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Mathematics, Music and Medical Science

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MATHEMATICS, MUSIC AND MEDICAL SCIENCE *

Two events earlier this summer, perhaps seemingly without relevance either to each other or to my title, when considered together point to common philosophical commitments whose historical origins are the subject of my brief discourse. The death of Helen Keller in June reminds us of the triumph she represents of intelligence over total deprivation of all means of human communication except through touch. [1] The other event was the conference on computer science and communication just held in Edinburgh, [2] demonstrating the dramatic growth of this subject. What relevance does music have to either of these examples of medical and mathematical science: to the silent, dark world of the deaf-blind or to the intellectual void within a computer? The answer is that we learn as children to communicate meaning first through hearing and speech. Parallel to the genetic and structural study of language, states of sensory deprivation of hearing and of vision reduce the study of human communication to its basic psychophysiological symbolism. We try to imitate this with computer models, with machines. But these contemporary studies of language and communication presuppose a definite conception of both sides of the relationship between the perceiving organism and the world perceived, and of the information communicated, which we need not look far in the literature of science, to say nothing of that of anthropology and genetic psychology, to recognize as the product of very general commitments underlying the sophisticated theory. These are commitments to a view of the

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[1] Obituary, *The Times* (London), 3 June 1968; *cf.* H. Keller, *The Story of My Life*, 6th ed. (London 1903).

[2] International Federation for Information Processing, *IFIP Congress 68*, Edinburgh, August 1968.

subject-matter assumed in advance of detailed research into it. How have they become so much part of Western thinking?

In 1623, Marin Mersenne opened his scientific discussion of music with the declaration that "nobody can reach perfection in music, nor understand or discuss it, unless he combines the principles of physics and medicine with mathematical reasoning." [3] I want to illustrate briefly, with some particular examples, how the invasion of medical science by mathematics in this interesting area of auditory and visual communication reduced the perceiving organism to a mechanism and information to a mathematical symbolism. The mathematical invasion had been a partial and potential programme at least since the protest against the simplifications of geometrical hypotheses in the Hippocratic treatise *On Ancient Medicine.* It became a complete and actual commitment in the period of Galileo, Kepler, Mersenne and Descartes.

The modern mathematical programme has inherited from the Greek mathematicians two essential elements: the quantification of biological phenomena in an appropriate form, and the demonstration of these quantified phenomena in the "Euclidean" sense of proving that they follow from the principles postulated in order to explain them. Thus the geometrical programme introduced by Euclid's optics into the analysis of visual perception, by postulating linear rays of vision and of light, offered at once a theory explaining the stable relationship between human seeing and the world seen, and at the same time a quantitative method of demonstrating what would be seen under specified conditions of distance, reflection, refraction and so on. [4] Similarly, in discussing the arithmetical analysis of musical perception, said to have been introduced by the Pythagoreans, Plato's friend Archytas of Tarentum wrote: [5] "Mathematicians seem to me to have an excellent discernment, and it is in no way strange that they should think correctly concerning the nature of particulars. For since they have passed an excellent judgement on the nature of the whole, they were likely to have an excellent view of separate things. They have handed on to us a clear judgement... not least on music... First they have

[3] Mersenne, *Quaestiones celeberrime in Genesim,* c. iv, vers xxi, q. lvii, art. xvi (Paris 1623) 1696b. These questions will be treated in full in my forthcoming book, *Galileo's Natural Philosophy: Theories of science and the senses,* and companion study of Mersenne; *cf.* Crombie, "The primary properties and secondary qualities in Galileo Galilei's natural philosophy," *Saggi su Galileo Galilei* (Florence, preprint 1969; to be published).

[4] *Cf.* A. C. Crombie, "The mechanistic hypothesis and the scientific study of vision," *Proceedings of the Royal Microscopical Society,* ii (1967), 3—112.

[5] Quoted by Porphyry of Tyre, *In harmonica Ptolemaei commentarius,* ed. John Wallis in *Operum mathematicorum volumen tertium* (Oxford 1699), 236—8; H. Diels, *Die Fragmente der Vorsokratiker,* 5te Aufl. hrg. von W. Kranz, i, § 47 (Berlin 1934); K. Freeman, *Ancilla to the Pre-Socratic Philosophers* (Oxford 1948), 78—9. Archytas was probably the main source of the mathematical and physical treatment of sound given by Plato in the *Timaeus* (67 AC, 80 AB); *cf. Timaeus vel de natura* divini Platonis, Marsilio Ficino interprete (Paris 1536).

judged that sound is impossible unless there occurs a striking of objects against one another... And so, when things impinge on the perception, those that reach us quickly and powerfully from the source of sound seem high-pitched, while those that reach us slowly and feebly seem low-pitched."

The relating of pitch to speed of motion of some kind, and eventually to frequency of vibration,[6] again established a stable quantitative relationship between perception and the world perceived. One of the earliest Greek musical discoveries was the identity of the purest consonances with the simplest numerical ratios. The difficulties produced by the somewhat inconsequential demands of the human ear, especially for the Platonic school of mathematical theorists but in fact for all attempts to demonstrate the musical qualities that should be heard with more complicated numerical ratios, are an example of the refusal of complex biological phenomena simply to vanish in the face of theory, however powerful. These difficulties have produced rich developments both in musical scales and composition, and in auditory physiology. But they did not ruin the mathematical programme: they merely complicated it. Thus the severest critic of the Platonic mathematical school, Aristotle's pupil, Aristoxenus of Tarentum, wrote of his own, more experimental approach:[7] "It is our endeavour that the principles that we assume shall without exception be evident to those who understand music, and that we shall advance to our conclusions by strict demonstration." There is only a short step from demanding strict mathematical demonstrations of biological phenomena to reducing them to a system of mechanisms.

