IT'S A FUNCTION OF TIME: A REVIEW OF THE PROCESS APPROACH TO BEHAVIORAL MEDICINE RESEARCH[1,2]

Kirk W. Brown, Ph.D. and D.S. Moskowitz, Ph.D.
McGill University

ABSTRACT

In many fields of science, phenomena are studied closely over time to make inferences about patterns of behavior and to allow for predictions of future change and stability. In behavioral medicine, traditional cross-sectional and longitudinal designs are useful for capturing highly stable or slowly-changing phenomena, but important behavior change can be missed by one-occasion measures or infrequent measurements taken at widely-spaced points in time. We review recent research showing how a more complete understanding of many forms of psychological and somatic phenomena can be achieved through intensive measurement within the temporal context in which behavior occurs. This "process approach" to research, conducted in both naturalistic and laboratory settings, is presented here and placed in a methodological and theoretical framework. We also attempt to make recent research on the non-linear dynamics of behavior more accessible by describing and illustrating the uses of time in behavioral medicine research.

(**Ann Behav Med** 1998, *20*(2):109–117)

INTRODUCTION

When something inert is set in motion, it will gradually come to life (1).

Albert Einstein's theory of relativity posited that space and time form a continuum—that space can be understood only in the context of time. In behavioral medicine, as in other branches of psychology, the examination of phenomena within the context of time has traditionally been more limited than in other domains of science. Cross-sectional and longitudinal designs virtually define the field's methodology. These designs are important for capturing generally static or slowly-changing phenomena, but important change in behavior can be missed by one-occasion measures or infrequent measurements taken at widely-spaced points in time. It is our contention that many forms of health behavior can be more fully understood when they are explored within the temporal context in which they occur. We provide an introductory review of the methodology and theory behind the "process approach" to health research with the intent to create a bridge from traditional linear-based approaches to recent dynamic systems views. Recent health research flowing from the process approach is also reviewed. On the basis of this research, we hope to demonstrate that a behavior–time continuum exists: behavior is inherently mobile, perpetually in motion over time, and a clearer understanding of mind–body processes can be gained by observing the unfolding of behavior in time.

TRADITIONAL RESEARCH APPROACHES: CROSS-SECTIONAL AND LONGITUDINAL DESIGNS

For many years, a dominant form of measurement in behavioral medicine has consisted of carefully constructed questionnaires designed to be administered on a single occasion. The Ways of Coping Checklist (WOC) (2), the Brief Symptom Inventory (BSI) (3), and the Profile of Mood States (POMS) (4) are but several examples. Individuals' responses on these measures provide descriptions about what they are like in general or over some specified period of time on a selected dimension or dimensions. These measures have considerable utility for the prediction of both health behavior and physical health and illness, especially over longer periods of time (weeks, months, or years).

These typically retrospective measures are assumed to tap characteristic(s) that, although measured at a particular point in time, exist in similar form across time. Alternatively, variability may be acknowledged but considered unimportant, and the respondent may be asked to mentally average his/her experience. Many of the most widely-used questionnaires have demonstrated high levels of test–retest reliability. Thus, when a scale requests a report on, for example, physical symptoms experienced over the past week or month, it is tacitly assumed that the responses derived represent a relatively stable, unchanging historical experience, not just the individual's experience at the time the report was made. When psychological characteristics such as personality traits are measured, the resulting scores are also assumed to hold in the future, given the widespread belief in the stability of traits. In either case, scores obtained at one point in time are assumed to be reliable measures of the variables of interest. Thus, one-occasion assessment relies upon an assumption of temporal stability, regardless of whether the behavior measured is *theoretically* understood to be stable or variable.[3]

However, this assumption can be questioned to the extent that individuals are not like their self-descriptions in every situation or even across broad classes of situations. Such intraindividual

[1] Preparation of this manuscript was supported in part by the National Cancer Institute of Canada with funds from the Canadian Cancer Society to the first author and by grants from the Social Sciences and Humanities Research Council of Canada and Fonds pour la Formation de Chercheurs et l'Aide à la Récherche du Québec to the second author.

[2] Comments by Irv Binik, Morton Mendelson, Dana Bovbjerg, and two anonymous reviewers resulted in substantial improvements to this article.

Reprint Address: D. S. Moskowitz, Ph.D., Department of Psychology, McGill University, 1205 Dr. Penfield Avenue, Montreal, Quebec, H3A 1B1, Canada.

