motion. In contrast, qualities like whiteness, heat, or cold, seem to resist this kind of explanation. Of course, this is exactly the kind of explanation that would eventually be offered by 17th century theorists, which is why the reasoning offered by Ockham above is particularly interesting for our purposes.

The existence of real qualities was also important for the Scholastic account of sensory perception.[8] The basic Neo-Aristotelian picture of sensory perception is one in which the forms of real qualities inhere in objects and are projected as 'sensible species', or spiritual copies of this form, through a medium. These sensible species then affect the sense organs, which assimilate the sensible forms. The various sensations of these qualities are transferred to the 'common sense', where the imagination produces an image or 'phantasm' of the object. Finally, the perceptible

percussion… That it is a quality is clear from the definition of a sensible quality; for example, sound causes a passion in the senses, and that it is an accident and not another category" (translation mine).

[8] For a discussion of this topic, see Perler, "Perception in Medieval Philosophy" and Simmons, "Explaining Sense Perception".

quality in question is recognized by the intellect.[9] The direct objects of sensation are what are called 'proper sensibles'. This term refers to those qualities that are 'proper to' each sensory modality (i.e. that can only be sensed through a single sensory modality, like colour, sound, etc.). These are contrasted with 'common sensibles', which are accessible through more than one sensory modality.

While Scholastic philosophers generally agreed that qualities like colour or heat exist in their subjects (e.g. redness is a quality of the rose), there was not a similar consensus with sound. Aquinas asserts that sound does not have a fixed existence in its subject, but rather exists both in its subject and in the medium surrounding it: "…Colour and odour and taste and the tangible qualities have a fixed and permanent existence in their subjects… sound is caused by [motion] and has no fixed and stable existence in a subject…" (Aquinas, *Sentencia libri De Anima* [*InDA*], II.16.1).[10] One thing to note here is the close connection Aquinas acknowledges between sound and motion. This should recall Ockham's assertion that a quality ought not be understood as a real, distinct entity if it can be explained in terms of motion. Given the close relationship between sound and motion, why would Scholastic authors view sound as a real quality?

One reason has to do with the status of sound as a 'proper sensible'. These explained the individuation of the sensory faculties, and one of the primary reasons they were able to do so lies

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[9] For an account of this process, see Aquinas, *Summa Theologicae* [ST] I.78.3. For a later account, see Suarez, *DA*, III.2.

[10] This seems to be the majority view. For instance, Suarez endorses a version of it, and cites Albertus, Philoponus, Averroes, Cajetan, and "others" as supporters (Suarez, *DA*, III.19.6).

with their ontological status as qualities.[11] Common sensibles, on the other hand, were understood as reducible to quantity, either as a species of quantity (size and number), as a quality pertaining to quantity (shape), or as a change in the quantity of distance (motion).[12] Reducing sound to motion, then, would seem to imply the consequence that hearing is not a proper sensory faculty. Given that the other proper sensibles are not obviously reducible to motion, and the reduction of sound to motion would have this consequence, it is preferable to retain their status as real qualities. This is important to note because, as I will argue, developments in music theory provided key evidence in favour of reducing sound to motion, threatening the Neo-Aristotelian account of sensory perception.

Understanding all of this, we can now return to Aquinas' comments above. Recall that he refers to the 2:1 proportion as the 'quidditative nature' of the octave, and states that musical harmonies are constituted by a combination of 'numerical proportion' as form, and 'sounds' as matter. Given what we have reviewed above, the 2:1 proportion informs the sounds, understood

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[11] "While it is true, however, that both common and [proper] sense-objects are all absolutely or of themselves [per se] perceptible by sense, yet, strictly speaking only the [proper] sensibles are directly perceived, for the essence and definition of each sense consists in its being naturally fitted to be affected by some such special object proper to itself" (Aquinas, *InDA* II.13.5). For the individuation of the sensory faculties, see Pasnau, "Sensible Qualities;" Perler, "Perception in Medieval Philosophy;" and Simmons, "Explaining Sense Perception."

[12] "Common sensibles are all reducible to quantity. As to size and number, it is clear that they are species of quantity… Shape is a quality about quantity, since the notion of shape consists of fixing the bounds of magnitude. Movement and rest are sensed according as the subject is affected in one or more ways in the magnitude of the subject or of its local distance…" (Aquinas, *ST*, I.78.3.2).

as real qualities, which serve as the matter. Together, this combination of form and matter makes an octave. The 2:1 form serves as the nature or definition of the octave in the sense that it is what makes the interval in question an octave, as opposed to some other interval. The sounds informed by the proportion, in turn, exist *in medio* and serve as the matter for this form. When the octave is perceived, the ear apprehends the sensible species of the sounds informed by the 2:1 proportion. One important thing to note here is that the sounds, as real qualities, are not just arrangements of, or motions in the medium – the 2:1 form of the octave does not merely refer to a proportion between motions in the air. Rather, the quality of sound exists in the medium as something real in its own right. In the following sub-section, I will discuss how this Neo-Aristotelian understanding of sonic perception was used in 16th century music theory to provide answers to important questions in this domain.

2.2 16th century music theory

My discussion will focus on Gioseffo Zarlino's *Istitutioni Harmoniche* [*IH*].[13] Zarlino's views were influenced heavily by those received from Antiquity and, in keeping with this tradition, Zarlino took the relationship between music and mathematics very seriously, holding the subject of music to be 'sounding number'.[14] Several chapters of the *Istitutioni Harmoniche* are dedicated

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[13] This work was one of the first treatises on music that attempted to encompass both music theory and musical practice and became a touchstone for later theorists.