If we count modern science as one product of Western Europe unmatched elsewhere, another is surely the music developed during the same period. But from antiquity music had meant more than simply the ordering of heard sound. It was an intimate part of a world of ideas concerned with the harmony of the cosmos and the "world soul", ideal proportions, and occult powers of sounds and words; it was an element in the harmony of the body and the soul, and hence a powerful instrument of education and an efficacious therapy in mental illness. In his standard textbook, *De musica*,[8] Boethius wrote that "music is involved not only in speculation, but also in morality. For there is nothing so peculiarly human as to be relaxed by sweet melodies, and set on edge by the opposite." He agreed with Plato that the reason for this was the structural "conformity", expressed in numerical ratios, between the three

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[6] *Cf.* Euclid, *Rudimenta musices eiusdem sectio regulae harmonicae...* Ioanne Pena... interprete (Paris 1557), ff. 7v—8r; M. R. Cohen and I. E. Drabkin, *Source Book in Greek Science* (New York 1948), 291; below note 11.

[7] Aristoxenus, *Harmonicorum elementorum libri iii*, ii (Venice 1562), 22; H. S. Macran, *The Harmonics of Aristoxenus* (Oxford 1902), 189.

[8] A. M. T. Severinus Boethius, *De institutione musica libri quinque*, i. 1—2, ed. G. Friedlein (Leipzig 1867); *cf.* Boetii *De musica* (Venice 1492).

kinds of music, *mundana, humana* and *instrumentalis,* the music of the heavens and the elements, of man, and of sound. Like was induced by like, civilized virtue by moderate and orderly music, lasciviousness by the soft modes, inhuman savagery by the harsh ones. Their music expressed the barbarous habits of the barbarous races and the civilized morality of the civilized ones—though, he wrote, "at the present time these are almost non-existent." Hence Plato's insistence that children should be taught only healthy music. Boethius illustrated the dangers by the well-known story of the drunken teenager from Taormina excited by "a somewhat Phrygian mode," who was on his way to burn down the house where his where was shut up with a rival when Pythagoras, "who happened to be observing the movements of the stars by night, as was his custom," heard about him. He immediately "ordered the mode to be changed, and so calmed down the spirit of the furious youth to a completely tranquil state of mind." Another example of the power of music well known to the early philosophers was the acceleration of the heart-beat by its movements. This example of the conformity of music with the body as well as the soul was said to have been reported to Hippocrates by Democritus, when the physician came to cure the philosopher of the alleged insanity for which his fellow citizens had shut him up. Boethius concluded: "From all this it clearly and indubitably appears that music is naturally linked with us in such a way that we could not do without it even if we wished. Therefore our intellectual powers must be applied so that we may also grasp scientifically what has been implanted in us naturally."

Within this context, part of Greek musical theory, with its stress on simple numerical ratios, remained familiar in medieval education through Boethius, Plato's *Timaeus,* and the study of music with arithmetic in the mathematical *quadrivium.* But between about 1550 and 1650 musical science was transformed by two happenings. The musical theorists were forced by the striking innovations of musical practice, first in polyphony and then in instrumentation, to follow the lead of Aristoxenus in taking the complex responses and demands of the ear into the computation of numerical simplicity. At the same time the mathematicians took up the challenge that, as William Wotton was to put it: [9] "Music is a physico-mathematical science, built upon fixed rules, and stated proportions; which, one would think, might have been as well improved upon the old foundations, as upon new ones, since the grounds of music have always been the same." The new mathematicians accepted the standing invitation offered by the grounds of music by looking beyond the alleged structural conformity between the human body and

[9] William Wotton, *Reflections upon Ancient and Modern Learning,* 2nd ed. (London 1697), 329; *cf.* J. M. Barbour, *Tuning and Temperament,* 2nd ed. (East Lansing, Mich. 1953).

soul and the so-called "sounding numbers"[10] of Pythagorean musical theory, and by asking how physically a numerical ratio became a pleasant or unpleasant sensation. Their point of departure was a physical analysis of the relationship between the quantitative "primary properties" of sound and the "secondary qualities" of sensation these produced through the human ear. In this way the mathematicians began the creation of the modern sciences of physical, psychological and physiological acoustics by making a series of fundamental discoveries.

Boethius[11] had reported the fundamental hypothesis that the pitch of sounds emitted by vibrating strings and other instruments depended on the frequency of impulses transmitted through the air, on the analogy of waves transmitted over the surface of water. The first important advance made in the sixteenth century was Girolamo Fracastoro's physical explanation of resonance published in 1546.[12] The response of a string to another in unison with it was a popular example of sympathetic magic. Fracastoro described how one day in a church he noticed some wax images, of which one always moved when a certain bell was rung, while the others stayed still. He pointed this out to some visitors in order to enjoy both their astonishment and his ability to dispel it by explaining that because the moving statue alone happened to be in unison with the bell, it alone responded to the frequency of the impulses propagated from the bell through the air. These likewise, he said, were the cause of the sympathetic vibrations of a stringed instrument. Another fundamental advance was the mathematical and experimental demonstration that pitch was proportional to frequency and hence that the musical intervals (octave, fifth, fourth, third, *etc.*) were ratios of frequencies of vibrations, whatever instrument produced them. This was begun about 1563 by Giovanni Battista Benedetti,[13] continued between 1589 and 1590 by Galileo's father Vincenzo Galilei[14]

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[10] Cf. Gioseffo Zarlino, *Le istitutioni harmoniche* (Venice 1573), 157 (1st ed. 1558).

[11] *De inst. musica*, i.3, 8—11, 14; *cf.* Gualtherus Miekley, *De Boethii libri primi fontibus* (Jena 1898). Boethius's main sources were Euclid, Ptolemy, and Nicomachus.

[12] Hieronymus Fracastorius, *De sympathia et antipathia rerum liber unus*, cc. 4, 11 (Venice 1546).

[13] Io. Baptista Benedictus, "De intervallis musicis," epist. 2, *Diversarum speculationum mathematicarum et physicarum liber* (Turin 1585), 283; C. V. Palisca, "Scientific empiricism in musical thought," in *Seventeenth Century Science and the Arts*, ed. H. H. Rhys (Princeton 1961), 104—9.

