Athletic Insight
The Online Journal of Sport Psychology

May, 2000
Volume 2, Issue 2

Chaos Theory: A New Science for Sport Behavior?

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ABSTRACT

Current theoretical approaches to research have contributed to our understanding of the effect of selected variables on other variables, yet have not sufficiently moved the sport psychology field closer to the goal of understanding, explaining, and predicting complex sport behavior. Therefore, the purpose of this paper is to present a brief overview of a more macroscopic approach for studying the complex, nonlinear system of sport behavior, namely chaos theory. Chaos based research may yield patterns of behavior which may provide a more functional understanding of sport behavior.

Introduction

Twentieth century attempts to further scientific knowledge have typically resulted in theoretical frameworks and methodologies that required either a deductive or an inductive approach. Some believe that deductive theorists sacrifice objective information for subjectivity and generalizations, while those inductively focused forfeit the 'big picture' and realism for the sake of statistical results (Blackerby, 1993). Although the two approaches have contributed to our understanding, we submit that neither approach has sufficiently moved the field closer to the goal of understanding, explaining, and predicting complex sport behavior.

Since the publication of the first sport psychology research (Triplett, 1897), sport scientists have attempted to understand and modify athlete behavior. For example, hundreds of studies and numerous theories have attempted to empirically examine and/or explain the relationship between arousal and athletic performance. Early researchers predicted a linear relationship known as drive theory (Hull, 1943; Spence, Farber, & McFann, 1956; Spence & Spence, 1966). Over time, results failed to completely support the linear relationship (Martens, Vealey, & Burton, 1990). In fact, results suggested that the relationship might be curvilinear instead of linear. Attention, therefore, turned to a theory descriptively named the Inverted-U Hypothesis (Yerkes & Dodson, 1908). Even though enthusiastically received by the scientific community, the curvilinear relationship has proved difficult to examine (Hardy, 1990; Hardy & Fazey, 1987). Recent theories of arousal, anxiety, and performance are multi-dimensional and nonlinear. For instance, the catastrophe model (Hardy & Fazey, 1987) predicts separate effects for cognitive and somatic anxiety and Kerr's (1985) reversal theory contends that the athlete's interpretation of her/his arousal level is the important consideration.

As noted, current thinking has shifted from linear to nonlinear and from uni-dimensional to multi-dimensional models for research. Sport psychology scientists now believe that the interactional approach of individual and situational factors will take the field closer to the goal of understanding, explaining, and predicting behavior (Davidson & Schwartz, 1976; Endler, 1978; Krane & Williams, 1987; Martens, Burton, Vealey, Bump, & Smith, 1990; Spielberger, 1971). However, this focus on multiple variables, complex systems, and nonlinear relationships is in direct opposition to the current Newtonian approach of trying to understand the world by examining individual components (Wallace, 1996). Rather, a macroscopic examination of complex, nonlinear systems is needed to aid our understanding. Therefore, the purpose of this paper is to provide a brief overview of such an approach, namely chaos theory. We acknowledge that in our attempt to explain and apply chaos theory to sport behavior, there is the potential for over simplification of a complex mathematical theory.

Overview of Chaos Theory

A number of scientists have called the development of chaos theory the most exciting scientific breakthrough in the 20th century (Blackerby, 1993; Gleick, 1987; Masterpasqua & Perna, 1997). Others consider the study of chaos theory to be the basis for a third axial period of the ways of knowing (Blackerby, 1993; Perna & Masterpasqua, 1997). Chaos theory begins where the traditional scientific method stops. Since the 1960's, scientists all over the world have investigated the application of chaos theory to various dynamical systems in fields such as biochemistry, biology, economics, mathematics, medicine, motor control, philosophy, physics, and psychology (Blackerby, 1993; Perna & Masterpasqua, 1997; Sternad, 1998).

For some, chaos is a science of process; a new way of thinking; a return to the study of phenomena on a human scale (Gleick, 1987). For others, the essence of chaos theory are the mathematical models used to formulate "strange attractors", "fractals", and "phase space." In our attempt to integrate chaos theory into the field of sport psychology, both of these doctrines will be examined.