[14] Zarlino, *IH* I.18. We also see Scholastic philosophers using this language – for instance, Albertus Magnus writes, "Seeing the note that is the 'diapason'… it is composed from the proportion of two

to the relationship between mathematics and music, but it is not until the end of Part I that he explicitly addresses the metaphysics of this relationship:

> Sounds are the material of consonances, and numbers and proportions their form… The goal of the action… is harmonious playing, or providing joy and delight, which is said to be the final cause; the agent, that is the musician, who is the efficient cause… Form is that species… which defines the thing in itself, as is proportion in consonance… In the formal, the first cause of the diapason [or octave] is number, that is, 2 and 1, and the second cause is the duple proportion, and thus for the other [consonances] in turn (Zarlino, *IH* I.41 in Corwin, 484).

In this passage, Zarlino applies the four Aristotelian causes to consonances or harmonies, with the musician as the efficient cause, the production of harmonious music as the final cause, the sounds as the material cause, and the proportion as the formal cause. His application clearly echoes features from Aquinas' discussion above: he identifies proportion as the formal cause, understanding it as a definition of the consonance like Aquinas, and identifies 'sounds' as the matter, or material cause, of the consonance. In what follows, I will discuss the kind of explanatory work this framework affords Zarlino.

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tones to one. Moreover, the genus containing this proportion is sounding number (… quoniam nota quae est diapason… componitur ex proportione duorum tonorum ad unum. Genus autem continens hanc proportionem est numerus sonorum… Albertus, Physics, II.2.2, translation mine.) Albertus' use of the word 'note' [*nota*] in referring to the diapason is ambiguous in this context. It could refer to a particular pitch that is an octave above or below a given pitch, or it could refer to the octave interval itself (i.e. the combination of the two pitches). Either way, it is important to recognize that he is talking about the interval of an octave that obtains between two pitches, regardless of what the original pitch is (i.e. it could be any note in the scale) and regardless of whether the second pitch is sounded above or below. The primary point Albertus makes here is that this interval, the octave or *diapason*, is a species of the genus of 'sounding number'.

One of the most significant topics in Zarlino's treatise for our purposes is that of musical consonance. This term has been employed loosely thus far to refer to something like 'musical harmony'. However, there is a more technical usage that I would like to introduce here. Musical consonance, in this more restricted sense, is a quality possessed by some musical intervals that makes them pleasant-sounding to a listener.[15] Its contrast, musical dissonance, is a quality that makes intervals sound unpleasant. The primary issue was that there seemed to be only a relatively small collection of consonant musical intervals. One of the main tasks for music theorists was to provide an explanation for why only this collection belonged to the consonant class.[16] This is one of the tasks that Zarlino uses the Neo-Aristotelian causal framework to tackle. In particular, he appeals directly to the mathematical proportion or ratio *qua* formal cause to explain the consonance of certain intervals.

As noted above, musical intervals are produced respectively according to a unique ratio. However, this is true of all intervals, both consonant and dissonant. Zarlino's strategy for

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[15] For instance, Mersenne writes, 'When two or more sounds are made together and at the same time, we call them 'consonant' when they attune well, and when they please the ear and the spirit' (Mersenne, *HU,* Abstract of Music Theory, translation mine).

[16] The consonant intervals in this period (and their respective ratios) were: the perfect octave (2:1), the perfect fifth (3:2), the perfect fourth (4:3), the major and minor thirds (5:4, 6:5), and the major and minor sixths (5:3, 8:5). It should be noted that we are speaking from the 16^{th} - 17^{th} century European perspective in which nearly all available listeners agreed on which intervals belonged to the consonant class. However, it is worth noting that the consonance/dissonance distinction persists today -- see Kameoka & Kuriyagawa, "Consonance Theory"; Trainor & Heinmiller, "Development of Evaluative Responses"; and Zentner & Kagan, "Infants' Perception".

explaining consonance is to focus on the forms of these intervals and to appeal to what he calls the *Senario* - the number six and the positive integers that precede it: "…in the Senario… one finds every simple consonance in actuality, and also the compound [consonances] in potentiality, from which arise each good and perfect harmony… [they are derived] from the forms, or proportions, and not from the sounds" (Zarlino, *IH* I.16 in Corwin, 300). Two things should be noted from this passage. First, Zarlino explicitly distinguishes between the forms (i.e. the ratios) and what he previously identified as their matter (i.e. the 'sounds'). It is the form of the interval that explains consonance, not the matter. The second thing to note is that Zarlino remarks that all the numbers that make up the consonant ratios, with the exception of the ratio of the minor sixth, are restricted to the numbers of the *Senario*.[17] The reason that Zarlino thought that the *Senario* could account for the phenomenon of consonance was because he thought that the number 6 was particularly special. It is the first of what Zarlino calls the 'perfect numbers' — numbers that are the sum of their factors (taking the factors to be 1, 2, and 3 -- Zarlino, *IH* I.13). Thus, the pleasing character of consonance is simply the result of the perfection of the *Senario* present in the forms of the consonant intervals.

Musical consonance is an excellent example of an application of the Neo-Aristotelian causal framework in this period. Zarlino clearly follows this model by treating the numerical ratios as the forms of their respective intervals and sounds as their matter. And, as we saw in Zarlino's explanation of musical consonance, the framework contributed a high level of explanatory power. The material of the interval (i.e. the sounds) explained what was being heard and how, while the form (i.e. the proportion) explained the perceived character of a given interval. What I mean by

[17] Zarlino provides an explanation for the consonance of the minor sixth in *IH* I.16.

this is that the matter of the interval explained the proper object of perception, along with how it reaches the listener, as outlined above in Section 2.1. Sounds are the proper qualitative objects of auditory perception, and they are perceived when their sensible species are assimilated by the relevant organ. However, the pleasant character of the consonant intervals made up of these sounds is explained not by the matter, which would be the same in consonant and dissonant intervals, but by the form of the consonance – its pleasing ratio. In particular, the simplicity and perfection of the forms of the consonances is what caused them to be perceived as pleasant. Our experience of consonance as 'pleasant' confirms what we would expect if we understand the forms of these intervals to be exceptionally simple and privileged numerical constructs. Thus, the case of musical consonance clearly exemplifies the explanatory efficacy of a framework that included real qualities and formal causes. The sounds, understood here as real qualities, fit into a broader explanation of the object and mechanisms of sensory perception. The ratio as form is then employed to explain what makes certain intervals special – their defining ratio is what explains their pleasing character. In the next section, I will turn to some developments in music theory that seem to directly challenge this framework. These developments put pressure on the musical ratios as formal causes and on sounds as the material for these forms. I will then show how the resolution of these worries ended up salvaging the musical ratios, but only to pave the way for the elimination of sounds and other proper sensibles as real qualities.