[14] Vincentio Galilei, *Discorso intorno all'opere di messer Gioseffo Zarlino da Chioggia* (Florence 1598), 103—5; "Discorso particolare intorno alla diversita delle forme del diapason" and "Discorso particolare intorno all'unisono," Biblioteca Nazionale Centrale di Firenze, MSS Galileiani 3, ff. 45r—46r, 54rv, 56r—57v (*c.* 1589—90); A. Procissi, *La collezione Galileiana della Biblioteca Nazionale di Firenze* (Rome 1939), 4—5; Palisca, *op. cit.*, 120—35. *Cf.* V. Galilei's earlier work, *Dialogo della musica antica e della moderna* (Florence 1581) where he gave an analysis of the fundamental volume of ancient sources: Aristoxeni musici antiquissimi *Harmonicorum elementorum libri iii.* Cl. Ptolemaei *Harmonicorum, seu*

and in 1614—1615 by Isaac Beeckman,[15] and completed between 1623 and 1633 by Mersenne. [16] Mersenne gave an experimental proof by counting the slow vibrations of very long strings against time measured by pulse beats or a second's pendulum. He then used the laws they had discovered, relating frequency to the length, tension, and specific gravity of strings, to calculate frequencies too rapid to count. The demonstration of these propositions enabled these mathematicians to explain consonance as the physical coincidence in the ear of the impulses produced by the terminations of vibration-cycles, with dissonance increasing as coincidence decreased, and to quantify Fracastoro's explanation of resonance.

We may recognize in Vincenzo Galilei's insistence both on the complexity and on the discoverable regularities of auditory experience something of Galileo's approach to natural science, and certainly a family likeness in the polemical aggressiveness to be made famous by his son. Vincenzo was skilled lutanist, a mathematician, and musical preceptor to the Florentine musical academy of the Camerata. Among the manuscripts inherited by Galileo he left a translation of Aristoxenus into Italian,[17] and he explicity followed the example of Aristoxenus in trying to build musical science up from auditory sensation, instead of imposing on it a rigid mathematical scheme in the style of the Platonists. One of his discoveries, described in his last published work and last manuscripts,[18] was that the traditional ratio 2 : 1, said to have been shown by Pythagoras to produce the octave, did so only with lengths of strings in that ratio: for the tensions of strings the octave

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de musica lib. iii. Aristotelis *De obiecto auditus fragmentum ex Porphyrii commentariis,* omnia nunc primum latine conscripta et edita ab Ant. Gogavino Graviensi (Venice 1562).

15 Isaac Beeckman, *Journal tenu... de 1604 à 1634,* publié avec une introduction et des notes par C. de Waard, i (La Haye 1939), ff. 23r—24r (1614—15).

16 Mersenne, *Quaestiones ... in Genesim* (1623), 1556—62, 1699, 1710; *La verité des sciences* (Paris 1625), 370—1, 567, 614—20; *Traité de l'harmonie universelle* (Paris 1627), 147—8, 447; *Harmonicorum libri,* lib. i, prop. ii, lib. ii, props. vi-viii, xvii—xxi, xxxiii—xxxv, lib. iv, prop. xxvii (Paris 1636); *Harmonie universelle,* "Traité des instruments," livre i, props. v, xii, xvi, xix, livre iii, prop. xvii, "Traitez de la nature des sons *etc.*," livre i, props. i, vii, xiii, livre iii, props. i, v, v=vi, xiv=xv, "Traitez de la voix *etc.*", livre i, prop. lii, "Traitez des consonances *etc.*," livre ii, prop. x, "Traitez des consonances *etc.*," livre i, props. vi, x, xii, xvii, xviii, xix, xxii, livre ii, prop. x (Paris 1636—37); above note 6, below note 23.

17 Biblioteca Nazionale Centrale di Firenze, MSS Galileiani 8, ff. 3r — 38v; Procissi, *op. cit.*, p. 8. *Cf.* H. Martin, "La 'Camerata' du Comte Bardi et la musique florentine du xvie siècle," *Revue de Musicologie,* xiii (1932), 63—74, 152—61, 227—34, xiv (1933), 92—100, 141—51; F. Fano, "La Camerata Fiorentina," *Istituzioni e monumenti dell'arte musicale italiana,* iv (1934); D. P. Walker, "Musical humanism in the 16th and early 17th centuries," *The Music Review,* ii (1941), 1—13, 111—21, 220—7, 288—308, iii (1942), 55—71; C. V. Palisca, *Girolamo Mei (1519—1594): Letters on Ancient and Modern Music to Vincenzo Galilei and Giovanni Bardi: A study with annotated texts* (American Institute of Musicology, 1960).

18 *Discorso* ... (1589), 103—5, *cf.* 92—5, 109, 116—8; "Discorso particolare intorno alla diversità delle forme del diapason," MSS Galileiani 3, ff. 45r — 46r; above note 14. Vincenzo died in 1591.

ratio was 4 : 1, and for the volumes of organ pipes 8 : 1. He poured scorn on the universal harmonies attributed to nature by the Platonists. Even when we knew the mathematical ratios, he pointed out that we could not always determine the quality of our sensations.[19] This was an observation to be developed by Descartes in distinguishing within the *perfection* or *douceur* of consonances between objective mathematical simplicity and subjective pleasure, between "ce qui les rend plus simple et «accordantes», et ce qui les rend plus «agréables» à l'oreille."[20] It was precisely when Vincenzo was doing this work that Galileo made his retreat from medicine in 1585 and lived mainly in his father's house in Florence, before returning to Pisa as lecturer in mathematics in 1589.[21] He reported what were evidently Vincenzo's results in his *Discourses on Two New Sciences* (1638),[22] before giving his own proof that the musical intervals were ratios of frequencies and his own physical explanation of resonance, consonance and dissonance.

Before Galileo wrote his account of acoustics in the First Day of the *Discorsi,* Mersenne had written down all the same results and a number of others and had sent most of them to a common friend, the musicologist Giovanni Battista Doni, in Rome.[23] One of his outstanding discoveries, related both to vibrating strings and to his concern with measuring time, was the law that the frequency of a pendulum is inversely proportional to the square root of the length. He had demonstrated this by 20 March 1634; Galileo's earliest known statement of it, in the First Day of the *Discorsi,* was written almost certainly in the spring of 1635.[24] After

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19 V. Galilei, *Dialogo* ... (1581), 46—7, 132—3; above note 14.

