Conceptualising Nonlinear Dynamic Systems for Health Psychology Research

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The application of nonlinear dynamic models and techniques to psychological research has revealed that systems behaviour often defies many commonly held assumptions about the world (Eidelson, 1997). Consideration of nonlinear dynamics systems has shown (i) that studying phenomena in isolation from their overarching context does not yield a complete understanding of the whole system (Barton, 1994) and (ii) the behaviour of systems (whether simple or complex) are frequently nonlinear and/or discontinuous (Barton, 1994; Guastello, 2002). Chaos and complexity are terms which have entered the psychological research vocabulary relatively recently. Yet, in other disciplines underlying theoretical constructs and developments have been brewing and evolving for decades.

To date, several theoretical models in health psychology that implicitly or explicitly link change with determinants of health have been developed or adopted (e.g. Janz & Becker, 1984; Madden, Scholder Ellen, & Ajzen, 1992; Ogden & Hills, in press; Prochaska & DiClement, 1984). Such models have produced a substantial body of research and knowledge on the relationships between biopsychosocial factors and health outcome. The adequacy of traditional research methods in psychology for answering the questions that they purport to answer has often been questioned (e.g. Barton, 1994; Cox, Karanika, Griffiths, & Houdmont, 2007).

The present paper explores nonlinear dynamic systems and their relevance to health research. It starts with the question why nonlinear dynamic systems should be used in health psychology research. It then moves to a delineation of some key concepts (complexity, emergence, homeostasis and self-organisation, nonlinearity and dynamics, chaos and unpredictability).

Why Nonlinear Dynamic Systems

A widely accepted view of health is the one put forward by the World Health Organisation, which defines health as “a state of complete physical, mental and social well-being and not merely the absence of disease or infirmity" (Constitution of the World Health Organization, 1946; http://www.who.int/suggestions/faq/en/index.html). A focus on both the individual and the broader family, societal or organisational system is conceptually and practically more viable than a narrow focus on the individual as the unit of analysis.

However, a dynamic, non-static understanding is inherent in such a complex perspective of health. This seems to be absent from the WHO definition. As Empt and Schiepek (2000) have noted, "nonlinear dynamics are salient in psychological change even if we are adopting a qualitative view on the phenomena" (p.677). By focusing on change, health psychology acknowledges the importance of dynamics, nonlinearity and systems. In other words, behaviour can not be looked at in the absence of its dynamic and historic framework (Galbicka, 1992; Marr, 1992). A number of established theoretical models reflect these elements.

The biopsychosocial model (Engel, 1977; Schwartz, 1982) takes a broad picture to understanding health and illness by looking at the interplay among biological, psychosocial and social aspects. This approach is also often termed holistic; in that it looks at the whole. The term 'holistic' may, however, overlook other essential aspects, such as change. The transtheoretical model of change (Prochaska & DiClement, 1984) looks at how behaviour change happens by placing emphasis on distinct stages of change. Although it has been criticised for not explaining why one moves to one stage to another (Roberts, Towell & Golding, 2001), emergent health research is now focusing on the role of critical events in sustained behaviour change (Ogden & Hills, in press). Other theoretical models, such as the health belief model (Janz & Becker, 1984), the theory of planned behaviour (Madden, Scholder Ellen, & Ajzen, 1992), are also useful for understanding how change happens.

It is argued here that there is a large volume of knowledge from nonlinear dynamics systems theory which is pertinent to the subject matter of health psychology and which can also be applied to advance theory and research. Sudden or discontinuous change, for example, is one core area of nonlinear dynamics theory, which could be easily integrated into the transtheoretical model of change to resolve controversies over why, how and when individuals move from one stage to another (see section on catastrophe below). Nonlinear dynamic systems can provide an alternative perspective to the current prevailing paradigm. This can be as successful in research as it is in practice. In healthcare management, for example, complex adaptive systems have been advocated as fresh understanding for the health care organisation and management (Plsek & Wilson, 2001).

It is important that nonlinear dynamic systems theory and methods are incorporated into health research. Implicitly or explicitly, health psychology deals with complex concepts whose relationships are often not as straightforward as traditional research approaches might allow to examine. Not only are psychosocial phenomena highly multidimensional, but they are also sensitive to a variety of external influences, interact in synergistic or inhibitory manners, have complex causal mechanisms and are dependent on both time and context (e.g. Karanika, 2006). They are neither static nor restricted to the level of the individual. They operate within an interface of the individual, group or family, wider societal context, and – most importantly– across time.

In the field of occupational health, for example, a review of state-of-the-art research on the relationships between work stressors and their health effects commissioned by the UK Health and Safety Executive (Rick, Thomson, Briner, O'Regan, & Daniels, 2002) concluded that the nature of these relationships is dynamic and nonlinear. It also brought to light the fact that only a small percentage of empirical research has explicitly examined these aspects.