3. Developments in Music Theory

In this section I will discuss two striking developments in music that occurred in this period: Vincenzo Galilei's experiments on string tension and Mersenne's research on the vibrating string. I discuss these developments because each one of them puts pressure on a different element of the

Neo-Aristotelian explanation of consonance. Vincenzo Galilei's experiments pose a direct challenge to the role of the musical ratios as formal causes, while Mersenne's work re-situates the role of these ratios in such a way that challenges the role of sounds *qua* real qualities. Before beginning my discussion, some caveats are in order. First, it should be noted that these are not the only developments in music theory in this period that challenged the Neo-Aristotelian framework; rather, they should be seen as particularly salient examples. Second, I am not asserting that these developments alone were sufficient to topple the Neo-Aristotelian framework. Rather, I am arguing that they directly challenged a framework committed to explaining sensory phenomena in terms of Neo-Aristotelian real qualities and formal causes. Seen in this way, these developments pave the way for the later mechanist approach to sensory perception. As I will argue in Section 4, the way in which these developments challenged the Neo-Aristotelian framework also provided a particularly salient and plausible model upon which to build a mechanist metaphysics of sensory perception.

The first development comes from composer, lutenist, and theorist Vincenzo Galilei, who discovered that the traditional ratios (i.e. those that have been discussed so far) only produce the expected intervals when applied to string lengths, but do not produce the predicted musical intervals when applied to other parameters, like string tension.[18] The ratios that have been discussed thus far were taken to refer to the proportion between lengths of string producing the pitches of a given musical interval. The instrument that was dedicated to the study of these ratios was called a monochord. This instrument was composed of a single string stretched between two

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[18] For a discussion of the connection between Vincenzo Galilei's work and Early Modern science from the musicology literature, see Palisca, "Galileo's Father".

fixed points attached to a hollow sounding body. The monochord was outfitted with movable bridges along the length of the string, which could be positioned to divide it according to the harmonic ratios. For instance, a bridge could be placed at the halfway point of the string to produce a pitch an octave above the pitch sounded by the undivided string, implementing the 2:1 ratio. What is important is that the ratios referring to string length, taken as the form or defining characteristic of any given interval, were assumed to obtain not only in the case of string length, but across other parameters as well.[19] However, Vincenzo Galilei's work shows that this is not the case. In an experiment recorded in his *Discorso intorno alle opere de Gioseffo Zarlino*, Vincenzo Galilei devised a way of testing whether the ratios that produce the consonances in the case of string length correspond to string tension. In this experiment he showed that, when a string is stretched successively by different weights, the octave is generated not by attaching a weight that is twice as heavy, but by one that is four times as heavy as the original (Galilei, *Discorso*, 104). In this case, the 2:1 ratio does not generate an octave, but a different interval. The upshot of this is that privileging the traditional ratios as the forms of their respective intervals is in some sense an arbitrary assignment. There is no clear reason for choosing the string length ratio rather than the

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[19] This is presumably why the spurious story of Pythagoras' discovery of the harmonic ratios was perpetuated for so long. The story, as reported in Boethius' *De Institutione Musica*, asserts that Pythagoras noticed pleasing harmonies coming from a blacksmith's shop and, upon investigation, realized that the hammers producing the notes when struck were in the traditional harmonic proportions. We know that this is false because, as with the proportions between string tensions, the proportions between the weights of solid bodies that generate the consonant intervals when struck do not correspond to the proportions found between string lengths (see Boethius, *De Institutione Musica,* I.10, 197).

string tension ratio as the true form of the interval in question. In fact, it seems like the selection of the string length ratios was somewhat a matter of historical accident (i.e. these were discovered first, so they were the ones that were assigned as the form).

This seems to be a significant problem for the dominant explanation of consonance because, if we understand a formal cause as providing the essential or definitional account of what something is, we should expect it to obtain in every instance of the thing it defines. However, Vincenzo Galilei's experiments reveal that the traditional ratios do not always accompany their associated intervals. For example, in the case of the octave, the 2:1 ratio is sometimes present, but under certain conditions, a different ratio obtains. Of course, one might argue that one or the other ratio *really is* the form of the interval it generates, but there seemed to be no principled way of deciding whether it is the string length ratio or the string tension one. This discovery puts pressure on what originally might have seemed attractive about explaining consonance according to its formal cause in the first place: the fact that the 2:1 ratio seemed uniquely connected with its associated interval and could be demonstrated. Thus, Vincenzo Galilei's discovery seems to challenge one of the fundamental aspects of the Neo-Aristotelian explanation of musical consonance: the ratios *qua* formal causes. [20]

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[20] Galilei reports his discovery in the context of a debate regarding whether unaccompanied vocalists will naturally sing intervals in accordance with the ratios prescribed by the just intonation system (i.e. the traditional ratios) or whether they will sing intervals that are 'tempered' or altered in some way. Following his report of the results of his investigations into string tension, he writes ,"It is not true, therefore, that the consonances cannot come from other genera of proportions than the multiple and