20 Descartes à Mersenne, 13.i. 1631, Mersenne, *Correspondance*, éd. C. de Waard, iii (Paris 1946), 24—5; *cf. ibid.* 18.xii. 1629, i. 1630, *ibid.* ii (1937), 338, 371; Mersenne, *Harm. univ.*, "Tr. des consonances *etc.*," i, props. xi, xii, xix, xxi, xxx, xxxii, *Harm. lib.*, iv, props. xvii—xxv.

21 Vincenzo Viviani, "Racconto istorico della vita di Galileo", Galileo Galilei, *Opere*, edizione nazionale, direttore A. Favaro, coadiutore I. del Lungo, xix (Florence 1907), 599—605; A. Favaro, "Serie settima di scampoli Galileiani," *Atti e memorie della Reale Accademia di Scienze, Lettere ed Arti in Padova*, n.s. viii (1892), 55.

22 Galileo Galilei, *Discorsi e dimostrazioni matematiche intorno a due nuove scienze,* i (Leiden 1638); *Opere*, ed. naz., viii, 138—50.

23 Mersenne à Nicolas-Claude Fabri de Peiresc, 20, iii. 1634 (*Correspondance*, iv, 81—2) and internal references show that he had completed by this date the first books respectively of *Harm. univ.*, "Traité des instrumens" and "Traitez des consonances *etc.*," and the first four books of *Harm. lib.* (above note 16); *cf.* Mersenne, *Correspondance*, iv, 105, 134, 175—7, 181—2, 255, 259—60, 345, 368; Doni à Mersenne, 8. xi. 1634, *ibid.* 392—4, 397, *cf.* v, 2, 35—41. For studies of Mersenne see H. Ludvig, *Mersenne und seine Musiklehre* (Berlin 1935) and the outstanding work by R. Lenoble, *Mersenne ou la naissance du mécanisme* (Paris 1943). Mersenne's own copy of *Harmonie universelle* with his annotations made between 1637 and 1648 has been published in facsimile by the Centre National de la Recherche Scientifique (Paris 1965).

24 Mersenne, *Harm. lib.*, ii, props. xxvi—xxix, *Harm. univ.*, "Tr. des instrumens," i, prop. xx; above note 23. Galileo's correspondance with Fulgenzio Micanzio in Venice between 19. xi. 1634 and 7. iv. 1635 (*Opere*, ed. naz., xvi, 163, 177, 193, 200—1, 203, 208—10, 214, 217—33, 236—7, 239—44, 254) indicates that he had not written the last part of the First Day of the *Discorsi* (where he discussed the

measuring the frequencies producing different pitches, Mersenne went on to measure the upper and lower audible limits of frequency.[25] With the same technique he showed experimentally that the frequencies of the fundamental note and the harmonics or overtones produced by a vibrating string were in the ratios 1 : 2 : 3 : 4 : 5 and so on.[26] The explanation [27] that the string was vibrating simultaneously as a whole and in these aliquot parts was later confirmed experimentally at Oxford by William Noble, Thomas Pigot and John Wallis.[28] Mersenne also pioneered the experimental measurement of the speed of sound, and showed that speed was independent of pitch and of loudness.[29] He equated loudness with volume displaced, and related its intensity to the square of the distance from the source.[30]

It was above all Mersenne who, by his systematic search for a stable and consistent physical basis for the phenomena of auditory sensation, confirmed the mathematical invasion into the medical science of hearing. Between 1625 and 1634, to begin with independently of Galileo and Descartes, he came to the conclusion that animals and plants were nothing but machines.[31] A limited mechanistic physiology used before this had indicated the general programme. For example Jacob Müller, who became professor of mathematics and medicine at Marburg, in 1617 offered as a public academic exercise the geometrical analysis of muscular

pendulum and acoustics) by the latter date, His letter of 9. vi. 1635 to Elie Diodati saying that he had sent a copy to Giovanni Pieroni and subsequent correspondence (*Opere*, xvi, 272—4, 300—4, 359—61) establishes this as the latest date of composition. This copy survives in Biblioteca Nazionale Centrale di Firenze, MS Banco Raro 31; *cf.* G.B.C. de Nelli, *Vita e commercio letterario di Galileo Galilei,* ii (Lausanne 1793) 616—8; Galileo, *Opere,* viii, 20—22.

25 Mersenne, *Harm. univ.*, "Tr. des instrumens," i, prop. xix, iii, prop. xvii, "Tr. ... des sons ...," iii, prop. v = vi, "Tr. de la voix," i, prop. lii; *Harm. lib.*, ii, props. xviii, xxxiii.

26 *Harm. univ.*, "Tr. des instrumens," iv, prop. xi = ix, vi, prop. xlii, vii, prop. xviii, "Nouvelles observations," iv; *Harmonicorum instrumentorum libri iv* (Paris 1636) i, prop. xxxiii, iii, prop. xxvii; *cf. Quaestiones ... in Genesim,* col. 1560; and the Aristotelian *Problemata,* xix. 8, 23—4, 38—9, 41—2.

27 Cf. Mersenne, *Correspondance,* iv, 150—1; Descartes à Mersenne, 25. ii. 1630, *ibid.* ii, 397; *ibid.* 22. vii, 28. xi. 1633, vol. iii, 458—9, 559; 15. v. 1634, vol. iv. (1955), 143—5; Beeckman à Mersenne, 30. v. 1633, *ibid.* iii, 403—4, 407—8; Ismael Boulliaud à Pierre Gassend, 21. vi. 1633, *ibid.* iii, 449—51; Christophe de Villiers à Mersenne, ix. 1633, *ibid.* iii, 488.

28 John Wallis, "Letter to the publisher, concerning a new musical discovery; written from Oxford, March 14, 1676/7," *Philosophical Transactions,* xii (1677), 839—42.

29 Mersenne, *Harm. univ.*, "Tr. ... des sons ...," i, props. vii, viii, xiii, xvii, xxi, iii, prop. xxi = xxii, "De l'utilité de l'harmonie," prop. ix; *Novarum observationum physico-mathematicarum ... tomus iii,* c. xx (Paris 1647).

