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BEHAVIOR ANALYSIS: THE THIRD BRANCH OF ARISTOTLE'S PHYSICS

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For Aristotle, the subject matter of physics was motion, which he understood as change in a very broad sense. In his *Physica,* Aristotle identified changes of quality (like color), changes of quantity, and changes of place or spatial location as varieties of motion. He regarded change of place as the principal type of motion and subdivided it into natural, forced, and voluntary changes of place, or motions (Aristotle, *Physica*; Pedersen & Pihl, 1974). According to Aristotle, the *natural motions* are circular, upward, and downward, and are exhibited by bodies in the heavens, fire and air, and earth and water, respectively. *Forced motions* are those that are initiated by an external mover and that contravene the natural motion of an object. The natural downward motion of a thrown clod of earth, for example, is contravened by an horizontal impulse imparted by the thrower. *Voluntary motions* are those exhibited by animate beings and their parts. The disciplines that study these three types of motion came to be called astronomy (including the study of mass attraction), mechanics, and psychology.

There are many similarities between the development of astronomy and the development of mechanics, and, as is well known, the two were unified by Isaac Newton in his celebrated *Principia.* But little attention has been paid to the development of psychology as the third branch of Aristotle's physics. The purpose of this review is to show that the development of psychology has been similar to the development of the other two branches of Aristotle's physics in at least three important ways: all three disciplines rejected Aristotle's teachings regarding motion, developed a productive graphical method to represent the motion in question, and used mathematics to describe the motion. In the case of psychology these developments came together in B. F. Skinner's important book, *The Behavior of Organisms* (1938).

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ARISTOTLE'S PHYSICS

Aristotle's teachings regarding motion were very influential (Sarton, 1952) and survived for a long time: roughly 17 centuries in the case of natural motion and forced motion, and at least 22 centuries in the case of voluntary motion. The central tenet of Aristotle's doctrine on motion is summarized in the following passage:

> [Things that exist by nature, viz., animals and their parts, plants, and the simple bodies (earth, fire, air, water) and their compounds] present a feature in which they differ from things which are *not* constituted by nature. Each of them has *within itself* a principle of motion and of stationariness. (Aristotle, *Physica,* p. 192^{b})

Thus, Aristotle taught that natural objects, whether animate or inanimate, possess an internal motive principle. Natural motions, for example, occur because the bodies that exhibit them have an "innate impulse" to do so. "Now, necessarily, everything which moves either up or down possesses lightness or heaviness . . ." (Aristotle, *De caelo,* p. 269^{b}). Similarly, Aristotle taught that objects that undergo forced motion have within themselves the potential of being so moved, and that contact with a mover activates the potential. This "actualization" theory (Koyré, 1978) permitted Aristotle to speak of forced motion as occurring in virtue of "the impulse which the body that is carried along or is projected possesses" (Aristotle, *Physica,* p. 216[a]). Hence, one may speak of velocity, or the intensity of forced motion, as a property of the object; a body is swift or slow in the same sense that it is black or white (Pedersen & Pihl, 1974). Voluntary motions are exhibited by entities that "being animate, have a principle of movement within themselves" (Aristotle, *Physica,* p. 284[b]). Generally speaking, "nature means a source of movement within the thing itself" (Aristotle, *De caelo,* p. 301[b]).

THE DEVELOPMENT OF ASTRONOMY AND MECHANICS

Rejection of Aristotelian Doctrine

Astronomy made considerable progress in antiquity, although it remained under the influence of Aristotelian internalism. For example, by the 5th century B.C., empirical astronomy had provided much information about the motion of celestial bodies, and by the end of the second century A.D., Ptolemy's geocentric system of the universe, as set forth in his *Almagest,* had become influential. The *Almagest* endured as the principal astronomical authority for well over 1,000 years, and Aristotle's internal-motive-principle theory survived with it. In the late 16th and early 17th centuries, however, the Aristotelian theory began to encounter difficulties. In Ptolemy's geocentric universe, all natural motions occurred with respect to a single point, namely, the center of the earth. But in Copernicus' heliocentric universe, circular motions occurred with respect to many points. The moon, for example, revolved about the earth, which in turn revolved about the sun. Kuhn (1957) argues that those who gave credence to Copernicus' theory (although there were not many) may have found circular motion about many centers considerably less "natural" than that about a single center. Kepler's discovery, around this time, that elliptical orbits simplified the celestial system may also have disturbed Aristotelians because the ellipse, which cannot be defined with respect to a single center, does not share the "perfection" of the circle (Kuhn, 1957).