The second development I will discuss comes from Marin Mersenne. I will argue that while Mersenne's work provided a solution to the problem presented by Vincenzo Galilei, it also provided significant means for 17th century theorists to challenge the necessity of real qualities in explaining sensory perception. Moreover, his work provided a particularly powerful and salient model for a detailed, mathematically quantifiable mechanist metaphysics of sensation according to which perceived sensible qualities covary with changes in motions in matter. Mersenne's encyclopaedic work *L'Harmonie universelle contenant la théorie et la practique de la musique* [*HU*] includes detailed descriptions of the relationship between the frequency of a pitch and the tension, mass, and length of a string producing it. These can be expressed in what have come to be known as 'Mersenne's Laws'.[21] The first law states that, keeping the string mass and tension constant, the frequency of a pitch is inversely proportional to the length of the string producing it (Mersenne, *HU*, Livre troisiesme du mouvement, de la tension, de la force, de la pesanteur, & des autres proprietez des chordes Harmoniques, P1). The second captures Vincenzo Galilei's discovery: it states that the frequency of a pitch is proportional to the square root of the string tension (Mersenne, *HU*, Livre troisiesme des instruments à chordes, P7). Finally, the third law

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the superparticular" (Galilei, *Discorso*, 104, translation mine). He does not tie this specifically to the Aristotelian conception of formal cause, but it is clear that he means it to be a challenge to any view that holds that the traditional ratios are somehow more natural or essential, or that they are necessarily connected to their associated intervals by some natural order.

[21] Jointly expressible as $f = 1/2L\sqrt{F/W}$, where f is frequency, L is string length, F is string tension, and W is mass-per-unit-length.

states that, keeping the tension and length constant, the frequency of a pitch is inversely proportional to the square root of its mass (Ibid.).

What is important to recognize here is that Mersenne's Laws, and the research that led to their formulation, reveal that that the numerical ratios refer only indirectly to the proportion between string lengths. The thing they characterize most directly is the proportion between the rates of vibration (i.e. frequencies) of the pitches. This is captured clearly by the more famous Galileo Galilei, son of Vincenzo, in his *Two New Sciences*: '…The length of strings is not the direct and immediate reason behind the ratios of musical intervals, nor is their tension, nor their thickness, but rather, the ratios of the numbers of vibrations and impacts of air waves that go to strike our eardrum' (Galileo, *Two New Sciences* in Drake 1989, 104).[22] The reader should note that this discovery seems to solve the problem presented by Vincenzo Galilei's experiments with string

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[22] I cite Galileo Galilei here for two reasons. First, Galileo provides a straightforward and succinct statement of the relationship between musical ratio and rate of vibration of the pitches involved. Second, it shows that Mersenne was just one of the figures in this period that was investigating the mathematics related to sonic perception, and that this work was being conducted simultaneously by multiple theorists in a relatively restricted timeframe (i.e. all occurring around the 1630's). It is likely that Galileo identified that the harmonic ratios refer to frequency of motions of air before Mersenne, especially given his father's work (for elaboration on this point, see Palisca "Scientific Empiricism"). However, I focus my overall discussion in this section on Mersenne for several reasons. First, he dedicated the bulk of his work to these harmonic concerns, while Galileo only discusses them in passing. Second, we have evidence that he corresponded extensively with Descartes regarding these discoveries, which will be an important connection in the next section. And, finally, he is the namesake of the aforementioned laws.

tension. To elaborate, regardless of whether a ratio is produced via string length or string tension, the frequencies of the pitches composing the intervals will be the same and, thus, the ratio between them will be the same. This is because, however a sound is produced, its rate of vibration (i.e. what we know as its fundamental frequency) will be the same. What Mersenne's Laws capture, and what Galielo Galilei puts so succinctly, is that the proportion between rates of vibration is what the musical ratios really track. In this way, it seems like the role of the ratios is salvaged – they really do obtain in every case. However, the way in which they are salvaged opens the door to questioning the role of sounds as real qualities underlying them, as we will see below.

The discovery that the ratios refer most fundamentally to frequency enabled Mersenne to formulate what has come to be called the Coincidence Theory[23] of consonance, captured succinctly at the beginning of the *HU*:

> Sound is no other thing than the percussion of air, which the ear apprehends when it is affected (*touchee*)… All the simple consonances are understood and explained by the first six numbers (1, 2, 3, 4, 5, and 6)… They represent the number and comparison of their percussions... The octave is the sweetest of all, after the unison, because its percussions are unified together more frequently… (Mersenne, *HU*, Abregé de la Musique Speculative, translation mine)

In short, Coincidence Theory asserts that consonance is explained by the rates of coincidence between the frequencies of the pitches that make up the interval in question. The more often and regularly the vibrations of the respective pitches coincide, the more consonant the interval will be, as we will see in more detail in the example below where Mersenne compares the relative consonance of the fifth and the fourth.

The first thing to notice in the passage above is that Mersenne begins with an assertion about the nature of sound: it is nothing other than the motion of air percussing the ear. This in itself

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[23] This term was coined by H.F. Cohen in *Quantifying Music*.

is a radical revision of the model of the nature of sound presented in Section 2.1. The reader will recall that the matter for the musical intervals on the Neo-Aristotelian picture was a real quality: sounds. Here, Mersenne introduces the idea that we can eliminate these real qualities and just talk instead of quantifiable motion of the medium. If the ratios describe relations between the motions of the physical stimulus, regardless of whether they are produced via string length or tension, this opens the door to understanding pitch, and sound in general, as fundamentally a function of these motions. I will argue below that this is exactly the line that was taken by mechanist philosophers like Descartes in the 17th century.

