THE APPLICATION OF CHAOS THEORY TO BEHAVIORAL OPTOMETRY

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ABSTRACT

Behavioral optometry is rooted in the system of numbers known as the 21-point visual analysis. Through the years additional performance tests and clinical insight have tempered the reliance upon mathematical formulation of case typings. The complexity and dynamic nature of the visual process necessitates new paradigms to objectively arrive at acceptable levels of performance. The new science of chaos holds promise in this regard, providing mathematical profiles of complex and dynamic human systems. Through study of the non-linear nature of the cardiac system, scientists are beginning to appreciate the purposeful chaos of the heart, wherein absolute equilibrium is undesirable. This paper explores the possibilities for application of chaos theory to the non-linear nature of the visual system.

KEY WORDS

chaos, non-linearity, complexity, dynamics, accommodation, vergence

The new science of chaos, as popularized in the recent book by James Gleick, offers a way of seeing order and pattern where formerly only the random, the erratic and the unpredictable had been observed.[1] Until the modern study of chaos began approximately 25 years ago, science had maintained faith in a predictable universe. However, during the past decade scientists have discovered the paradox that many dynamic systems that are governed by deterministic Newtonian mechanics also exhibit chaos.[2] The earliest attempts to analyze the complex balance between orderly and chaotic forces in nature occurred in the application of non-linear mathematical formulae to atmospheric conditions.[3] Such applications began to account for the turbulence and unpredictability of weather. From this research the theory of nonlinear dynamics has evolved into a major field of exploration, most notably in theoretical physics and biology.

The hidden order in chaos has begun to contribute greater insight into health care. Nowhere has this been more apparent than in the field of cardiology. Chaotic activity can be seen in the mathematical model of a single heart cell, and is particularly useful in research on cardiac arrhythmia.[4] Contrary to conventional assumptions, a healthy heart must beat somewhat chaotically rather than in a predictable pattern. As reported in the New York Times,[5] researchers presented evidence at a 1989 meeting of the American Association for the Advancement of Science that a perfectly regular heartbeat is more likely to presage sudden death than good health. It appears that the sympathetic and parasympathetic nervous systems, which regulate the heart, work against each other in a purposefully chaotic interplay. Only when the heart is approaching death do the two systems reach perfect equilibrium. Researchers have concluded that a certain amount of chaotic variability is essential to organs that must constantly adapt to changing conditions.

From the preceding it should be apparent to practitioners of behavioral optometry that chaos theory holds promise for greater understanding of the visual system. We shall consider one example of non-linear dynamics in each of three major dynamic visual input components, namely the ocular motor, accommodative and vergence systems. We shall then consider accommodative-convergence interaction. Lastly, the ability to conceptualize visual function as a time-space continuum will be discussed in the context of phase space diagrams. The gross-motor system need not be elaborated in this paper because the vestibular system itself, as well as its anti-gravitational components, is widely held to be non-linear.

1. Ocular Motor System

One example of non-linear dynamics in the ocular motor system is Troxler's phenomenon. A well-known principle of physiological optics, Troxler's phenomenon is the observation that the eye is not perfectly motionless when an individual stares at a target. Rather, steady fixation or position maintenance involves a series of micro-tremors. These minute oscillations are necessary to prevent the retinal image from fading.[6] Stabilized retinal images disappear from consciousness. However, if these micro-tremors occurred with absolute rhythmicity and periodicity, the brain would adapt to this steady-state stimulation and the image would again fade. Consequently some degree of non-linearity is necessary to avoid predictability and to keep the image in consciousness.

Although there is only scant mention of the eyes or vision in his book on chaos, Gleick[1] does reference a specific model for the erratic eye movements of schizophrenics, which is controversial. What is germane, however, is the conceptualization of erratic eye movements as an example of non-linearity in the oculomotor system that goes to an extreme and is no longer purposeful in the schizophrenic. Application of the tools of chaos can possibly reveal the dynamic behavior of periodic and aperiodic oscillations of nystagmus—a condition whose etiology, to this day, remains obscure.

2. Accommodative System

The accommodative mechanism similarly displays purposeful non-linearity. It has been found that the degree of accommodation oscillates slightly all of the time at a frequency of up to two times per second.[7] Although these oscillations occur in a regular, sinusoidal pattern, they are of variable frequency. This variable frequency of oscillation seems purposeful and integral to our ability to change accommodative response instantaneously and accurately. Think of a runner in the starting blocks, gently rocking back and forth on her fingertips and toes, waiting for the gun to fire. That is the purposeful micro-oscillation of steady-state accommodation, waiting for the brain's signal that it's time to locate elsewhere.