Kepler also suggested that the motion of celestial bodies might be caused by an external force rather than by the natures of the bodies themselves. Galileo ignored this and most other ideas of his German contemporary (de Santillana, 1955), but it reappeared not long after in the writings of Robert Hooke. Amid much controversy, but ultimately with much success, Isaac Newton turned Kepler's idea into the force of universal gravitation. In so doing, he moved the cause of the circular or elliptical motion from inside to outside the celestial bodies. According to Newton (quoted in Koyré, 1965),

> These [gravitational attractions] are manifest qualities. . . . And the *Aristotelians* gave the name of occult qualities to such qualities only as they supposed to lie hid in bodies, and to be the unknown cause of manifest effects. . . . Such occult qualities put a stop to the improvement of natural philosophy, and therefore of late years have been rejected. (p. 145)

In rejecting the Aristotelian doctrine, Newton was able to unify celestial and terrestrial mechanics.

Unlike astronomy, mechanics (i.e., the study of the motion of sublunary bodies) progressed little in antiquity; Aristotle's authority on mechanics was not seriously challenged until medieval times. The Aristotelian legacy in the Middle Ages had two components. The first was the idea that velocity was a property of a body, like its color. The second dealt with the cause of projectile motion and was more confused. Aristotle is sometimes said to have subscribed to the antiperistasis theory of his teacher, Plato (Clagett, 1959; Koyré, 1978), which states that a projectile continues to move in the absence of contact with the mover because the air that it displaces travels behind it and impels it forward. However, Clagett (1959) and Kuhn (1957) note that Aristotle contradicted himself on this point. In fact, certain passages in the *Physica* (e.g., p. 216[a], quoted above) suggest an incompatible "impetus" theory, whereby projectile motion is said to persist in virtue of the impetus that it receives from the mover. Fourteenth-century schoolmen by and large held to the impetus theory and tended either to attribute it to Aristotle or to reconcile it with his teachings (Clagett, 1959; Koyré, 1978). It is fair to say, then, that early medieval scholastics subscribed to a two-fold Aristotelian internalism: Motion was an inherent property of a moving body, and forced projectile motion continued in virtue of an internal impetus that was communicated to it by the mover.

In the case of mechanics, the objection to

Aristotelian internalism was voiced by the English Franciscan, William of Ockham, in the first half of the 14th century. This celebrated Oxford logician led the Nominalist school of philosophy, which held that velocity and impetus, for example, were mere names, not actual entities possessed by bodies. According to the Nominalists, one does not see a body's velocity or impetus; instead one sees the body at Point A at a particular time and at Point B at some later time. According to William of Ockham (quoted in Clagett, 1959):

> I say that local motion is . . . nothing else but the fact that the moving body is in different parts of space in such a manner that it is not in any one part. . . . [T]he moving body . . . remains the same in itself, so that it neither acquires anything new nor loses anything existing in it [like velocity or impetus]. But the moving body does not remain always the same with respect to its surroundings, and so it is possible to assign "before and after," that is, to say: "this body is now at A and not at B," and later it will be true to say: "this body is now at B and not at A." (pp. 589–590)

In this passage, William of Ockham suggests that projectile motion should be treated exactly, and only, insofar as it is perceptible to the senses. This project was taken up by a group of logicians and natural philosophers at Merton College, Oxford (Thomas Bradwardine, William Heytesbury, Richard Swineshead, and John Dumbleton). Influenced by the anti-Aristotelian nominalist philosophy, these scholars proposed to treat sensible motion per se, and their work marked the beginning of modern mechanics (Pedersen & Pihl, 1974).