[3] As pointed out by an anonymous reviewer, one-occasion measurement is also appropriate when the focus is on the relation between variables at a specific point in time. This points to another major use of one-occasion measurement. Relations between variables may be stable even when the characteristics themselves are variable over time. However, as we argue later, relations between variables may become further clarified when considered in the context of their joint fluctuation over time.

variability has been demonstrated by a number of studies that have conducted repeated sampling of behavior. For example, in contrast to the picture of coping assumed by one-occasion measures of coping style, studies of coping process have revealed a marked degree of variability in coping efforts across diverse stressful encounters (5–7). Folkman, Lazarus, Gruen, and DeLongis (8) found that three predominant forms of coping—confrontive, seeking social support, and planful problem-solving—exhibited very low autocorrelations across a six-month period.[4]

Few would question the fact that psychological and physical indices are subject to fluctuations brought about by psychological, social, environmental, and other influences. However, in practical terms, these fluctuations have, until relatively recently, been difficult to measure systematically. As such, variability in the expression of behavior has often been treated as error, and the assumption of psychological and physical stasis, over either short or longer periods of time, is tacitly relied upon in many clinical and research endeavors.

A second assumption upon which one-occasion, retrospective measures are based is that when individuals are asked to reflect back upon their physical or psychological experience, their answers will be reasonably accurate. The validity of this assumption can also be questioned. There are inherent limitations to human memory in accurately describing past experience (9,10), and such limitations have been demonstrated in health research (11,12). Retrospective reports require individuals to estimate, aggregate, and perform relatively complex information manipulations. Thus, such reports are subject to a number of sources of error, including memory decay, the salience of events, retrospective reconstructions, current psychological states, and idiosyncratic anchor events that undermine the validity of the data obtained (13).

Incorporating time into research designs enables a researcher to address a concern that is important in many areas of psychology: whether, and how, a characteristic will demonstrate stability and change over time. Time can be used in several ways: First, measurement can be conducted regularly or systematically over time spans of interest—over a week, a month, or a year, for example. Second, measurement can be conducted within or across developmental periods of interest, such as adolescence or senescence. Third, time can be used by manipulating the spacing between measurement intervals, such as by taking measurements more frequently during periods where rapid change is expected, such as during infancy, and less frequently during periods where change is expected to be relatively slower, such as during middle adulthood.

The incorporation of time into methodological designs is not new in behavioral medicine. Research employing longitudinal designs has contributed significantly to current thinking in a number of domains, including the course of diseases, the effects of psychosocial intervention on major illnesses, and long-term personality–health interactions. Traditionally, however, this time-based research has used only a few measurement points and intermeasurement intervals spanning fairly long periods, of a month or more, or even across developmental periods, such as middle childhood and adolescence, in the search for stability and change.

There appear to be implicit expectations about the characteristics of the phenomena examined in traditional longitudinal research. The phenomena are expected to change slowly enough to be tracked adequately with long intermeasurement intervals. Also, change is often expected to be permanent or unidirectional, rather than ongoing or repeated. Generally, the analysis of change in longitudinal research has been restricted to linear or simple nonlinear methods, such as trend analysis, and more sophisticated approaches, including the various time-series analyses, functional data analysis (14), and other strategies designed to examine nonlinear dynamics are infrequently used. The General Linear Model, widely used by psychologists, assumes linearity in the data and is very limited in its ability to handle curvilinear or non-proportional relations. As a result, nonlinear change has been neglected.

In sum, longitudinal studies are suitable for characteristics that change slowly, permanently, or steadily and linearly. However, time is also a factor in phenomena that change rapidly, repeatedly, or nonlinearly. Further, such change may be embedded in apparently slowly-changing or linearly-progressive phenomena. The picture of stable and linear change provided by measures collected at widely-spaced intervals can mask the dynamics inherent in behavior.

CAPTURING THE RUNNING STREAM OF BEHAVIOR

In behavioral medicine and other domains, expanded longitudinal studies have recently begun to measure behavior intensively over time in an attempt to overcome the limitations of both kinds of traditional designs discussed above. This new research, which follows a process approach (15,16) to methodological design, has minimized the difficulties associated with one-occasion, retrospective measures by collecting data on behavior as it occurs in laboratory or natural situations. By expanding the longitudinal design to include many measurements, or samples of behavior, researchers can study stability and change in psychological and physical processes more closely and carefully. This approach has also begun to shed new light on a number of biopsychosocial phenomena, because the focus of research broadens to include process, or the dynamics of behavior over time, as well as its structure or form. This methodological approach provides a frame-by-frame motion picture of behavior (13), rather than snapshots at a single time or at widely-spaced time points.