This conception of sound underlies the details of Mersenne's explanation of consonance, which holds that the phenomenon is a result of regular percussions of the eardrum. To unpack this, we should look at another passage where Mersenne compares the consonance of the fifth and the fourth:

> But there is still another means of knowing by how much the sweetness of the fifth surpasses that of the fourth, because the terms of the fifth are multiples of one another, that is to say 3/2 yields 6, which shows that the percussions are unified two times in six rounds, and the terms of the fourth [4/3] multiplied are 12, which shows that the percussions are unified 3 times in 12 rounds, which is to say that when the higher sound of the fourth hits the air 12 times, it is unified three times with the lower sound of the fourth. (Mersenne, *HU*, Part I, 'Livre Premier Des Consonances', XXVI, 72, translation mine)

We see here that Mersenne understood each distinct pitch to be constituted by a series of motions, or percussions, of air, where higher pitches consist of a faster series of motions than lower ones. Whenever two pitches sound simultaneously in a musical interval, their motions will line up at various points. The intervals whose respective motions line up more often are the more consonant ones. For example, the octave has a frequency ratio of 2:1. This means that the higher pitch will percuss twice for every single percussion of the lower pitch. This interval will be more consonant than the perfect fifth, for instance, whose frequency ratio is 3:2.[24]

The main thing that we should notice about Coincidence Theory, in contrast with Zarlino's theory, is that it takes the ratios in question to describe material, efficient interactions. While Mersenne mentions the numbers 1-6, there is no discussion of these numerical relationships attaching to 'sounds' as real qualities. When Mersenne does discuss the intervals' ratios, he does so in the context of using them to describe purely physical interactions of air and bodies. This was most likely a direct result of his experiments on sound and, in particular, those supporting the discovery that the traditional ratios refer to the frequency of a pitch (i.e. the motion of any vibrating body). This discovery thus opens the door to questioning the role of Neo-Aristotelian real qualities in an account of consonance, and sonic perception more generally. Mersenne himself recognizes this. While he is hesitant to assert definitively that his work demonstrates the obsolescence of real qualities, he expresses the belief that it constitutes strong evidence for it: "Nevertheless, I do not estimate that sound should be different from the movement of bodies that hit the eardrum, as it is not necessary to add a quality of the third species, which we ordinarily call a 'passive quality',

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[24] Mersenne is not the only figure that subscribed to Coincidence Theory – Galileo, Beeckman, Hobbes and others give similar formulations and, as we will see, Descartes accepts a version of it. However, I cite Mersenne here because he was one of the first to publish it and he arguably dedicated the most time and effort to the science of sound in this period. This explanation of musical consonance as a function of the coincidence of physical sound percussions (or, later, sound waves) became the dominant account for centuries, arguably culminating in Helmholtz's *On the Sensations of Tone*. However, the explanation of consonance is far from settled and debates about this issue continue to this day.

insofar as the movement of air is sufficient to explain all that is made through sound" (Mersenne, *HU*, Part I, Livre premier de la nature et des proprietez du son, I, 1-2, translation mine).[25] So, even if it seems like Mersenne's work helps the Neo-Aristotelian account of consonance by solving the issue regarding the ratios *qua* forms introduced by Vincenzo Galilei, another issue remains. This is because, if Mersenne's theory holds up, a more parsimonious explanatory option, one involving only efficient causation and motions of bodies and the medium, is available to account for consonance. If that is correct, then the utility of including real qualities in one's explanation is directly challenged.

In this section, we have seen how two notable developments in music theory challenged elements of the Neo-Aristotelian explanation of musical consonance. Vincenzo Galilei's experiments on string tension challenged the role of the ratios as formal causes. This led to further investigations into the nature of consonance on the part of Mersenne. Mersenne's work reinstated the musical ratios, but in such a way that challenged the status of sounds as real qualities. In the next section, I will argue that Mersenne's work provided an important example for the mechanization of sensory perception. More specifically, it provided one of the only available

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[25] Mersenne expresses his hesitancy in the Preface to the *Harmonie Universelle*, writing, "…when I explain sound through the movement of air, I by no means prevent that one posits species, which flow through the air like heat…" (Mersenne, *HU*, General preface to the reader, unpaginated, translation mine). This hesitancy is characteristic of Mersenne generally, and Mersenne's broader relationship with Neo-Aristotelian philosophy is a matter of debate. For further discussion of this topic and the extent to which Mersenne saw his work as compatible with Aristotelianism, see Garber "Frontlines of the Scientific Revolution."

empirically supported examples of the mechanization of a sensory modality in which features of qualitative perception directly correspond to mathematically quantifiable changes in motion.

4. The Influence of Music Theory on 17th Century Philosophy

In this final section, I will explore how these developments in music theory influenced the mechanistic-style metaphysics of sensory perception popular in the 17th century, focusing primarily on Descartes.[26] I will argue that these musical developments played a significant role in supporting the credibility of the mechanist metaphysics of sensory perception. I will first show how these musical developments put pressure on the same elements of Neo-Aristotelianism that 17th century mechanists were interested in targeting. Then I will discuss how developments in music theory provided a unique opportunity for Descartes to concretely demonstrate his metaphysics of sensory perception – one that was yet unavailable for other sensory qualities.

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[26] As I will note throughout this section, we can see this influence in several philosophers that we might think of as sharing 'mechanistic' inclinations. However, I focus primarily on Descartes for reasons of space, and because he is clearly connected to the music theoretical tradition through his early *Compendium Musicae*.

4.1 Targets of the 17th century mechanists

While there was a myriad of mechanist-style frameworks on offer in the 17th century, there was a remarkable amount of agreement regarding their theoretical targets in the Neo-Aristotelian framework. In addition to commitments like substantial form and prime matter, the topic that received some of the most widespread criticism was real qualities and, in particular, sensible qualities.[27] For instance, Bacon's treatment of heat in the *Novum Organum* is an early example of an attempt to reduce real qualities to bodies in motion (Bacon, *Novum Organum*, Book II, Aphorism 20, 262-273). We later find a similar rejection of the quality of heat in Descartes:

> 'One may … imagine the form of fire, the quality of heat … For my part, I am afraid of mistakenly supposing there is anything more in the wood than what I see must necessarily be in it, and so I am content to limit my conception to the motion of its parts' (AT XI: 7/CSM I: 83).

Later, in a letter to Mersenne in 1643, Descartes explicitly rejects real qualities in general: "I assume no 'real qualities' in nature, which are added to substance, like little souls to their bodies, and which can be separated by the power of God…" (AT III: 648). We find a similar sentiment in Hobbes' *De Corpore*, where he states, "I define an Accident to be *the manner of our conception of body*" (Hobbes, *De Corpore*, Part II, Ch. VIII, 2, emphasis mine).