A Science of Process

Emanating from the work of Newton, the predominant paradigm throughout the fields of science has employed a reductionist philosophy (Wallace, 1996). This microscopic approach examines isolated parts of a complex system in hopes that by understanding the parts, the whole would also be understood. As such, the linear reductionist approach requires that the researcher isolate a variable or variables within the system under study for data collection at a specific time. The previous reference to the arousal-performance relationship is a good example. It was Hull's (1943) intention in the development of drive theory to isolate and present the basic principles of behavior. Utilizing a reductionist approach, researchers manipulated arousal levels while measuring performance in simple conditioned responses. Under these conditions, results generally supported drive theory (Spence, 1964). However, under the more complex and realistic conditions associated with sport, drive theory has not been able to predict athletic performance (Martens, Vealey, & Burton, 1990). Isolating and understanding the parts of a complex system has not led to an understanding of the whole. Comparable results throughout the scientific community led a number of researchers to realize "the futility of studying parts in isolation from the whole" and signified an end to their reductionist philosophy in science (Gleick, 1987, p. 304). New explanations to resolve complex phenomena were needed.

As a science, chaos is interested in finding the difference between error and noise in complex systems. Its goal is to examine and understand the whole in its simplest form. The science of chaos is driven by the belief that simple nonlinear systems can produce complex results. The focus is on determining the universal relationships and boundaries of that system. Chaos is not about disorder. Rather, it attempts to find the order in a seemingly chaotic system. By utilizing a progression of measurements over time and space, models can be developed to simulate the behavior of complex systems. Chaos theorists believe that viewing the world from a different perspective allows one the opportunity to see.

Mathematical Models

Along with the need for better solutions, the evolution of chaos theory coincided with the development of computers capable of running massive mathematical programs. For the first time, scientists were able to set up computer models designed to repeatedly predict specific outcomes. One of the first such researchers to use this method was Edward Lorenz. Lorenz had broken weather into 12 numerical rules or equations that expressed laws of nature (Gleick, 1987). Using a typical reductionist philosophy, he reasoned that by learning to understand the separate laws, he could understand the whole and thus, be able to predict the weather. Based on initial conditions, the physical laws would determine the future.

Indeed, when fed into the computer, Lorenz's model produced recognizable weather behaviors that displayed familiar patterns over time. However, using a graphical display, he noted that the patterns had disturbances which were never quite the same. The patterns displayed an orderly, disorder. One day, wanting to examine a particular sequence in more detail, Lorenz started his program in the middle. This time results were drastically different. After checking for computer errors, he realized what had happened. When entering the initial conditions, he had rounded .506127 to .506 erroneously assuming that the difference was inconsequential (Gleick, 1987). The realization that small differences in initial conditions could lead to drastically different results led to Lorenz's fascination with the mathematics of complex systems and the beginning of the scientific revolution known as chaos theory.

Defining Features

In simplest terms, chaos theory uses models to describe the behavior of complex systems. Models are possible because all complex or chaotic systems have three defining characteristics; deterministic, orderly, and sensitive to initial conditions (Kellert, 1993).

The basic tenet of chaos theory is that simple systems with simple laws can result in complexity (Gleick, 1987). Thus, all complex systems are comprised of simple laws that determine its behavior. Something is determining the behavior of the system. The challenge of the chaos scientist is to identify the simplest rules that determine the behavior. The key is to discover the equation ruling the system's behavior.

The second characteristic is that all chaotic systems are orderly. Though the name of the theory suggests disorder, chaos predicts order in a complex and seemingly chaotic system (Gleick, 1987). While the momentary behavior appears random and chaotic, the general pattern is quite predictable because the behavior of the system is entirely determined by factors which interact with the system. By measuring and plotting a progression of variables over time and space, the overall behavior of the system can be modeled. Though exact outcomes of the interaction between factors at specific points in time remain unpredictable, distinguishable patterns emerge that provide information of how varying conditions affect the system. Thus, by focusing on the overall boundaries and behavior of the system, researchers are able to find a sense of order and pattern. In chaos theory, there is an inherent order in all seemingly chaotic systems.

TEXT TEXT TEXTFinally, chaotic systems are sensitive to initial conditions (Kellert, 1993). Sensitive dependence means that even a microscopic change in the factors that affect the system at the onset will produce exponential changes in the overall behavior and pattern of the system over time. This extreme dependence on original conditions provides much of the unpredictability of complex systems. Infinitely small differences result in dramatically different output. Because the differences are virtually impossible to measure, predicting the exact state of the system at any specific time becomes irresolvable. However, regardless of initial conditions, a chaotic system will display some type of order which can be modeled.

Based on these characteristics, chaos theory provides a method which allows researchers to plot the behavior of complex systems as they change over time (Handford, Davids, Bennett, & Button, 1997). Developing models enables researchers to foresee and comprehend changes in the overall behavior of that system (Gleick, 1987; Handford et al., 1997).