30 *Harm. univ.*, "Tr. ... des sons ...," i, props. xii, xv, *cf.* props. iii, iv cor., xxx, and livre iii, prop. xxi cor. iv; *Harm. lib.* ii, prop. xxxix.

31 Mersenne, *La verité des sciences* (1625), 16—20; *Les préludes de l'harmonie universelle* (Paris 1634), 156—9, *cf.* 118; *Harm. univ.*, "Tr. de la voix," i, prop. li = lii; *cf. L'impieté des deistes*, ii (Paris 1624) 372—8, *Les questions théologiques, physiques, morales, et mathématiques* (Paris 1634) 229—32. *Cf.* Lenoble, *Mersenne* (1943), 74—5, 155—6, 192, 316—25, 501; Crombie, references above notes 3, 4, below note 39.

action *De natura motus animalis et voluntarii exercitatio singularis, ex principiis physicis, medicis, geometricis et architectonicis deducta.*[32] The complete theory of the physiological automaton reduced physiology to a branch of the demonstrative science of applied mechanics. For Mersenne the theory came to hand in the first place as a useful weapon in a theological and metaphysical campaign for the uniqueness, responsibility and validity of human reason against two enemies: Neoplatonists such as Telesio, Campanella and Giordano Bruno who linked men with animals and plants as common participants in a world soul; and sceptics who followed Montaigne in using animal intelligence to cast doubt on any superior claims for men. Mersenne distinguished men sharply from animals because God had given men alone reason, conscious discrimination and freedom of choice. But if animals were simply machines, this left him free, as it did Descartes, to use the imitation of natural processes by means of technological artefacts to give experimental philosophy a powerful insight into possible explanations of them.

Mersenne, like Descartes, used this engineering approach to define the objects of scientific research into the nature of the information mediated by the senses into the living body. In the animal-machine the problem of sensation did not arise, because the light or sound or other external physical motions striking the sense-organs simply stimulated other, internal physical motions of response in accordance with the construction of the machine. This introduced the interesting conception of a purely mechanistic information system. They confined the problem of sensory information to man. Mersenne skirted the philosophical problem of how physical motions of any kind could cause something so different in kind as sensations. Instead, he embarked as an experimental physiological psychologist on his impressive programme of exploring the correlations between auditory and optical stimuli and the sensations they produced. This work occupied about twenty-five years and had two further products. It led him to envisage a kind of psycho-physiological engineering, through the emotions and dispositions of the soul induced by music, that would surpass in its power of rational control any use of music in medicine or education available to antiquity.[33] It also led him to make an original analysis of language.

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[32] Giessen, 1617; *cf.* C. Webster, "The College of Physicians: 'Solomon's House' in Commonwealth England," *Bulletin of the History of Medicine*, xli (1967) 400.

[33] Cf. Mersenne, *Quaestiones ... in Genesim*, cols, 1619—24; *La verité des sciences*, 16—17, 32; *Les préludes de l'harmonie universelle* (Paris 1634), 212, 219—22; *Questions harmoniques* (Paris 1634), 91—9; *Harm. univ.*, Préface générale au lecteur, "Tr. ... des sons ...," i, props. i—ii, "Tr. de la voix," i, "Tr. des consonances *etc.*," i, prop. xxxiii; *Harm. lib.* i, prop. ii; Lenoble, *Mersenne*, 522—31. For. his later work on the science of music see *Cogitata physico-mathematica* (Paris 1644) and *Novarum observationum...* (1647), and on light and vision *Universae mistaeque mathematicae geometriae synopsis* (Paris 1644) and *L'optique et la catoptrique* (Paris 1651).

If it was language that chiefly distinguished men from animals, Mersenne said that this was fundamental, for language meant conscious understanding of meaning. The speech and jargon of animals was a kind of communication, but not language, for they mindlessly emitted and responded to messages simply as machines. But what were the basic elements of human language, and was it possible to invent from them a perfect system of communication between all men? He had become interested in language first in his campaign against the Cabalistic belief in the magical and occult powers of words and sounds. The question whether there was a natural human language in which the names of things revealed their natures went back to Herodotus and Plato, had been discussed by Dante, and arose again in the Neoplatonic and Cabalistic speculations of the fifteenth and sixteenth centuries. Mersenne violently rejected the belief that an occult identification gave a name power over the thing named. At first he thought that God might have revealed natural names to Adam in Hebrew, but later he rejected any idea of a natural language and firmly proposed a purely rational theory making words simply arbitrary signs. Because all men in common possessed reason, they had developed languages in which these spoken or written physical signs signified meanings. For the same reason it was possible to translate a common understanding of meaning from one into another of the variety of languages diversified by the different historical experiences, environments, needs, temperaments and customs of the different races. But if no language was naturally prior to any other, Mersenne saw in this analysis of their basic common elements a means of inventing a perfect universal language that would convey information without error.[34]

The idea of devising a universal means of communication had arisen in the sixteenth and seventeenth centuries out of comparative studies of ancient and modern languages aiming to find a common language for all nations. Mersenne based his linguistic experiments on a calculus showing the number of possible permutations and combinations of a given number of elements. When in 1629 he tried to interest Descartes in this scheme, he received the famous reply that a language expressing perfectly a perfect knowledge of truth could be achieved only in an earthly paradise.[35] But this cold water did not quench his optimism.

[34] See *Quaestiones ... in Genesim*, cols. 23—4. 470—1, 702—4, 1197—1202, 1217, 1383—98, 1692; manuscript continuation, Biblioteque Nationale, Paris, MS lat. 17, 262, pp. 511, 536 (Lenoble, *Mersenne*, pp. xiii—xiv, 514—7); *L'impieté des deistes*, 167; *La verité des sciences*, 67—76, 544—80; *Traité de l'harmonie universelle*, "Sommaire ..." (item 9); *Questions inouyës* (Paris 1634), 95—101, 120—2; *Harm. univ.*, Préface générale au lecteur, and "Tr. de la voix," Préface, livres i, ii, props, vii—xii; *Harm. lib.*, vii; Mersenne's discussions from 1621 to 1640 with Guillaume Bredeau, Descartes, Jean Beaugrand, Peiresc, Gassendi, Comenius and others in *Correspondance*, i, 61—3, 102—3, ii, 323—9, 374—5, iii, 254—62, iv, 329, v, 136—40, vi, 4—6, vii, 447—8, x, 264—74; Lenoble, *Mersenne*, 96—109, 514—21.