With a few notable exceptions, the dominant mode of integrating nonlinear dynamic systems into psychology has been theoretical and qualitative, rather than methodological. Incongruence still seems to exist in applied psychology on the methods that are conventionally used to examine these relationships, often producing a “discontinuity between model and reality” (Barton, 1994). An over-reliance on traditional methods may further perturb theoretical developments, urging some to argue "for a more broadly conceived and eclectic framework […] that acknowledges the limitations of an applied science" (Cox, Karanika, Griffiths, & Houdmont, 2007, p.1). Wilkinson (1999) urged researchers to "recognise practices that institutionalise the thoughtless application of statistical methods" (p. 603). Although extreme, this point highlights the close relationship between theory and method, which are not always aligned in practice. It is only natural that where theory goes, research method ought to follow.

It is important that such the nonlinear dynamic systems perspective is successfully translated from health theory into research methods, design and analysis. The remainder of this discussion examines the main themes in nonlinear dynamic systems and their relevance for health psychology research, providing some examples, where available.

Complex systems

Social or human systems (e.g. organisations, families, individuals, the human brain) are viewed as complex and adaptive (Barton, 1994; Biggiero, 2001). A complex adaptive system is "a large collection of diverse parts interconnected in a hierarchical manner such that organization persists or grows over time without centralised control" (Eidelson, 1997, p.43). The term 'complex' points to the existence of a network of interactive agents and a dynamic nonlinear behaviour of the system, whereas the term 'adaptive' emphasises the nature of such systems as self-organising (Eidelson, 1997; Holland & Miller, 1991).

Human systems display all the properties of complex adaptive systems (such as nonlinear effects, interconnected but autonomous components, self-organisation or decentralised control, dynamic processes and emergence), but differ in the fact that the central element of the system exhibits self-awareness (Holland & Miller, 1991) ("the capacity of the self to think itself", Biggiero, 2001). This is reflected in psychological theories that view health as operating within a framework of the individual's interactions with environmental stimuli (e.g. the biopsychosocial model; the cognitive activation theory).

In health theory, for example, the proximate determinants framework (Mosley & Chen, 1984) specifies that there is a direction of effects between proximal (e.g. immediate influences) and distal (e.g. socioeconomic causes) determinants of health (also see Boermaa & Weir, 2005 for research on HIV/AIDS using this framework). The cognitive activation theory (Eriksen, Olff, Murison, & Ursin, 1999) defines as determinants of an individual's level of activation (1) the interaction of the individual with their environment, (2) alarm-evoking stimuli, and (3) the discrepancy between outcome expectancy and actual event. This interaction can, in turn, lead to motivation and self-regulatory behaviour that seeks to reduce the perceived discrepancy.

Whilst systems can be composed of numerous elements, the behaviour of the whole can differ from that of its constituent elements. As such, systems may have *emergent properties* that are often not describable by structural or mechanistic accounts. They can not be decomposed into their elements and properties, studied and recomposed again, as some of these properties can only exist in relation to these systems. The Gestalt assertion that the whole is more that the sum of its parts exemplifies this point (Vallacher, Read, & Nowak, 2002). A property of a system is emergent if it is possessed by its system but not by any of that system's elements (Bunge, 2004). Whether a system will exhibit emergent properties depends on a number of characteristics, including the number of elements, complexity and density of interactions (Sawyer, 2003).

An essential characteristic of human and social systems, self-organisation is defined as the process by which structure or pattern comes into being over time in a system without the influence of external control (Barton, 1994). Human behaviour "involves the action of forces to maintain, displace, or dissipate behaviour in various ways and controls possible states of equilibrium, stable or unstable" (Marr, 1992, p.249). Self-organisation is essential for system adaptation, such that the most adaptive systems are those that are most able to respond to environmental influences (Guastello, 2002). Self-organisation has been studied in cognitive psychology (memory; Carver & Scheier, 1998), clinical psychology (depression; Barton, 1994), as well as social psychology (e.g. leadership in groups, Guastello, 1998; Michaelides, 2006; Zaror & Guastello, 2000). The perspective of self-organization of behaviour has been used to study the dynamics of the anorectic processes (Empt & Schiepek, 2000). In this study, synergies between cognition, emotion and behaviour, and feedback dynamics, defined recovery from anorexia nervosa as a dynamic, self-organizing system.

Nonlinearity

Seemingly straightforward and intuitive, the term 'nonlinear' is used to describe an extremely wide multitude of relationships, effects and phenomena. Linear effects are proportional effects or simple combinations of predictors. Nonlinearity underscores the observation that effects or responses are disproportionate to their causes (Carver & Scheier, 1998). Nonlinear phenomena are non-additive, often with difficult to solve equations, and can generate more than a single outcome behaviour (Strogatz, 2003).