3. Vergence System

Fixation disparity is an imprecision in bifoveal fixation. Fixation disparity has been referred to as a purposeful error of the binocular system.[8] What purpose might such an error serve? Again we point to the concept of an error signal or activity being desirable in a non-linear, dynamic system. Hence, the purposeful error is merely another example of non-linearity in a dynamic system which must be prepared for change. In this instance, fixation disparity serves as a constant stimulus to the vergence system. Its chaotic nature is evident in the internal variability of points plotted on a graph.

4. Accommodative-Convergence Interaction

The significance of an earlier statement bears repetition: A certain amount of chaotic variability is essential to organs that must constantly adapt to changing conditions. The hallmark of visual efficiency is the ability to adapt to changing conditions. This is epitomized in the inter-relationship of accommodation and vergence wherein degrees of freedom are essential.

Similarly to the way in which the cardiac system displays a purposeful tug of war between the sympathetic and parasympathetic systems, the accommodative-convergence interaction reflects a purposeful tug of war between the skeletal and visceral systems. We noted earlier that absolute equilibrium between two such systems is undesirable and, in the case of the heart, can actually presage death. The visual analogue of absolute equilibrium between the accommodative-convergence systems is orthophoria and emmetropia. Behavioral optometrists have long contended that induced orthophoria and emmetropia are neither desirable nor indicative of good visual health.[9] Consequently, the concept of low hyperopia and exophoria at nearpoint serving as a buffer to nearpoint stress is a window to the issue of purposeful chaos in skeletal-visceral interaction.

5. Time-Space Continuum

Scientists have developed phase-space plots to image the time-space properties of dynamic systems. A basic principle of physics is that every dynamic system has phase properties that, when propelled into motion, form a time-space continuum.[1 p.135] One can visualize such a phase-space plot by thinking of the diagram of a pendulum's path in space, or of the familiar swoops of a weather system on a meteorologist's map. Numerous findings in optometric clinical practice lend themselves to being conceptualized in this manner. What picture comes to mind when one is asked to visualize bimanual chalkboard circles? A series of concentric loops which rarely overlap, but time-average to form a circular figure. Chalkboard circles are therefore, among other things, a phase-space diagram of how the patient integrated and organized space over the course of time.

Consider the function of accommodative facility—the ability to change accommodative response over time. The clinician knows what the end result is by the number of cycles per minute, but the numbers do not reveal the qualitative aspect of performance over time. Did the patient begin sluggishly and become more rapid and facile with time, or did performance deteriorate with time?[10] Was it variable as a function of the time of day or as a result of tasks performed prior to the examination?[11] This is an instance where the lack of sufficient data to plot a phase-space diagram of the function leaves us with questions about the applicability of the function itself.

At the other extreme, fixation disparity is an example of a function where rudimentary phase-space plots are integral to the analysis of the findings. The slope and form of the forced-vergence fixation disparity curve have been important contributions in our ability to map the performance of the individual over time. As useful as this has proven to be through its own versions of case-typing (curve-typing), a three-dimensional plot of vertical and horizontal fixation disparity factored in with accommodative intrusions would provide even greater insight.

CONCLUSION

It appears that deterministic chaos in the visual system may be an avenue for the behavioral optometrist to explore the differences between a "functional" and "classical" approach. Behavioral optometry assumes that the linear optics of graphical analysis cannot adequately explain the wide variabilities in visual function. Chaos theory is a justification for the tempering of linear models of the visual system, and a caution in applying graphical analysis to the dynamics of human vision. Behavioral optometry would benefit by the application of mathematical formulae to arrive at a healthy degree of chaos for a variety of visual functions. Most assuredly, mathematical modeling will not account for all irregularities in visual function. However, it may contribute to a better appreciation of lens-prescribing regimens, or to the recognition of when vision therapy is indicated or to be terminated.

Checking, chaining and typing was an early attempt to express a mathematical model for non-linearity of the dynamic properties of the visual system. Regrettably, it was ahead of its time. It is time, now, to take a fresh look. Classic modeling can and should be augmented by newer insights into the dynamic properties of the visual system. Applied research in cardiology should serve as an impetus for this goal. Although classic modeling in cardiography has contributed much to the welfare of man, EKGs often cannot portend cardiac crises. Episodes of a patient walking out of a physician's office with a normal cardiogram, and succumbing to a heart attack on the way home, continually spawn interest in non-classical models of chaos to augment interpretation of cardiographic activity. The need to better differentiate normal from abnormal cardiac behavior is overt in analyzing the electrical activity of heart tissue. Though removed from life and death, the quality of vision deserves no less treatment than the condition of the heart.

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