Since real qualities were so widely criticized in the 17th century, it is worth looking at the stated reasons for this. First, 17th century mechanists cite that these are mysterious entities, somehow resistant to explanation. For instance, Descartes remarks,

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[27] For discussion of the 17th century mechanists' targeting of real qualities by 17th century mechanists, see Pasnau, *Metaphysical Themes*, Ch. 19 & 22.

> [T]here is no way of understanding how these… attributes (size, shape, and motion) can produce something else whose nature is quite different from their own – like substantial forms and real qualities which many supposed to inhere in things; and we cannot understand how these qualities or forms could have the power subsequently to produce local motions in other bodies (AT VIII: 322/CSM I: 285).

Here Descartes claims that how substantial forms or real qualities interact with things like bodies is opaque. Earlier in the *Principles*, he also addresses the unificatory role that substantial form is supposed to provide: 'We certainly cannot think up any kind of glue which could fix together the particles of two bodies any more firmly than is achieved simply by their being at rest. For what could such a glue be?' (AT VIII: 71/CSM I: 246).

If these theorists rejected real qualities on the grounds of being 'mysterious' or 'unintelligible', one would assume they felt there was a better way of accounting for the qualitative features of the world. This brings us to the second reason for targeting real qualities: the mechanists believed the explanatory work done by these entities could be achieved more intelligibly and parsimoniously by appealing solely to geometrical properties of bodies and their efficient interactions. For instance, in the *Traité de la lumière* passage above, we see Descartes stating that he only wants to involve "what must necessarily be in" the phenomenon in question, which he thinks is limited the material composition and motion of its corporeal parts. There are also numerous places in the *Principles* where he emphasizes how all qualities of objects and our perceptions of them can be explained mechanically.[28] For instance, in Article 198 of Part IV, titled 'By means of our senses we apprehend nothing in external objects beyond their shapes, sizes, and motions', he writes:

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[28] Of course, with the exception of the mental state itself. I mean here to include only the causal chain leading up to the formation of the idea in the soul.

> … We do not find that anything reaches the brain from the from the external sense organs except for motions of this kind. In view of all this we have every reason to conclude that the properties in external objects to which we apply the terms light, colour, smell, taste, sound, heat and cold – as well as the other tactile qualities and even what are called 'substantial forms' – are, so far as we can see, simply various dispositions in those objects which make them able to set up various kinds of motions in our nerves… (AT VIII: 322-323/CSM I: 285).

Here we see him stating explicitly that all perceptible qualities and the mechanism of their perception can be reduced to geometrical properties of *res extensa*.

Section 3 showed how developments that put pressure on an interval's ratio as its formal cause led to the opportunity to question the status of sound as a real quality. Here, I have shown how the commitments challenged by these developments were the same elements that 17th century mechanists were most concerned with eliminating. If nothing else, this shows that the challenges music theory posed to the Neo-Aristotelian framework would be welcome to these figures, provided they knew about them. In what follows, I will show that theorists were very much aware of these developments in music theory and argue that music theory provided a more positive impetus for mechanist frameworks than simply weakening Neo-Aristotelianism at the appropriate junctures in theoretical space. Namely, I will argue that these music theoretical developments lent considerable and much-needed plausibility to the mechanist model of sensory perception.

4.2 Consonance and 17th century mechanism

We saw that Descartes and other mechanists thought that their explanations were an improvement on those that rely on real qualities, but one might ask why they thought this. One answer has to do with the parsimony of such explanations: if we can explain qualities and their perception without adding extra entities to our ontology, then we should do so. In addition, though, we saw that Descartes and others believed their explanations were somehow more intelligible. However, the reader should recall that it was exactly the seeming inconceivability of reducing qualities to motion or quantity that motivated Scholastic authors to include real qualities in the first place. What changed to make the reducibility of qualities to features of extension seem more intelligible to 17th century theorists? In this section, I will argue that the case of musical sounds was instrumental in supporting the intelligibility of such a framework.

The first thing that we should note is that Isaac Beeckman was one of the early mechanist philosophers with a significant interest in music theory and it was at Beeckman's urging that Descartes wrote the *Compendium Musicae* in 1618.[29] I bring up the *Compendium* for two main reasons. First, it demonstrates Descartes' very early interest in music theory. Second, it shows that Descartes was initially focused much more on abstract music theory and mathematics than on mechanistic physics. In fact, his account of musical consonance is fairly traditional, focusing on the simplicity of the ratios and their application to string length. The only passage in the *Compendium* where he mentions the physicality of sound is when he discusses sympathetic vibration (i.e. when a vibrating body causes another nearby body to vibrate without touching it). He connects this to perception, writing:

> It may be conceived in the same way if one says that sound strikes the ears with many percussions and is quicker where the sound is higher. For then, so that the sound AB may arrive uniformly with the sound CD, it ought to strike the ears with five percussions, while CD strikes once. But the sound CF will not return as quickly to the unison; for that cannot be done until after the second stroke of sound CD… *The same will be explained whatever way one conceives sound to be heard*. (AT X: 110, translation and emphasis mine).[30]

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[29] For a thorough discussion of Beeckman's work on music theory and mechanism, see Cohen, *Quantifying Music*, Ch. 4.1. It should also be noted that Descartes *Compendium* was not published until 1650, after Descartes' death.

[30] The letters refer to line segments in a diagram in the original text that are meant to represent higher and lower pitches in proportion to one another.

This passage indicates that Descartes was entertaining the idea that sonic perception could be understood mechanistically, although his preferred explanation of consonance does not rely on it. It is especially important to note that Descartes clearly states at the end of the passage that the mechanistic view he references is hypothetical, and not one he explicitly endorses at this point.