Nonlinearity is not something new. Carver and Scheier (1998) note that psychologists "accustomed to thinking in terms of interactions as determinants of behaviour are already accustomed to thinking in nonlinearities" (p. 253). At their simplest level, nonlinear phenomena in psychology include inverted-U hypotheses or models with interaction effects. Teachman (2006), for example, examined the dynamic relationship between ageing and negative affect (neuroticism, anxiety and depression symptoms). He uncovered a curvilinear relationship, with mean symptom levels increasing until mid-30s, declining until mid-70s and then increasing again. Other common nonlinear effects in psychology include threshold and ceiling affects (increase in a predictor has no effect on the outcome until a critical level is reached, and vice versa), indirect and interactive effects (moderated and mediated relationships), or different varieties of the generalised linear model (for example, logistic regression).

Both linear and nonlinear equations can contain parameters that are invariant over limited time intervals but that change over long time periods (Halasz, 1995). In terms of analysis, Halasz (1995) also notes that linear models can be valid in the closer local ‘neighbourhood’ of points. In addition, local interactions at the proximal individual or group level can give rise to global phenomena at the distal system level (for example, organisational culture or safety culture) – this relationship can be bidirectional.

Dynamics, Chaos, Unpredictability

Dynamics refers to the way that the state of a variable or the effect of a variable on another change; they can be linear or nonlinear. More interestingly, and in the context of nonlinear dynamics, the term is reserved to denote change in an autoregressive way, such that values of a variable depend on the previous state (and values) of that variable and subsequently influence the next state (Vallacher & Nowak, 1997). Some psychosocial variables can have immediate consequences, whereas others exert their effects in the longer term (for example, burnout and posttraumatic stress disorder), depending on the system’s ability and resources to recover from instabilities in the longer-term.

Since psychology’s early days human behaviour has been understood as being intrinsically dynamic (Nowak & Vallacher, 1998), as noted earlier. For example, the life-span perspective takes a developmental approach by considering the individual with respect to their prior history and likely future development. This is an important dimension, as it not only examines the role of different biopsychosocial factors for health and illness, but also puts these on a temporal dimension of transition, growth and development.

The trajectory of behaviour or behaviours of a dynamic system can be described in terms of its attractors. An attractor is a state towards which behaviour gravitates (Carver & Scheier, 1998). A fixed point attractor is one towards which all behaviour inevitably gravitates and leads to a stable state of equilibrium (e.g. the final state of a pendulum, death; Carver & Scheier, 1998). A limit cycle (or periodic orbit) attractor is one where behaviour oscillates between two (or more) different states (e.g. homeostatic processes, mood swings, changes in attitudes; (Abraham, Abraham, & Shaw, 1990). A more interesting type of attractor is what is known as a strange attractor, which operates under chaotic dynamics, capable of producing deterministic, yet random and unpredictable behaviour.

In models of chaotic attractors even arbitrary changes in initial conditions can produce dramatic changes in later states through repeated iterations (Carver & Scheier, 1998). Sensitive dependence on initial conditions, also called the 'butterfly effect', was termed by the meteorologist Lorenz after the popular metaphor that the flapping of the wings of a butterfly can ultimately result in a storm in a distant part of the plane. Sensitivity to initial conditions arises from the inherent dynamic properties of a system, not from randomness of impinging events, nor from a large number of degrees of freedom (Marr, 1992). Initial conditions are sometimes arbitrary starting points and behaviour can often be influenced by slight perturbations introduced at any point in time (Mandel, 1995). A familiar concept in psychology and organizational science, this phenomenon has been linked to Bandura's concept of 'sensitive dependencies', such that "the unforeseeability and branching power of fortuitous influences make the specific courses of lives neither easily predictable nor easily socially engineerable" (1994, as cited in Mandel, 1995).

One example is the work of Fredrickson and Losada (2005) who, using the broaden-and-build theory of positive emotions (Fredrickson, 1998), applied the Lorenz system to represent the dynamical relations between positivity and positive psychological and social functioning (flourishing). They envisaged that the key predictor in flourishing would be the ratio of positive to negative effect. They found that the bifurcation between flourishing and languishing is positivity to negativity ratio of 2.9, with an upper limit of 11.6. Too much positivity will be harmful but some negativity can be beneficial for the system. The study provides a dynamic temporal perspective to the theory and illustrates how principles of chaos and complexity can be used to understand affect and psychological health.