The methodological difference between cross-sectional, traditional longitudinal, and extended longitudinal or process approaches can be illustrated with an example. Figure 1 displays physical symptom data for two participants from a daily sampling study (17), in which data were collected multiple times per day for 20 days. Both participants had approximately the same mean level of symptom intensity over 20 days. Thus, if a one-occasion retrospective measure had been used to tap the level of symptoms over the past three weeks, both individuals would have had similar scores, assuming, of course, that they would have been able to reconstruct their experience accurately. The dot-connected lines in both parts of Figure 1 represent the three scores that would have been obtained if a measure of symptoms had been administered once a week for three weeks. Unlike the one-occasion assessment, this traditional longitudinal approach would have differentiated the two individuals. While person A's level of symptomology held generally steady over the three time points, person B's increased in intensity.

The process approach also differentiated between the two sets of data, but in much greater detail than the traditional longitudinal approach. First, A's symptomology fluctuated over the entire course of the study period; B began the study with no symptoms

[4]An autocorrelation is the correlation of a variable with itself, where the variable has been measured at multiple points in time. When the score on a variable changes relatively little across time (i.e. the score is highly stable), the autocorrelation will be high. When the score on the variable changes more substantially (i.e. it is highly variable from one measurement occasion to another), the autocorrelation will be low.

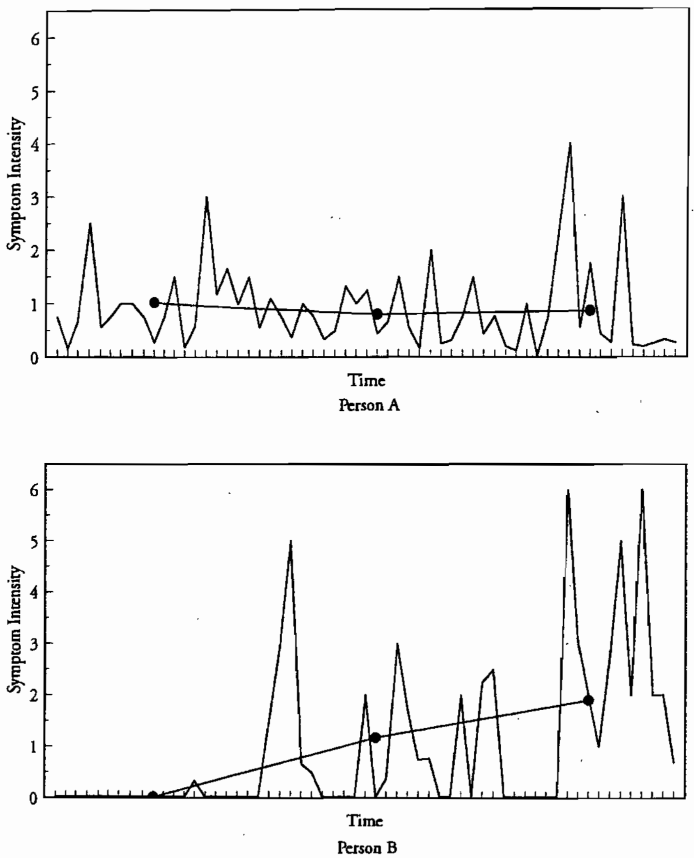

FIGURE 1: Physical symptom data over 20 days for two daily sampling study participants.

and later experienced them with varying levels of intensity. Second, A had only very brief periods of symptom-free experience, while B had symptoms in bouts, interspersed with periods of health. Finally, the intensity of A's symptoms was comparatively low over the three weeks, while B experienced periods of intense symptomology.

Such detailed pictures of behavior over time have proven to be highly valuable in a number of domains for a variety of purposes. If, for example, the data displayed in Figure 1 represented the experience of pain in two different patients, medication such as morphine could be administered more effectively using detailed knowledge of the dynamics of the experience over time. A's symptoms could be dealt with using a relatively low but steady dose of medication, while B could be administered higher doses only at selected points in time. In fact, it is due, in part, to a recognition of the differential experience of pain over time from person to person that has led some to advocate for patient-controlled analgesic administration (18). If the differential pain experiences of A and B were linked to particular affective states, such as anger or anxiety, psychological intervention efforts could be fine-tuned to more effectively serve the needs of each individual.