In the *Compendium* we see Descartes' earliest comments on music theory, spurred in part by Beeckman, another mechanist. While his comments in this work indicate that he had not fully accepted a version of his mature metaphysics of sensory perception at this time, it is incredibly important to note that musical sound was one of the first recorded cases where he considers the possibility that qualitative elements of sensory experience can be explained by mathematically quantifiable motions. Moreover, the reader will note that the passage above is highly reminiscent of the Coincidence Theory of consonance that we saw Mersenne defending. Thus, it is no surprise that Descartes later subscribes to a version of this view, writing in *L'Homme*:

> …These small vibrations compose the sound, which the soul will judge to be sweeter or harsher according to whether they are more equal or unequal between them… Several sounds combined together will be consonant or dissonant depending on whether… the intervals between the small vibrations that compose them are more equal or unequal (AT XI: 150, translation mine).

In this passage, we see that Descartes has now transitioned to accepting an explanation of consonance that clearly relies on the supposition that sound is composed of physical vibrations.[31]

I say Descartes' endorsement of a version of Coincidence Theory here is unsurprising not only because he considers such a theory earlier on in the *Compendium*, but also because we see him corresponding with Mersenne on this very issue around the time that he was working on

[31] For a discussion of Descartes on the perception of consonance, see Romagni, "Cartesian Sensory Perception".

L'Homme.[32] For instance, we see them discussing various aspects of auditory perception, and Coincidence Theory specifically, in a letter from January 1630 (AT I: 105-114). In the letter, Descartes links the perception of pitch to motions of air, writing, "it is necessary that [the sound] strike the ear at least two or three times, so that by the interval that is between the two strokes we estimate how low or high it is…" (AT I 107, translation mine) and a little later on, "I don't think you can understand the fifth without the higher string having struck at least three times your ear; nor the fourth without it hitting it four times, and thus the other [intervals]…" (AT I 109, translation mine). Regarding consonance, he writes:

> ... If you take care to calculate as I have of the recurrence of the sounds of the consonances, you'll find that the sounds that make the fourth, recommence together not at the twelfth stroke ... but at the fourth stroke of the higher sound, and the third stroke of the lower. The same goes for the fifth when they come together, the third stroke of the higher and the second of the lower; whereas for the twelfth, they recombine also at the third stroke of the higher, but the first stroke of the lower, which makes the twelfth simpler than the fifth (AT I 108, translation mine).

Both these passages show that Descartes was corresponding with Mersenne about the details of Coincidence Theory at the time of the composition of *L'Homme* in the context of generating mechanist-style explanations of the perception of auditory qualities. What is more, Descartes raises his aims of replacing Aristotelian real qualities with such explanations a little bit further on in the

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[32] While *L'Homme* was not published during Descartes' lifetime, we know from his correspondence that he was working on it in the early 1630's.

same letter, stating that "… the qualities that you have taken from Aristotle… is one of the main things that I will try to explain" (AT I 109, translation mine).

What all of this shows is, first, that an interest in music theory and the mechanization of sound emerge alongside one another early in the 17th century. More than this, though, it shows an important progression in Descartes' thought. Beginning with the *Compendium Musicae,* we find that the case of musical sound is one of the earliest cases where Descartes considers a mechanical explanation of sensory perception. Then, in his correspondence with Mersenne, we see him engaging in discussion of Coincidence Theory in the broader context of explaining auditory qualities, like consonance and pitch, mechanistically. Moreover, Descartes makes these comments right before expressing his intention to replace Aristotelian real qualities with a mechanist-style account. Finally, he explicitly endorses a form of Coincidence Theory in *L'Homme*. I take all of this as support for the claim that the Early Modern mechanists, and Descartes in particular, were influenced by the developments in music theory discussed above. However, we have yet to come to the final element in my argument: the alleged intelligibility of the mechanist view and its connection to musical sound.

How is it that music and its perception supported the comprehensibility of a framework that did not rely on real qualities? As we saw in Section 2.1, real qualities were important for explaining sensory perception in the Neo-Aristotelian model. They provided the proper objects of sensation, as well as an explanation of how qualities were perceived. Mechanist philosophers replaced this with a model in which the extended properties of the perceived object cause motions in the medium, which mechanically affect the sense organ. These motions are then transmitted through the body, culminating in perception.[33] On this model, the perceptible features of objects are explicable in terms of their geometrical properties and motions. The important thing here is that this model was not obviously plausible at the time – the reader should recall that one of the arguments in favour of real qualities was their resistance to reduction to motion. I will show in this final portion that musical sound played a key role in combatting this argument by providing much-needed empirical support for the mechanist model of sensation.

First, we saw in Section 2 that sound was already closely linked to motion on the Neo-Aristotelian view in a way that contrasted with other sensory qualities. In addition, the work that was discussed in Section 3 showed how a perceived quality could be shown to reliably covary with a change in a physical stimulus in a mathematically quantifiable way. This kind of reduction of sensory qualities to calculable physical interactions is one of the hallmarks of the 17th century mechanist picture. What is significant is that sound was arguably the first sensory quality whose mathematically quantifiable mechanization was supported with any kind of detailed evidence.

First, let us look at how Descartes deals with different sensory qualities and their perception. In *L'Homme,* Descartes addresses how each sensory modality functions in his system. While he unsurprisingly dedicates the most space to discussing visual perception, he includes a

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[33] Of course, theorists differ on the details of this picture. For instance, Hobbes holds that a sensation is a physical state caused by this chain of causes (Hobbes, [*EW*], Vol. 1, pp. 389-391), while Descartes holds that a sensation is a mental state that is caused by this chain of mechanical interactions (AT VIII: 315-316/ CSM I: 279-280).

highly detailed account of the workings of audition. Importantly, it is the only sensory modality for which he provides detailed specifics regarding the physical stimuli that our perceptions track. For instance, he outlines that loudness is tied to the force of the stimulus, pitch is tied to its speed or frequency, and 'sweetness' or consonance is tied to its regularity:

> [The sound] is found louder or softer according to whether the ear will be struck [*frappée*] with more or less strength; but when several follow each other, like those that make up the vibration of strings that can be seen by the eye… then these small vibrations compose the sound, which the soul will judge to be sweeter or harsher according to whether they are more equal or unequal between them; and that it judges higher or lower according to whether they will follow each other faster or slower; so that if they are half, or a third, or a fourth, or a fifth part etc. faster than the other, they compose a sound that the soul judges higher by an octave, or a fifth… etc. (AT XI: 150, translation mine).