Catastrophe theory

Not all dynamic change in nature is continuous. Catastrophe theory can be used to describe and model sudden and discontinuous changes in a system's state (Brown, 1995; Stewart & Peregoy, 1983; Thom, 1975; Woodcock & Davis, 1978). There are seven elementary catastrophe models, of varying degrees of complexity. The cusp model, one of the simplest and most widely used, explains the discontinuous change between two stable states of a variable. It has one order parameter (outcome) and two control parameters (predictors): the asymmetry parameter determines the change between the two stable states, and the bifurcation parameter determines the strength and discrepancy between them (Guastello, 1995, 2002). At low bifurcation, changes between the two stable states are gradual and continuous, approximating a linear relationship. As the bifurcation increases, the impact of the asymmetry parameter on the order parameter becomes discontinuous, resembling a fold-over or S shape. As a result, at high bifurcation values the system can exhibit one of two different behaviours, depending on the asymmetry parameter.

Adopting a change process perspective, relapse in alcohol use disorders has been modelled as a cusp catastrophe (Huffort, Witkiewitz, Shields, Kodya, & Caruso, 2003). Huffort et al (2003) reasoned that nonlinear dynamic approaches could better capture the complexity of the relapse process than the traditional linear models. Cusp catastrophe models have also been used to explain exposure and accidents in health care workers involving blood-borne pathogens (Guastello, Gershon, & Murphy, 1999). Similarly, catastrophe theory has been applied to understanding expectancies, formation and dissolution (Carver & Scheier, 1998), motivation (Guastello, 1987), learned helplessness, and schizophrenia (Woodcock & Davis, 1978).

A note on methodology

Although linear methods have been described as the cornerstone of statistical methods, they can not always account for what happens in psychosocial systems (Barton, 1994). The use and application of complex systems, nonlinear dynamics, self-organisation, and catastrophe theory has generated a lot of interest in the social sciences in general and in psychology in particular (see Eidelson, 1997; Guastello, 2002; Schuldberg, 2002; Vallacher, Read, & Nowak, 2002). So far, however, and whilst these concepts are intrinsically incorporated in our repertoire of theories, their methods have not been fully exploited in health psychology and cognate areas. Philippe (2000), for example, argues for the acknowledgement of the potential of nonlinear dynamics for epidemiological research. Similarly, Albrecht, Freeman & Higgibotham (1998) argue for complexity theory as a powerful unifying construct for the development of interdisciplinary health research.

The theoretical and methods framework of nonlinear dynamics can be used either (a) in a qualitative, heuristic or metaphorical way, or (b) computationally by applying mathematical equations (Barton, 1994; Guastello, 2002). However, and perhaps due to the fact that nonlinear dynamic methods are remarkably heterogeneous, one of the main difficulties with this paradigm is the confusion of concepts and techniques, which can, in turn, lead to confusion over how to test hypotheses (Barton, 1994). Strogatz (2003) reports that “the mathematician Stanislaw Ulam once said that calling a problem nonlinear was like going to the zoo and talking about all the interesting non-elephant animals you see there” (p. 181). Nonlinear dynamic systems can be examined by using qualitative methods, statistical modelling or simulation (see Gilbert & Troitzsch, 2005; Smith & Conrey, 2007). Although there is agreement that the conventional experimental design is ill-adapted to nonlinear dynamic theory (Halasz, 1995), it is also unclear what a nonlinear dynamics toolbox for the social sciences should consist of. Mandel’s (1995) observation that nonlinear dynamic techniques specifically adapted for the social sciences “are currently scarce and may prove difficult to apply and interpret” (p. 107) is no longer the case. It should be noted that a division between linear and nonlinear approaches is unproductive. Both dynamical and static and also linear and nonlinear models can be viewed as complementary rather than as incompatible paradigms (Mandel, 1995).

The potential of nonlinear dynamics for the development of theory and the cross-fertilisation of methods is exciting. In the area of well-being at work, the availability of advanced methods has already stimulated the re-examination of established theories (e.g. Elsass & Veiga, 1997; Fletcher & Jones, 1993; Jones, Bright, Searle, & Cooper, 1998; van Veldhoven, Taris, de Jonge, & Broersen, 2005). Adoption and adaptation of appropriate methods could help unravel the ‘endemic complexity’ of psychosocial variables (Mitchell, 2004) and of human physical and psychosocial health.

Conclusion

It was argued in this paper that health psychology can benefit from an explicit adoption of nonlinear dynamic systems. Complexity, change and nonlinearity are often integral to psychological phenomena and can make significant demands on research. Viewing health within a complex adaptive systems framework is important for interpretation and causality, measurement and modelling, as well as for developing theory. Examination of snapshots of behaviour or omission of possible nonlinear effects can lead to inaccurate or incomplete models of psychosocial phenomena, often leading to what Kasl (1978; as cited in Hochwarter, 2004) termed the ‘triviality trap’. Nonlinear dynamic systems perspectives in research are best placed to help meet these challenges of creating simple, parsimonious models that can explain complex behaviours (Nowak, 2004). The explicit use of nonlinear dynamic systems theory and methods can provide a fertile future for health psychology research.

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