Graphical Methods and Mathematical Description

In the case of astronomy, the development of a graphical method and the use of mathematical description were closely related. The groundwork for the application of mathematics was laid by Pythagoras and his followers in the latter half of the 6th century B.C. The Pythagoreans promulgated the doctrine that the visible world had a mathematical structure, and that natural events could be described mathematically. This doctrine of Pythagorean philosophy powerfully influenced Greek and Hellenistic science during the last 5 centuries B.C. Before Pythagoras, mathematical methods were either purely practical or purely abstract (Pedersen & Pihl, 1974). After Pythagoras, mathematics became a way of understanding nature, at least in principle.

Around 400 B.C., Plato suggested a rudimentary graphical method that linked the Pythagorean doctrine with the well-developed geometry of the day. He suggested that the motion of a celestial body might be represented by a circle. Eudoxus of Cnidos (c. 405–355 B.C.), Plato's mathematical colleague at the Academy, was the first to take up Plato's suggestion. The task set by Plato was to show that celestial phenomena could be accounted for by a system of regular circular motions. Eudoxus' system was not very successful in this respect, but it marked the beginning of a serious effort to apply geometry, by means of the circle, to astronomical phenomena. This effort culminated 5 centuries later in Ptolemy's *Almagest,* which realized the Platonic goal.

In the case of mechanics, the Merton scholars had decided to treat sensible motion *per se.* They had also decided to treat it quantitatively (Pedersen & Pihl, 1974). Their most important contribution was the so-called Merton relation, or mean-speed theorem, which is the now familiar "distance equals rate times time" formula. The Merton relation, which was probably discovered in the early 1330s (Clagett, 1959), marks the beginning of mathematical description in mechanics.

The Oxford logic (i.e., Nominalism) and mechanics rapidly became known in other parts of Europe (Clagett, 1959). The new mechanics influenced the Parisian scholastic, Nicole Oresme, who developed a graphical method for representing the Merton school's "sensible motion." Oresme represented the velocity of a body at a given time by a vertical line, the length of which corresponded to the magnitude of the velocity. For each instant of the motion a vertical line representing the velocity could be drawn on the horizontal time line. The set of all vertical lines defined a plane figure that Oresme referred to as the configuration of the motion. By the end of the 14th century Oresme's graphical method had become widely known; it continued to be influential through the 17th century and, with various improvements, on into modern times (Clagett, 1959). Oresme's method was important to mechanics because it led Galileo to the solution of the problem of free fall, which in turn made Newton's mechanics possible (Clagett, 1959, 1968). In contemporary physics, Oresme's method survives in the well-known position versus time graph and its first two derivatives (velocity and acceleration versus time graphs). The velocity versus time function is an Oresmean configuration.

To summarize, the three developments in astronomy were the use of circles to represent celestial motions, the application of geometry, and the abandonment of Aristotelian "internalism" in favor of an external force. Plato's circles made Ptolemy's geometrical applications possible. Ptolemy's universe, as modified by Copernicus and Galileo, was the foundation for Newton's important achievement, which entailed rejecting Aristotelian doctrine.

In mechanics, the three developments were the Nominalist rejection of Aristotle, the mathematical work of the Merton school, and Oresme's graphical method. The Nominalists influenced the Merton scholars (and later philosophers [Koyré, 1978]), who initiated an anti-Aristotelian mathematical mechanics. Oresme's graphical system furthered the mathematical work, which ultimately led to Newtonian mechanics.

THE DEVELOPMENT OF PSYCHOLOGY

Internalist Doctrine

As in the case of mechanics, the first development in psychology was the rejection of the dominant internalist doctrine. Over the centuries the name of the internal motive principle had changed from soul (seated, according to Aristotle, in the heart) to mind (seated in the head), but the faculties remained the same, as did the idea that the internal entity was responsible for the movements of animate beings and their parts. As is well known, the initial objection to the internalist perspective was voiced by Watson (1913, 1930), whose polemical writings were remarkably similar to those of his Nominalist forebears. Watson (1930) argued that "voluntary motion" should be treated insofar as it is perceptible to the senses, the same program that Ockham had suggested for forced motion 6 centuries earlier. To account for behavior from outside the organism, Watson (1930) proposed a kind of comprehensive reflexology, but this ultimately proved unsatisfactory. Watson's theory was eventually replaced, via Thorndike's law of effect, by Skinner's system of behavior.