This kind of detail, all of which is empirically supported by the work discussed in Section 3, is not provided for other sensory modalities. And while Descartes does provide a thorough treatment of vision both in *L'Homme* and the *Dioptrique*, it is worth noting what he leaves out. Virtually all the detail is dedicated to what would be considered 'common' sensibles by Scholastic philosophers, all of which are already closely connected to motion. The 'proper' sensible for vision, colour, is not considered in depth in these works.

When we find a more thorough discussion of colour in the *Meteors,* the account is highly speculative. First, Descartes stipulates that light consists in "the action or movement of a certain very fine material whose particles must be pictured as small balls rolling in the pores of earthly bodies" (AT VI: 331/O: 336). He then goes on to discuss how we can understand the colours produced by shining light through a triangular prism as a function of the spin of the particles of the medium. He provides a succinct summary of this point in the unfinished *Description du corps humain*, where he writes:

> … We have sensory awareness of two kinds of motion which these balls have. One is the motion by which they approach our eyes in a straight line, which gives us the sensation of light; and the other is the motion whereby they turn about their own centres as they approach us. If the speed at which they turn is much smaller than that of their rectilinear motion, the body from which they come appears *blue* to us; while if the turning speed is

> much greater than that of their rectilinear motion, the body appears *red* to us (AT XI: 255-256/CSM I: 323).

While this treatment is more thorough, the account remains speculative. First, light must be stipulated as a motion. This is also true in the case of sound above, but the difference is that sound had been observed for centuries to have a close connection to motion, while light did not. And second, the empirical evidence Descartes cites doesn't directly support his explanation of colour as particle spin. There is a large leap to be made from observing that colours are only produced in specific regions when light passes through a prism to concluding that our perception of colour must be caused by the spin of particles. Again, the evidence in the case of sound is much more direct. One can observe and count the motions of a string and see that they correspond to the harmonic ratios. In this way, the case of sound provided an example where the physical motions could be mathematically quantified and correlated to specific qualitative perceptions.

If we consider the direct evidence regarding sound that was available to Descartes and other mechanist philosophers, and the notable lack of evidence regarding other sensory qualities, we can see how this case served as a particularly significant example of how proper sensible qualities are reducible to mechanistic interactions. In light of this, it should not be surprising that Descartes uses the example of sound in the beginning of *Le Monde* to support his claim that sensory ideas need not resemble their objects, stating that "most philosophers maintain that sound is nothing but a certain vibration of air which strikes our ears" (AT XI 5/CSM I 82).[34] Mersenne himself suggests that sound is the key to understanding the nature of qualities and our perception of them the *Harmonie Universelle*, writing:

> …Sound can shed more light on philosophy than any other quality. This is why the science of music must not be neglected, even if songs and concerts were entirely abolished and

[34] Thanks to an anonymous reviewer for calling my attention to this passage.

> prohibited; because they are not the principal end of music, as the Practitioners believe, who disregard or are ignorant of reason. In effect, if through knowledge of sounds and their proportions we can give entrance to the proportions of the objects of sight, smell, and taste, there is no honest man that would not prefer this knowledge to all the songs and concerts that could be made following the rules of art (*HU, Livre premier des Consonances,* Prop. XXXIII, Cor. III, 88, my translation).

Of course, none of this is definitive evidence in favour of the claim that the mechanists were *exclusively* inspired by the case of sound and musical perception, nor am I trying to defend such a strong claim. However, I take what I have put forth in this section to support the claim that theorizing about musical sound was *at least one of* the driving forces behind the mechanization of sensory perception, and an important one at that. This has been shown by the following points in this section. First, we have seen that developments in music theory put direct pressure on some of the primary Neo-Aristotelian targets of the 17th century mechanist philosophers. Second, I have shown that 17th century mechanist philosophers were aware of these developments and directly incorporated them into their theorizing, evidenced explicitly in the development of Descartes views on the metaphysics of sensory perception. And, finally, I have argued that musical sound lent important plausibility to an otherwise highly speculative and seemingly implausible model of sensory perception by providing detailed evidence that perception of auditory qualities reliably tracks mathematically quantifiable motions of bodies.

5. Concluding Remarks

I have argued here that the case of the octave, and consonant intervals like it, both undermined the Scholastic Neo-Aristotelian account of sensory perception, as well as provided a strong example for the mechanistic model of sensation that became popular in the 17th century. There are several things that contributed to this result. First, the Neo-Aristotelian account of sound was already vulnerable due to its close connection to motion. Building on this, developments in music theory challenged the role of formal causes and real qualities in the explanation of the perception of the octave and other musical intervals. In addition to putting direct pressure on some of the same features that would become targets of the 17th century mechanists, the research that led to these developments in music provided a particularly strong and empirically supported example of how sensory qualities could be reduced to quantifiable interactions between bodies in motion. This is to say that the implausibility of reducing qualities to motion or quantity was one of the primary arguments in favour of retaining real qualities in one's ontology. As shown directly above, the case of musical sound provided concrete empirical evidence not only of a link between motion and a sensory quality, but of how mathematically quantifiable motions could be seen to reliably covary with perceptible qualitative changes. Such evidence was not available for other sensory modalities, and mechanist accounts of them had to remain speculative. Taken together, this constitutes strong evidence for the claim that music theory was an important factor in the development of the 17th century mechanization of sensory perception.

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