[35] Descartes à Mersenne, 20. xi. 1629, Mersenne, *Correspondance*, ii, 327—8.

He had argued that natural science could discover only the quantitative externals of things. Hence it should be possible to invent a language of quantities that "could be called natural and universal" [36] and would be a perfect means of philosophical communication. He proposed to construct with his combinatory calculus a system of sounds representing the quantitative properties of things, so that the sciences could all be taught with no other language than that of a musical instrument, and two philosophers unable to converse in any other way could communicate with each other perfectly on the strings of two lutes.

All this exemplifies the new vision offered by the mathematical programme and the mechanistic philosophy, when ideas and optimism went far ahead of technical possibilities, but we may recognize in them the origins of familiar contemporary commitments. At the same time our present interests help to sensitize the "seeing eye" of the historian. The analytical reconstruction of the history of science must inevitably involve also an analysis of science, and in this manner the present and the past illuminate each other by the development of the tradition itself. Contemporary linguistics and interest in very general questions of communication show us Mersenne's problems, and those of George Dalgarno, John Wilkins and Leibniz,[37] in a new light. Contemporary medical science shows us the power of those commitments to quantification, demonstration, and the hypothetical model brought into physiology by mathematics and all put neatly together in few words written by Malpighi in 1664. Malpighi described how, in discovering "the mechanisms of our body, which are the basis of medicine," the investigator "proceeding *a priori* has come to form models [*moduli et typi, modelli*] of them." He gave as an example Kepler's demonstration of the retinal image by means of a *camera obscura* with a lens, so that "the mathematician produces all the effects that are observed in vision in the state of health and disease in animals, demonstrating *a priori* the necessity of those effects... from knowledge of the mechanism made by man analogous to the eye." [38] A corresponding model for the ear was

[36] *Les questions theologiques,* quest. xxxiv, „"Peut-on inventer une nouvelle science des sons, qui se nomme psophologie?" p. 158 (expurgated edition: see Lenoble, *Mersenne,* xx, 399—401, 518; Mersenne, *Correspondance,* iv, 74—6, 203—6, 267—71), *cf.* iii—iv, 2, 11; *Harm. univ.,* "Tr. ... des sons...," i, prop. xxiv (language played on a lute), "Tr. de la voix," i, props. xii, xlvii — 1 (artificial rational languages), "De l'utilité de l'harmonie," prop. ix (symbolic language, acoustical telegraph).

[37] *Cf.* George Dalgarno, *Tables of the Universal Character* (Oxford 1657?), *Ars signorum, vulgo character universalis et lingua philosophica* (London 1661); John Wilkins, *An Essay towards a Real Character and a Philosophical Language* (London 1668); and for a systematic historical discussion O. V. C. W. Funke, *Zum Weltsprachenproblem in England im 17. Jahrhundert: G. Dalgarno's 'Ars Signorum' (1661) und J. Wilkins' 'Essay Towards a Real Character and a Philosophical Language' (1668)* (*Anglistische Forschungen,* xlix; Heidelberg 1929); Paolo Rossi, *Clavis universalis: Arti mnemoniche e logica combinatoria da Lullo a Leibniz* (Milan & Naples 1960); *cf.* W. C. & M. Kneale, *The Development of Logic* (Oxford 1962).

[38] Marcello Malphighi, "Responsio ad Epistolam, cui titulus est, De recentio-

offered by a musical instrument. After Thomas Willis, recently Professor of Natural Philosophy at Oxford, had in 1672 identified the cochlea as the sensitive organ of hearing, in the Académie des Sciences the anatomist Joseph Guichard du Verney with the aid of the physicist Edme Mariotte proposed the "conjecture" that it operated by resonance.[39] He suggested that it responded along its spiral selectively to different notes in the same way as the strings of a lute responded to their corresponding fundamentals and harmonics. We can rediscover in these lines of seventeenth-century mathematical medicine, both culminating in Helmholtz, a freshness of intellectual experience made sophisticated by an awareness of the singularity of their methods and of precisely how their conjectures stood in relation to their technical frontiers.

For a final legacy of music to medical science we may return again to Mersenne. His study of communication led him to become interested both in musical instruments that could reproduce the human voice by imitating vowel and consonant sounds, and also in the physiology of natural speech. These investigations suggested to him a method of communication for deaf-mutes by teaching them to produce speech by forming the tongue and lips in appropriate positions and to associate these with written words and the things they signified.[40] This problem had been pioneered in Spain, and was taken up by others both in France and in England. One English physician, John Bulwer, in 1644 and 1648, described three methods of communication for the deaf and

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rum medicorum studio dissertatio epistolaris ad amicum" (1664), *Opera posthuma* (Amsterdam 1698) 276, 289—90 (in Latin and Italian); *cf.* Crombie, "The mechanistic hypothesis..." (1967), 68—86, above note 4.

[39] Thomas Willis, *De anima brutorum,* i, c. 14 (Oxford 1672); Joseph Guichard du Verney, *Traité de l'organe de l'ouïe* (Paris 1683) 68, 78—98; *cf. Histoire de l'Académie royale des Sciences,* i, (Paris, 1733) 395—8 (Année 1684); Crombie, "The study of the senses in renaissance science," *Proceedings of the Tenth International Congress of the History Science: Ithaca, New York 1962,* i (Paris 1964). 93—117. Wiliam Holder, *A Treatise on the Natural Grounds and Principles of Harmony* (London 1694) cited the analyses of consonance and resonance by Galileo (9—17, 45—9) and Mersenne (104), and suggested a resonance theory of consonance and dissonance based on Willis's physiology. *Cf.* H. von Helmholtz, *On the Sensations of Tone as a physiological basis for the theory of music,* 2nd English ed., translated, thoroughly revised and corrected, rendered conformal to the fourth (and last) German ed. of 1877, with ... addtitional notes and... appendix ..., by A. J. Ellis (London 1885; New York 1954; 1st German ed. 1865), *Treatise on Physiological Optics,* translated from the 3rd German edition [1909], ed. by J. P. C. Southall, 3 vol. (Menasha, Wisc., 1924—25; 1st German ed. 1867), both with valuable historical notes; P. J. Kostelijk, *Theories of Hearing. A critical study of theories and experiments on sound-conduction and sound-analysis in the ear* (Leiden 1950); G. von Békésy, "Current status of theories of hearing," *Science,* cxxiii (1956), 779—83.