Since Watson's time, the externalist perspective on behavior has become synonymous with Skinnerian psychology, and many examples of this perspective can be found in *The Behavior of Organisms*. For example, in discussing discrimination Skinner asserts that

> An organism can be said to "tell that two stimuli are different" if any difference whatsoever can be detected in its behavior with respect to them.... What "learning to tell the difference" refers to ... is the widening of the difference in strength in related reflexes through alternate conditioning and extinction. (pp. 169–170)

In the second chapter of *The Behavior of Organisms* (p. 44), Skinner refers to his system of behavior as positivistic and confined to description, but this is an overstatement. Many elements of Skinner's system are more consistent with realism. These include reflex strength, the reflex reserve (including the immediate reserve), drive, and emotion. For example, consider the following, which is highly critical of nominalist positivism and strongly supports realism:

> The materialist, reacting from a mentalistic system, ... is likely to regard conceptual terms referring to behavior as verbal and fictitious. ... [For example, Holt's] objection to such a term as "instinct" seems to be reducible to the statement that you cannot find the instinct by cutting the organism open. A similar argument is commonly advanced against the concepts of "intellect," "will," "cognition," and so on.... But the objection to such terms is not that they are conceptual but that the analysis which underlies their use is weak. The concepts of "drive," "emotion," "conditioning," "reflex strength," "reserve," and so on, have the same status as "will" and "cognition" but they differ in the rigor of the analysis with which they are derived and in the immediacy of their reference to actual observations. (pp. 440–441)

In this passage Skinner endorses the central tenet of most versions of realism, namely, that it is possible in principle to infer the existence of unobservable entities from measurements on observables. This is exactly what Skinner does in the case of the reflex reserve:

> In one sense the reserve is a hypothetical entity. . . . But I shall later show in detail that a reserve is clearly exhibited in all its relevant properties during the process that exhausts it and that the momentary strength [of the reflex] is proportional to the reserve and therefore an available direct measure. The reserve is consequently very near to being directly treated experimentally. (p. 26)

In several places, Skinner discusses instances in which behavior that has produced a smooth curve on a cumulative record is interrupted, and then compensates for the interruption by returning to the projected course of the smooth curve. According to Skinner, "this compensatory effect . . . is fairly strong evidence of an underlying reserve wherever it occurs" (p. 298; but cf. Skinner, 1950). This is an exceptionally good example of realist epistemology.

The strands of realism in *The Behavior of Organisms* indicate that its epistemological foundation is more complicated than might be supposed. Although positivism has enjoyed a renaissance of sorts in recent years (Churchland & Hooker, 1985; van Fraassen, 1980), late 20th-century philosophy of science has tended to favor realism (e.g., Leplin, 1984). This does not mean, of course, that realism should be encouraged in contemporary behavior analysis. It does suggest, however, that the proper epistemological foundation of behavior analysis merits closer examination, especially in light of contemporary philosophy of science. Interesting work on this problem has been begun by Coleman (1984), Smith (1986), and Zuriff (1985).

In spite of the realist strands in *The Behavior of Organisms,* it is clear that Skinner favored a broadly conceived, albeit somewhat tainted, positivism, and that he saw it as an antidote to the metaphysics of internalist theories of behavior (pp. 3–6; see also Smith, 1986). Similarly, nominalism and Newton's objection to "occult" causes served as antidotes to metaphysics in the development of mechanics and astronomy.