Typically, one-occasion measures, whether used in cross-sectional or traditional longitudinal designs, are not amenable to data collection at a detailed level, even if memory decay and distortions were not problematic. Also, as the manipulation of the data in the example illustrates, scores on behaviors measured intensively over time can be summarized into single scores or a small set thereof. Data summarized in this fashion would still have

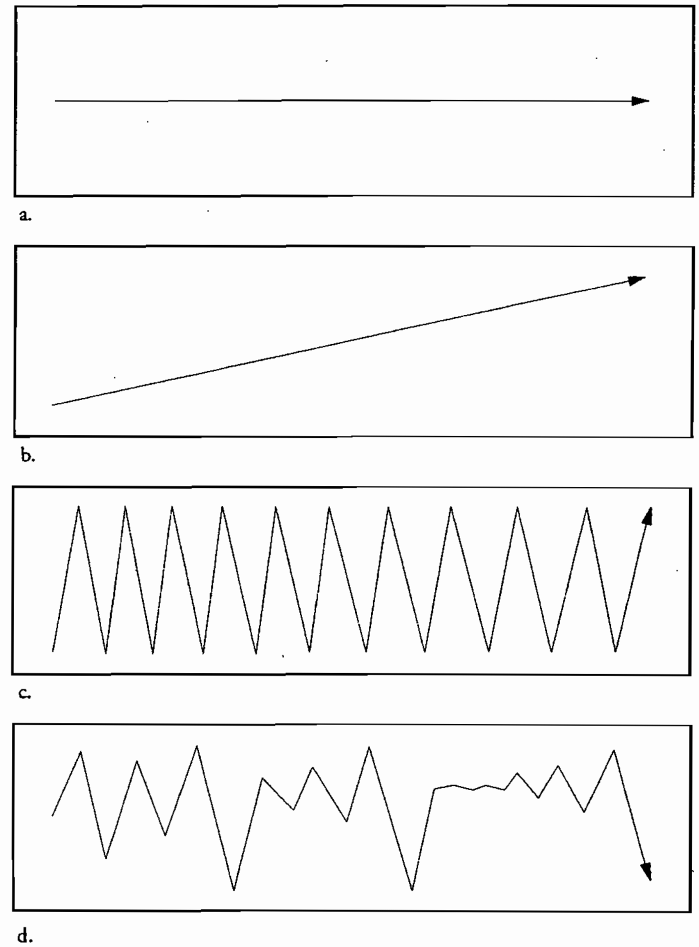

FIGURE 2: Time series graphical representations of four types of behavior patterns: (a) static–linear; (b) linear–dynamic; (c) nonlinear–dynamic (limit cycle); (d) nonlinear–dynamic (non-periodic or chaotic pattern).

the advantage of being relatively free from retrospective biases, and this strategy has been used to good advantage in process research (19). However, we will show in this paper that retention of the time-embedded information available through extended longitudinal research can be important both for clinical decision-making and to aid the theoretical understanding of phenomena under study.

CLASSIFYING THE DYNAMICS OF BEHAVIOR

Behavior or systems can be categorized along two primary dimensions: static versus dynamic and linear versus nonlinear (20). Static behaviors or systems are treated independently of time, and equilibrium is assumed. In contrast, dynamic behaviors or systems are time-dependent, and the state of a system at any given moment is at least partially a function of what has taken place at earlier points in time. In linear systems, behavior can be generally represented by a straight line, while in nonlinear systems behavior is represented by some form of curved or spiked line.

In practice, these dimensions operate together as, for example, linear–static systems (e.g. zero-slope line); linear–dynamic systems (e.g. non-zero-slope line); or nonlinear–dynamic systems (e.g. sine-wave or chaotic patterns). Figure 2 displays the possible combinations. Static–linear and linear–dynamic systems are also called steady-states, which indicate stable homeostatic processes. In nonlinear dynamics, sine-wave patterns are also called periodic patterns or limit cycles (e.g. 7-day mood cycles, [21]; weekly interpersonal behavior cycles, [22]). Chaotic patterns are also termed aperiodic (e.g. healthy heart rhythms) (23).

Figure 2 presents idealized steady-state and periodic patterns, but in actuality some noise or randomness is common in such patterns. While irregular phases in these patterns may occur, there is always a return to a baseline steady-state or cycle. On the other hand, unstable chaotic processes have no baseline or normal state, and transitions or changes in the pattern are never exactly repeated (24). Even in chaotic processes, however, an underlying order or self-organization is evident, and thus they do not represent randomness. In living systems, limit cycles and chaotic processes are encountered much more commonly than steady-states, which appear to be quite rare (25).