[40] *Harm. univ.,* "Tr. de la voix," i, prop. li. On instruments for imitating human speech see "Tr. des instrumens." vi, props. xxxi—xxxii, xxxvi, vii, prop. xxx; Pierre Trichet à Mersenne, 9. i. 1631, *Correspondance,* iii, 2—9, de Villiers à Mersenne, xi. and 14. xii. 1633, 15. vii. 1635, *ibid.* iii, 538—53, 578—97, v, 293—4, Mersenne à Peiresc, 1 and 15. vii, 17. xi. 1635, and Doni à Mersenne, 30. ix. 1635 *ibid.* v, 269—72, 299—300, 478—82, 410—5.

dumb: by hearing through a stick held in the teeth, by hand signs, and lip reading.[41] Asserting in the rational spirit of Mersenne that "words are nothing else but motion",[42] Bulwer began with an account of the movements of the larynx and mouth in producing speech. This led him to the question: "That the motions of the parts of the mouth in speech are so remarkable, that some have (not without successe) attempted to imitate them by mathematicall motions."[43] He wrote: "So that if a man (for curiosity or strangenesse sake) would make a puppet or other dead body, to pronounce a word; let him consider on the one part, the motion of the instruments of the voyce; and on the other part the like sounds made in inanimate bodies; and what conformity there is that causeth the similitude of sounds; and by that he may minister light to that effect. But to come neerer to the point. Many of the learned are of opinion, and perswaded in their judgments, that the imitation of the motions of our speech may be effected by insensible creatures, if a dextrous man would employ his time in contriving and making such an instrument to expresse those different sounds; which not having more then seven substantiall differences; besides, the vowells (as some who have carefully noted them, doe affirme) it would peradventure be no hard matter to compose such an engine, which because it will be a subtle imitation of the worke of nature, it will be necessary that our artist have this qualification of being more than superficially tinctur'd in anatomy, the better to be acquainted with the muscules, and the nerves inserted into their heads,

[41] John Bulwer, *Chirologia: or the Naturall Language of the Hand. Composed of the Speaking Motions, and Discoursing Gestures thereof. Whereunto is added Chironomia: or the Art of Manuall Rhetoricke. Consisting of the Naturall Expressions, digested by Art in the Hand, as the chiefest Instrument of Eloquence, by Historicall Manifesto's, exemplified out of the Authentique Registers of Common Life, and Civill Conversation. With Types, or Chyrograms* (London 1644); *Philocophus: or, the Deafe and Dumbe Mans Friend, Exhibiting the Philosophicall verity of that subtile Art, which may inable one with an observant Eie, to Heare what any man speaks by the moving of his lips. Upon the Same Ground, with the advantage of an Historicall Exemplification, apparently proving, That a Man borne Deafe and Dumbe, may be taught to Heare the sound of words with his Eie, & thence learne to speake with his Tongue* (London, 1648), dedication sigs. A 2—6, pp. 49—54, 71. Sir Kenelm Digby (*Two Treatises in the one of which, the Nature of Bodies; in the other, the Nature of Mans Soule; is looked into: in way of discovery, of the Immortality of Reasonable Soules*, i, ch. 28, Paris, 1644, 257), in arguing that "hearing is nothing else but the due perception of motion (cf. below note 42), cited "the ordinary experience of perceiving musike by mediation of a sticke: for how should a deafe man be capable of musike by holding a sticke in his teeth, whose other end lyeth upon the vyall or virginals, were it not that the proportionall shaking of the sticke (working like a dauncing in the mans head) did make a like motion in his braine, without passing through his eare? and consequently, without being otherwise sound, then as bare motion is sound;" cf. Holder, *Elements of Speech* (1669) 160 (below note 49), du Verney, *Traité de l'organe de l'ouïe*, 90, *Histoire de l'Académie royale des Sciences*, i, 397.

[42] *Philocophus*, 19; cf. 70—1 on the physiology of the ear; Mersenne, *Harm. univ.*, "Tr. ... des sons...," i, props i—ii, *Harm. lib.*, i, prop. ii.

[43] *Philocophus*, 45—8; cf. 110—2 on birds imitating human speech and inanimate noises; cf. Mersenne, *Harm. univ.*, Preface générale au lecteur, sig. Aiii; J. Cohen, *Human Robots in Myth and Science* (London 1966).

which are the principles and springs of all those outward motions whereby speech is perform'd and uttered. And I believe the modell must be in fashion of a head, which is the royall part unto which speech is intrusted; for as the tongue and lips articulate; the head resounds. Frier Bacons brazen head, and that statue formed by Albertus Magnus which spake to Thomas Aquine, and which he mistaking for a magical device brake, was certainly nothing else but mathematical inventions framed in imitation of the motions of speech performed by the instruments in and about the mouth."