Graphical Method

The research tradition in psychology that rejected internalist metaphysics also made productive use of a graphical method. The method is the cumulative record of responding, which Skinner used extensively in *The Behavior of Organisms.* The cumulative record represents sheer description of "sensible" voluntary motion in the same way that Oresme's configurational system represented sheer description of sensible forced motion. Moreover, the two graphing systems convey identical information about their respective types of motion. Because the slope of a cumulative record represents the rate of responding, its first derivative is a rate versus time function, or an Oresmean configuration (cf. Figures 58 and 59 in *The Behavior of Organisms*). Skinner remarked on the importance of rate versus time functions (p. 60), and used them in his discussions of discrimination (pp. 208, 248, 255) and the effects of drugs on behavior (pp. 411, 413).

Just as the first derivative of a cumulative record of responding is an Oresmean configuration of behavior (i.e., a rate vs. time function), the integral of an Oresmean configuration of motion is a cumulative record of displacement (i.e., a position vs. time function). This isomorphism between the position versus time graph in mechanics and the cumulative record in behavior analysis has been discussed by McDowell (1979), and has been put to use in at least one experiment (McDowell & Sulzen, 1981).

Just as the circle (and later the ellipse) played an important role in astronomy, and just as the Oresmean configuration played an important role in mechanics, the cumulative record played an important role in Skinner's system of behavior. This graphical method was developed to represent an organism's rate of responding (pp. 57ff), which Skinner identified as the principal dependent variable in his system (pp. 20–21). It is important to recognize that Skinner's chief interest was in dynamic phenomena, such as extinction and the development of discriminations, in which response rate changes with time. The cumulative record is well suited to the visual representation of these changes in rate, as Skinner noted (p. 60). Furthermore, "the cumulative curve has a special advantage in dealing with the notion of a reserve [e.g., it can show the time course of the reserve's exhaustion] and with its subsidiary effects (such as compensation for temporary deviations)" (p. 60). It is difficult to imagine how Skinner's system of behavior could have been effectively developed or persuasively communicated without a graphical method like the cumulative record.

Mathematical Description

Skinner recognized the importance of quantitative accounts of behavior (e.g., pp. 85, 189, 432), and his system in *The Behavior of Organisms* entails the beginnings of mathematical description. Skinner first used mathematics to describe the time course of extinction (p. 88). He found that the logarithmic equation, $N = k\log t$, described a cumulative record of extinction (actually, its "envelope") after one reinforcement. This equation expresses the cumulative number of responses emitted, N, as a function of time, t. Its first derivative gives the rate of responding as a function of time, and its second derivative gives the change in rate of responding (i.e., the response acceleration) as a function of time. Of course, this relationship between the original logarithmic function and its derivatives is identical to the relationship in mechanics between the position versus time function and its derivatives (McDowell, 1979). Notice that the mathematical description is closely tied to the graphical method, just as was the case in astronomy and in postmedieval mechanics.

Later in *The Behavior of Organisms,* Skinner used the somewhat more complicated logarithmic equation, $N = k\log at + bt + c$, to describe extinction following responding that had been both reinforced and punished. The more complicated equation reduces to the simpler form when $a = 1$, $b = 0$, and $c = 0$. Skinner comments:

> The curve is ... the same type of equation used to describe simple extinction.... Although the fit is not perfect, we are perhaps justified in concluding that in spite of the ... [punishment] the reserve presents itself for emission in essentially the same fashion. (p. 158)

In this passage Skinner suggests that it may be reasonable to conclude that simple extinction and extinction following punishment are the result of the same process, because both can be described by the same function. If so, it would then follow that punishment, even though it may temporarily suppress responding, does not affect the reflex reserve. Although this argument can be questioned, and Skinner's tentativeness in advancing it was justified, it nevertheless represents a noteworthy application of mathematical description in Skinner's system. As was the case for simple extinction, the mathematics in this instance is used to describe the cumulative record. This is in fact true of every instance of mathematical description in *The Behavior of Organisms.*