THEORETICAL TENETS ARISING FROM THE PROCESS APPROACH

There is currently a great deal of interest, in psychology and a number of other fields, in Chaos Theory, a branch of nonlinear dynamics that focuses upon chaotic or non-periodic processes and phenomena (26,27). Other theoretical frameworks embedding the time series approach and exploring nonlinear dynamic phenomena include the Complexity Theory (28) and the General System Theory (29). It is only comparatively recently that psychology has begun to explore such phenomena, but work that has been done both within and outside the field has discovered common theoretical underpinnings which cut across the entire spectrum of nonlinear dynamic phenomena.

First, behavior is frequently "more than a line" in nature. Over time and circumstances, behavior of many different kinds appears to be in a perpetual process of fluctuation and change. Process research in psychology and elsewhere has suggested that non-linearity is so ubiquitous that, to use an analogy from zoology, to study it is like studying all animals that are not elephants. Indeed, some authors have concluded from observation of behavior in both clinical and social contexts that process and change is more fundamental than stasis and structure (30,31).

The second theoretical tenet that has arisen from the study of psychological phenomena over time is that they have a transactional nature; persons, behaviors, and events interact over time, sometimes in complex ways. Interaction over time can be explored in terms of, for example, concurrence, lead/lag relations between variables, and the relation of behavior to predisposing characteristics. By way of illustration, Brown and Moskowitz (17) conducted a time-sampling study in which participants reported affective and symptom experiences multiple times per day for 20 days. Unpleasant affect bore both a significant concurrent and temporal (i.e. lagged) relation to symptoms within days, such that higher levels of unpleasant affect predicted a greater frequency of various kinds of illness symptoms later in the day. Similarly, Stone, Neale, Cox, Napoli, Valdimarsdottir, and Kennedy-Moore (32) found that on a day-to-day basis, reporting more desirable life events was related to more sIgA antibody (a front-line component of immune defense found in saliva), and reporting more undesirable events was related to less sIgA antibody. Desirable events also predicted positive effects on sIgA levels one and two days later, suggesting a temporal link between these variables in daily life.

The study of interaction, or interrelation, allows for the elucidation of the systemic properties of different forms of behavior. This approach is a marked shift away from the reductionist stance that has dominated science in the past. When behavior is shown to vary in relation to other behaviors or events, one can speak of "behavioral systems," of behavior as part of, influencing, and being influenced by, an interactive complex of behaviors and events. For example, blood pressure is influenced by a variety of somatic and psychological events, including posture, blood lipid levels, and states such as anxiety and mood. It is also affected, indirectly, by events in the social and physical environment.

One of the primary advantages to temporal measurement is the ability to explore the situational or contextual correlates and determinants of health behavior and somatic processes. In essence, this capacity shifts a basic question about human behavior from "Will the person's behavior be the same under changing circumstances?" to "Under which circumstances will the person's behavior be the same (or different)?" The work of Riedbord and Redington (33–35) has explored how heart rate trajectories differ according to different cognitive and emotional circumstances arising during psychotherapy. Wood, Magnello, and Sharpe (36) have shown how energy levels systematically fluctuate over the day among patients with chronic fatigue syndrome. This kind of work is important for several reasons. It helps to determine to what extent behavior reflects stable characteristics rather than states. It helps to pinpoint important temporal antecedents of physical or psychological events. It can shed light on the adaptive (or maladaptive) significance of behavior in terms of the context in which it is expressed. Finally, it can serve as a guide to health behavior interventions.

One way that the dynamics of behavior can be understood in methodological terms, both when single and multiple variables are of interest, is through the incorporation of "phase" into measurement protocols, along with the traditional measurement of "state." Phase reflects time-related change in the magnitude or intensity of expression, rate of occurrence, duration, or form or behavior, whereas state reflects a particular value or score obtained at a particular time (37). Figure 3 shows the time course of a hypothetical variable for three individuals.

When measured at a single point (time = 10 in Figure 3), all three persons display the same level on the variable. Historically, however, each person has arrived at that point on a different trajectory. Person A is measured in the midst of a slow decline on the variable; Person B is assessed in the middle of a rapid increase over time; and Person C's behavior is observed during a period of stasis.

The study of phase is important because it captures the nonlinear, sometimes unpredictable, and discontinuous nature of change that is common in behavior. Prediction of the future time course of behavior and the interactive nature of different phenomena can thereby be enhanced. The patterns displayed in Figure 3 illustrate that knowing a person's score on a behavior at one time point is necessary but insufficient to predict that person's score at subsequent points. Predictive ability will be enhanced to the extent that the rate and direction of change of a variable is known (38).