To create a model, each variable is plotted on its own dimensional space over time (known as "phase space" in chaos language). Each point in phase space represents a complete description of the system in one of its possible states (Kellert, 1993). By connecting the plotted points, a model or pattern of the overall behavior of the system emerges. When the pattern emerges, it is considered a strange attractor. Thus, at any moment, chaotic systems are either flowing to or temporarily maintaining an attractor state (Handford et al., 1997).

Since chaotic systems are extremely sensitive, a seemingly inconsequential change in one factor will modify the behavior of the system. Such a change is known as a bifurcation and the result is that the system will move from one attractor to another in phase space (Handford et al., 1997). A more drastic change in the behavior of the system is known as a critical point. A critical point is the point where the behavior of the system changes from increasing to decreasing (Quentmeyer, 1998). Critical points can occur with either the introduction of a new factor or drastic changes in already present factors, causing the behavior pattern to change.

Application of Chaos Theory to the Study of Sport Behavior

Adopting a chaos theory approach is not without precedent in the field of sport. Kelso and associates (Kelso, 1981; Kelso & Schoner, 1988; Scholz & Kelso, 1990) have successfully used chaos theory to study the coordination of movement patterns. Models have been developed that reveal strange attractors, bifurcations, and control parameters. Furthermore, this research strategy has made it possible to explain, predict, and experimentally test new phenomena in movement behavior (Kelso & Schoner, 1988).

How do strange attractors, phase space, and critical points relate to the field of sport psychology? It is our contention that research using a chaos theory approach will yield patterns which may provide a more functional understanding of sport behavior. The chaos scientist can define initial conditions and identify innumerable individual and environmental influences to be measured. The data would then be plotted to create a phase space or model of the dynamic system's behavior. Once established, variables that influence the system can also be identified.

In a more practical application to the field of sport psychology, the chaos perspective allows researchers the opportunity to focus on "how" instead of only "why." For example, instead of focusing on why the flow experience occurs in volleyball, researchers could examine how the experience occurs. Once the path is established, researchers are often able to foresee the variables which cause the system to display unpredictable behavior (Kellert, 1993). Thus, developing a mathematically-based model of the psychological correlates which lead to the development of flow in sport might help scientists identify the controlling variables. Perhaps the nine fundamental components of flow identified by Jackson and Csikszentmihalyi (1999) could be measured and fed into a chaos model to help us better understand and predict the experience. Similarly, the variables thought to contribute to the development of momentum could be measured and plotted, allowing researchers to identify strange attractors which lead to the development of positive or negative momentum. Additionally, the effects of time-outs and other various coaching strategies could be examined. Researchers may find that, with one timely substitution during a basketball game, coaches can create bifurcations that change the behavior and performance of the team. Substituting another player may even bring the team to a critical point where the play changes from positive to negative or from negative to positive. As such, a chaos theory perspective could examine the fourth, fifth, and sixth stages of the multidimensional model of momentum in sport (Taylor & Demick, 1994). The influence of sensitive dependence could likewise be examined. Subtle initial differences such as the composition of pre-competition meals, the interaction between teammates, or the coach's inadvertent shift of an individual's mood may drastically influence the resultant team's performance.

The chaos theory perspective would also allow sport scientists to return to the study of phenomena on a human scale by providing researchers a macroscopic approach to understanding complex systems. Individual parts of a system would no longer have to be studied in isolation because the chaos method of discovery is capable of measuring and plotting an unlimited number of variables over time. Perhaps this approach will help us better understand complex sport behavior.

Using another real-world example, sport psychology researchers could develop and test a model addressing the outcome of tennis matches. It may be that two or three simple psychological laws determine successful performance. Perhaps the simple, orderly inverted-U relationship (Yerkes & Dodson, 1908) between arousal and performance does determine the outcome. Utilizing the macroscopic chaos perspective would require a cross discipline approach of examining a multitude of variables. The phase space of potential variables such as the players' physiological arousal, cognitive state anxiety, somatic state anxiety, telic state, and paratelic state (Gould & Krane, 1992) could be plotted over time. Additionally, qualitative data assessing the athletes' perception of match importance, interpretation of anxiety, and self-confidence could be incorporated into the model. Once plotted, a pattern or strange attractor may emerge which predicts the overall behavior of athletes playing competitive tennis. Thus, while unable to predict the exact outcome at any time, sport scientists would be able to foresee and comprehend changes in the athletes' behavior. Adopting this interactional research strategy should move the sport psychology field closer to the ultimate goal of understanding, explaining, and predicting behavior.

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