Skinner used mathematical description in a similar way in treating discrimination (pp. 186ff). He shows cumulative records during the development of a discrimination. All responses were recorded, including those emitted when the discriminative stimulus was absent. These records (e.g., Figure 54) are concave downward because responding comes to occur less frequently when the discriminative stimulus is absent. Skinner again used the more complicated logarithmic equation (with, however, $a = 1$) to describe these curves. Because he thought that discriminative responding was the result of extinction when the discriminative stimulus was absent, he subtracted from the cumulative records those responses emitted in the presence of the discriminative stimulus. The somewhat simpler logarithmic form, $N = k\log t + c$, described the resulting data, averaged across rats. Now "if the present interpretation of a discrimination is correct, [these] curves should resemble those obtained during extinction. . ." (p. 189). Skinner showed that this was the case. Here again, he took the similarity in function forms as evidence that the processes responsible for the behavior were similar.

Skinner also used mathematical description in discussing drive (chapter 9) and the interaction of drive and conditioning (chapter 10). He showed (p. 344) that a power function with an exponent of 0.7 described the time course of satiation in his rats. That is, when food was continuously available, the cumulative number of pellets of food eaten was a power function of time. The same function, with the same exponent, was found to describe the cumulative record when a lever press was required for each pellet of food (p. 354). Skinner also discussed Bousfield's (1934) contradictory finding that the exponential, $y = a(1 - e^{-bt})$, provided a better description of the time course of satiation, although he did not attempt to reconcile his findings with Bousfield's. Coleman (1987) has provided a more detailed discussion of Skinner's use of a power function to describe satiation.

The mathematics in *The Behavior of Organisms* can be criticized (e.g., Verplanck, 1954). For example, the logarithmic and power functions are not asymptotic, which means that they cannot adequately describe phenomena, like extinction, in which the rate of responding approaches zero with time. Moreover, these function forms have no rational basis. Other concave-downward forms (e.g., Bousfield's exponential) might provide as good a description of the data. In the absence of a rational foundation for the mathematics, it is difficult to select a particular function form from a variety of similar forms. Skinner recognized this limitation:

> The equation [for the discrimination curve] is wholly empirical, and no significance is to be attached to its constants. It might be possible to derive a rational equation for this and the extinction curve from the notion of a reflex reserve but I see no reason to press too eagerly toward this natural conclusion, since all the factors entering into the curve have not by any means been identified. (p. 189)

The suggestion that a rational equation might be derivable from the notion of a reflex reserve has been taken up by Killeen (1988).

Difficulties with mathematical description are not unique to behavior analysis. For example, the form of the ballistic curve was a troublesome problem in mechanics, and many arbitrary function forms were proposed before the rational basis of mass attraction was discovered. Nevertheless, as Skinner noted, a rational mathematics is a natural conclusion to his system of behavior. The initial steps toward this goal were taken in *The Behavior of Organisms.*

CONCLUSION

The development of the three branches of Aristotle's physics was similar in at least three important ways. All three disciplines entailed the rejection of internalist theories of motion, the development of a productive graphical method to represent the motion, and the application of mathematics to describe the motion.

The only claim being made in this review is that the three events mentioned above occurred in the histories of astronomy, mechanics, and psychology. In particular, it is not claimed that identical lines of development can be traced in the actual histories of astronomy, mechanics, and psychology. For example, in the cases of astronomy and mechanics it is clear that the rejection of internalist theories was a rebellion against Aristotle. In the case of psychology this is not clear. The success of anti-Aristotelian mechanics, rather than opposition to Aristotelian doctrine per se, may have given rise to Watson's rejection of internalist theories of behavior. Historians of science may be able to clarify this sort of detail.

Astronomy and mechanics have developed into highly successful disciplines. It would be illogical to conclude that behavior analysis, because it bears some similarity to these disciplines, must be on the right track. The ultimate value of behavior analysis will not be known for many years. Nevertheless, the similarities are interesting and, it must be admitted, provocative. According to Ernst Mach (1883/1960):

> They that know the entire course of the development of science, will, as a matter of course, judge more freely and more correctly of the significance of any present scientific movement than they, who, limited in their views to the age in which their own lives have been spent, contemplate merely the momentary trend that the course of intellectual events takes at the present moment. (pp. 8–9)

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