Interactions between variables can be elucidated through time-based measurement when, for example, the occurrence of a behavior is related to an increase or decrease in another behavior. To illustrate, the occurrence of physical symptoms may be related to a large increase in, or a lengthy duration of, unpleasant affect (cf. 39). The measurement of affective state only at time point 10 in Figure 3 would offer little, if any, information on the nature of this temporal interaction. If a large increase in unpleasant affect were related to the occurrence of symptoms, measurement over time would suggest that Person B would be more likely than the others to show a significant link between the two variables.

Measurement at a single time point can demonstrate that when, for example, the frequency or intensity of one variable is high, the score on another variable is also high. However, such concurrent correlational findings have limited descriptive and predictive utility when scores on the variables of interest change over time and situations. A nonlinear relation occurs when an increase in X, for example, does not necessarily correlate with a proportional increase or decrease in Y. In this respect, Goerner (40) notes that taking ten aspirin does not soothe a headache ten times as much as taking one aspirin. There may be important factors contributing to the strength of the relation between two variables which depend on: (a) ceiling effects (as in the aspirin example); (b) the chronicity or duration of the behaviors or events in question, such that one variable, like stress, influences another, like immune functioning, only after it has persisted for a period of time; (c) the direction of change occurring when the measurement is collected, such as when one variable (e.g. alcohol consumption) influences another (e.g. smoking) in one way when it is increasing and in another way when it is decreasing; or (d) threshold effects, as when an event or behavior of high intensity (e.g. depression) affects other variables (e.g. body weight), but not when it is of low intensity.

The nature of measurement becomes particularly important when interest is in causal relations. As West and Hepworth (41) point out, most psychologists would, in their heart of hearts, like to demonstrate causality. However, many conceptions of causality minimally imply temporal precedence (42,43). Terms like "predictor" and "influence" cannot be used correctly without temporal measurement. Discoveries of such important phenomena as feedback loops in cardiovascular reactivity (44), bidirectional causality between the immune and central nervous systems (45), and "dynamical disease" (27,46) have been based upon demonstrations of temporal precedence and influence.

It is clear that a shift from the search for stasis and constancy to an exploration of change and variability represents a fundamental shift in both our thinking about behavior and in how research projects are designed (25). Combs (15, p. 131) has called this a change from the "logic of stones" to the "logic of water." Arguably, process and change are the natural subject matter of psychology, which embraces such inherently fluid phenomena as thought, emotion, memory, perception, and somatic events (15,47).

COMBINING IDIOGRAPHIC AND NOMOTHETIC APPROACHES

The process approach to measurement is both idiographic and nomothetic in nature. Time-based research is inherently idiographic, as it involves measurement of the behavior of single individuals over time. Nomothetic analysis is then often used in such research to compare the behavior of groups of individuals. This combinatorial strategy comes from the recognition that while group averages can smooth out real individual change over time (48), an exclusive focus on individuals provides no information on behavioral generality among groups. Designs of this nature specifically incorporate the temporal dimension in a two-step procedure: first, each case or individual is assessed or sampled separately over enough time to ascertain some form of temporal patterning; the rate of sampling should vary directly with the expected rate of change of the behavior(s) in question (38). For example, a detailed *in vivo* exploration of the mind/body dynamics involved in cardiovascular reactivity may require many measures to be taken throughout the day, given the relatively high sensitivity of the cardiovascular system to affective, physical, and environmental events (49). A study of change in chronic pain experience could