Bulwer was impressed by the social, civil and legal disabilities of deaf-mutes, who were often considered imbeciles, but he pointed out that most mutes were so because they had been deprived by deafness from birth of any experience of speech and of the normal discipline of human communication over a growing intelligence.[44] He quoted from Sir Kenelm Digby the case he had met, while he was in Spain in attendance on the Prince of Wales (later King Charles I), of a nobleman who had been "borne deafe, so deafe, that if a gun were shot off close by his eare he could not heare it, and consequently he was dumbe; for not being able to heare the sound of words, he could never imitate, nor understand them." But the youth's whole manner and appearance, "and especially the exceeding life and spiritfulness of his eyes, ... were pregnant signes of a wel-temper'd mind within." After "physicians and chyrurgions had long employed their skill, but all in vaine," he was taught by a good priest "to heare the sounds of words with his eyes, and thence to speak with his toungue."[45] This he learnt so well that, although a little unsteady in controlling the pitch of his own voice, he could recognize that of others and could accurately reproduce the sounds of English and of Welsh spoken by members of the Prince's suite. Bulwer's explanation of this case was strictly rational. He rejected "that supposed infallible sympathy of the nerves of hearing and speech" which "many physicians have confidently affirmed to be the onely cause why a man deafe from his nativity, is consequently dumbe: ... whereas this Lord having got a pair of eare-spectacles before his eyes, whereby the dependencie that speech had upon the eare was taken away: there remained no signe of a sympatheticall league of silence contracted between the tongue and the eare: but the tongue set at liberty, proves free, and being *sui juris,* leaves the unprofitable eare, and by art enters into an auditory league of amity and allyance with the eye, which now officiously becomes *ad succedaneum,* or *qui pro quo,* for eare."[46]

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[44] *Philocophus,* 102—9; *cf.* 88—97, 109—38.

[45] *Ibid.,* 55—61, quoting Sir Kenelm Digby, *Two Treatises,* i, ch. 28, 254—6; *cf. Philocophus,* 91—2, 155—68. Charles went with Buckingham to Spain in 1623.

[46] *Ibid.,* 113—4.

After his encounter with this example of training the eye and mind "in conceiving the visible sound of speech,"[47] Bulwer collected together from literature and experience a large number of other cases showing, as he put it, "how the objects of one sense may be known by another," and how this "community among the senses" provided "other avenewes unto the braine"[48] through which those deprived of their normal sensory equipment could communicate. He cited from Felix Plater one case "of a certaine Abbot, who being made blinde, mute, and deafe by the malignity of the French pox," could be communicated with only by "drawing letters upon his naked arm" with a finger or a piece of wood. Another case in which touch supplied the deficiency of other senses was that of an ingenious English gentleman "who through some sicknesse becoming deaf, doth notwithstanding feele words, and as if he had an eye in his finger, sees signes in the darke; whose wife discourseth very perfectly with him by a strange way of arthrologie or alphabet contrived on the joynts of his fingers; who taking him by the hand in the night, can so discourse with him very exactly; for, he feeling the joynts which she toucheth for letters, by them collected into words, very readily conceives what shee would suggest unto him."[49]

Bulwer made the interesting point that "if speech were naturall to man, there is no reason but men borne deafe and dumbe, (their tongues being commonly free,) might come out with it without hearing or teaching," and so „the most unanswerable argument against the naturality of any language is, that they who are naturally deafe, speeke not at all."[50] Another fundamental question raised by these

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[47] *Ibid.*, 181—3. Spoken words could seen at a greater distance and sooner than heard.

[48] *Ibid.*, 64—76, sig. A5.

[49] *Ibid.*, 106—7. For further discussions of this question in England see William Holder, *Elements of Speech: an essay of inquiry into the natural production of letters: with an appendix concerning persons deaf and dumb* (London 1669); John Wallis, "A Letter of Doctor John Wallis to Robert Boyle Esq., concerning the said Doctors Essay of Teaching a person Dumb and Deaf to speak, and to understand a Language; together with the success thereof, made apparent to his Majesty, the Royal Society, and the University of Oxford," *Philosophical Transactions*, v (1670), 1087—99; Holder, *A Supplement to the Philosophical Transaction of July, 1670: With some reflexions on Dr. John Wallis, his letter there inserted* (London 1678); Wallis, *A Defence of the Royal Society, and the Philosophical Transactions, particularly those of July, 1670, in answer to the cavils of Dr. William Holder* (London 1678); *Grammatica linguae anglicanae, cui praefigitur, De loquela; sive de sonorum formatione: tractatus grammatico-physicus, editio sexta. Accessit Epistola ad Thomam Beverley: de mutis surdisque informandis* (London 1765; 1st ed. Oxford 1653); G. Dalgarno, *Didascalocophus or the Deaf and dumb mans tutor...* (Oxford 1680); *cf.* Jo. Conrad Amman, *Dissertatio de loquela qua non solum vox humana, & loquendi artificium ex originibus suis eruuntur: sed & traduntur media, quibus ii, qui ab incunabulis surdi & muti fuerunt, loquelam adipisci, quique difficulter lonquuntur, vitia sua emendare possint* (Amsterdam 1700).

[50] Bulwer, *Philocophus*, 133—5; Table, unnumbered sig. b. 5. He was arguing against Montaigne.

natural experiments in the extirpation of particular senses was that discussed famously by John Locke:[51] what would a man born blind with congenital cateract see after an operation giving him sight? How do we come to correlate the information received through seeing, touching and hearing into a perception of a single world? Locke's Oxford contemporary Willis and the mathematical physiologists of the Académie des Sciences[52] raised the parallel question of how this humanly perceived world was related to those available to the variety of sensory equipments of the different invertebrate and vertebrate animals. We are still trying to answer these questions. They have a practical application in pre-operative training in cases of restorable deprivation. Above all they enlighten the complexity of that most complex and human of all human phenomena, language itself.

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[51] *An Essay concerning Humane Understanding,* ii. 9 (London 1690); *cf.* M. von Senden, *Space and Sight: The perception of space and shape in the congentially blind before and after operation* (London 1960); Crombie, "The mechanistic hypothesis..." (1967) 84—6. For discussions of this question in relation to language *cf.* Denis Diderot, *Lettre sur les aveugles, à l'usage de ceux qui voyent* (London 1749), *Lettre sur le sourds et muets, à l'usage de ceux qui entendent et qui parlent* (Paris 1751); E. Bonnot de Condillac, *Traité des sensations* (1754) and *Logique* (1780), in *Oeuvres complètes,* iii, xxii, (Paris 1798).

[52] Willis, *De anima brutorum,* i, cc. 3—15; *Histoire de l'Académie royale des Sciences,* i (1733), 18—19, 36—7 (1667), 117 (1670), 179 (1674), 223—8 (1677), 243—8 (1678), 278—81 (1679), 395—8 (1684); *cf.* Mersenne, *La verité des sciences,* 16—20.