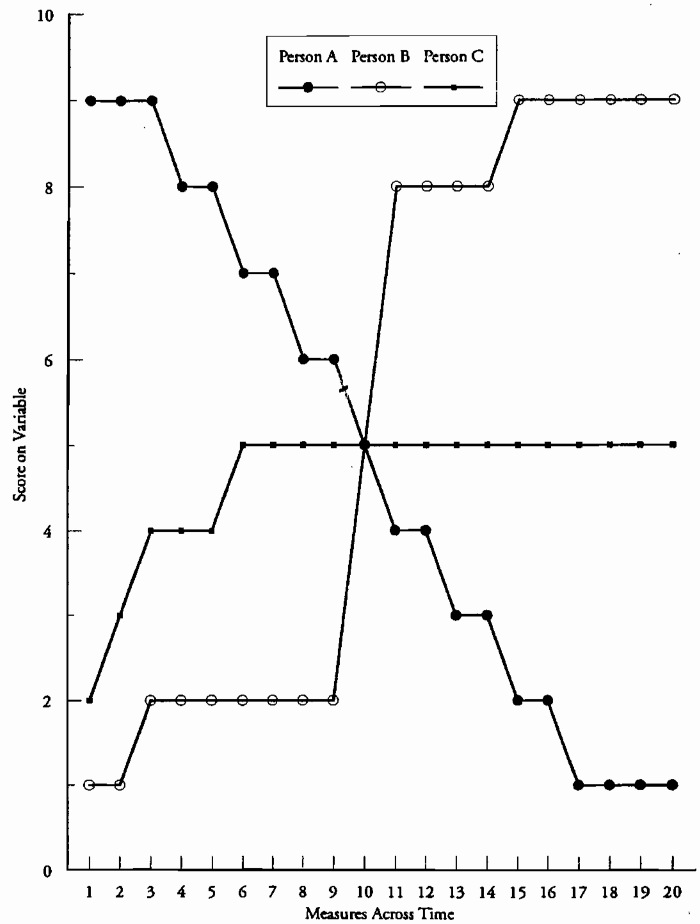

FIGURE 3: Three different behavior trajectories plotted over time. Adapted from Haynes, Blaine, and Meyer (1995).

sample behavior less frequently, given that the rate of change in this variable is likely to be slower (50).

In the second step, an estimate of the degree to which each individual exhibits the temporal pattern in question is used as a variable for comparison and contrast across individuals. The form that such a variable takes will depend on the analytic strategy chosen. Data aggregated over time may be placed in a summary measure, such as a mean, or a within-subject standard deviation or variance. However, time-series and nonlinear dynamic analyses typically keep the data in its original temporal form, such that each individual's data enters analysis with the number of data points (e.g. 50, 100, 1,000) equal to the number of measures originally taken over the course of the study.[5]

The process approach adds a third dimension to the traditional persons × variables procedure typically employed in nomothetic

[5]While statistical approaches to time series data are not discussed here, a number of excellent sources are available. An extensive and practical discussion of various forms of analyses based on both aggregated and time series data in psychology is provided by West and Hepworth (41). Gottman (51) and Bowerman and O'Connell (52) present and illustrate a range of time series analyses. Jaccard and Wan (53) discuss various approaches to the analysis of time-embedded behavioral medicine data. Explorations and explanations of the spectrum of nonlinear dynamic (including chaotic) phenomena are found in Abraham and Gilgen (26), Glass and Mackey (27), and Vallacher and Nowak (54), among others. Major computer-based statistical packages (SAS, SPSS, BMDP, S-PLUS, and others) support a range of analyses utilizing temporal data.

research—that dimension is time. Any phenomenon that changes over time is amenable to study using this approach, whether the change reflects development, adaptation, adjustment, regulation, rhythm, learning, or any of the various forms of intervariable temporal covariation (16). For example, Levor, Cohen, Naliboff, McArthur, and Heuser (55) used a daily self-monitoring methodology to study the temporal influence of stress, emotional arousal, and physical activity on migraine headache cycles. Significant elevations of stressful events were found over the four days leading up to and including a migraine day, while physical activity declined over the same period. The inclusion of time in research permits not only the study of temporal patterning and interactions between variables at the group or nomothetic level, but also the idiographic study of individual differences in patterns and interactions. For example, in a daily self-monitoring study of blood glucose levels (BGLs) among diabetic patients, Halford, Cuddihy, and Mortimer (56) found wide individual differences in the strength and direction of daily stress–BGL relations. This interindividual variability would have been missed had the data been aggregated across cases beforehand or had the variables been measured cross-sectionally.

In the study of any complex phenomenon, a trade-off is often made between detailed exploration of a small number of individuals and general description of a larger group. The idiographic–nomothetic approach helps to meet a long-standing challenge in behavior research: to bridge the gap between microscopic and macroscopic levels of description and explanation.

The collection of temporal data takes two general forms: measurement by an experimenter and self-report. Experimenter measurement is well-known; laboratory recording of, for example, various physiological responses and coding of overt behavior from direct observation or videotape have been done extensively for years. Self-report has also been used extensively for such activities as behavioral monitoring in therapy (57), but it is only quite recently that this methodology has been used in the service of research exploring temporal phenomena. Several major self-report approaches are used which differ primarily in the way that the sampling of the variable(s) of interest takes over time. Collectively called Ecological Momentary Assessment (EMA), these various self-report strategies have been described in detail elsewhere (10,58,59).

RECENT RESEARCH: THE NONLINEAR DYNAMICS OF HEALTH AND PSYCHOPHYSIOLOGY

Research in human biology has a long history of treating time as a key variable. Many biological cycles in, for example, diurnal body temperature, immunological functioning, and hormonal levels are well-known, and research into somatic rhythms of various kinds, their effects on behavior, and implications for medical treatment continues to be very active. The formalization of fundamental concepts in nonlinear dynamics and applied to behavioral medicine, such as homeostasis, limit cycles, and positive and negative feedback loops owes much to research charting the dynamics of biological phenomena.

Study of the process nature of behavior has been taken up by a number of health researchers in recent years, particularly by those using ecological or ambulatory methodologies for the exploration of *in vivo* behavior. It has been taken up by investigators who collectively represent a broad band of interests in health psychology and behavioral medicine, including but not limited to the following: coping processes (60–62); menstrual–mood cycles and premenstrual affective change (63–66); ambulatory blood pressure variability and its psychosocial links (49,67,68); day-to-day emotion–body dynamics (17,69–71); the day-to-day experience of chronic pain (51,72); psychoneuroimmunologic processes in both medical and non-medical populations (32,73,74); and psychological stress and somatic events (19,55,56,75).

Process research has shown that psychological and somatic states are highly variable over time both within and across persons, often rhythmic, and influenced, on an ongoing basis, by both inner and social and environmental circumstances. A clearer understanding of the temporal and situational specificity of behavior has been acquired by this research. It has also improved the precision of causal inferences. Finally, it has pointed to improvements that could be made in clinical decision-making. For example, blood pressure research has shown that ambulatory measures are better predictors of clinically-significant events such as organ damage or cardiac arrest than one-occasion pressure readings (see 76 for review).

PROBLEMS AND POSSIBILITIES IN THE PROCESS APPROACH AND PROCESS RESEARCH

Issues Pertaining to the Process Approach

There are several problems and challenges unique to process measurement. While frequent observational or laboratory measurement or self-report of behavior in natural settings are generally technically feasible, in some cases the number of data points necessary to identify reliable temporal patterns may be extensive and intrusive for the participant (77). Also, the frequency and accuracy of self-report measurement requires the use of participants with relatively high levels of motivation, good self-awareness skills, and sometimes the ability to create prompts to self-rate (77,78). For some individuals—for example, those experiencing the stress of a serious illness such as cancer—the requirements of regular sampling may be too great a mental responsibility to bear.

While studies conducted in natural settings serve to enhance ecological validity, it is possible that the intensive self-monitoring required of daily study participants may disrupt the ecology of daily experience and thereby threaten the external validity of findings (72). Thus far, the potentially disruptive aspect of intensive time-sampling has not been explored. Other problems associated with participant burden have also been discussed, such as attrition and the role of incentives (78).

Many of these problems have been shown to be surmountable, however, and many research studies employing frequent self-ratings have reported high rates of both compliance with protocols and study completion. Recent research in behavioral medicine has attempted to capitalize on the advantages of real-world methods while sidestepping the need for extensive self-reports, exemplified by studies collecting daily measures of cardiovascular responsivity through ambulatory blood pressure monitors (49).

As discussed above, temporal measurement allows for the exploration of the situational contexts of psychological and physical events and processes. However, an exclusive focus upon contextual links with behavior may encourage the view that human behavior is at the mercy of the situations and circumstances in which people find themselves (79). Exploration of the role of traits or goals, situational intentions, and other motivational variables may help to identify how contextual variables are construed by the person and thereby help to identify stable relations between behavior and the environment (cf. 19,80).

Process designs typically focus upon one or at most a small set of behaviors. Because most studies of this nature collect many repeated measures of behavior, it is not possible to cast a broad net of measurement, as is often done in one-occasion or traditional longitudinal designs. Thus, process research usually seeks to understand a limited number of behaviors or phenomena (and their interactions) in great detail, rather than many behaviors in general ways. Which approach is most suitable will depend on the goals of the research, and of course, the two approaches can be combined. Questionnaire measures can be given at briefing sessions before laboratory or ecological assessment is done or afterwards, before debriefing. Traditional longitudinal designs can also incorporate intensive sampling into periods between traditional measurement points. The combination of both static and process measurement permits the collection of data on behaviors that can be expected to change little over time, along with those that may change more rapidly, and allows for an examination of the interaction between them. Studies of the predictive effects of personality traits upon day-to-day coping behavior (61) and physical health (17) have employed this combination of approaches.

Issues Pertaining to Empirical Process Research

The rise to prominence of ambulatory research designs has greatly facilitated the study of the normal workings of dynamic health phenomena. Such phenomena may best be studied in natural settings for two reasons: first, artificial time intervals are not imposed, as they often are in the laboratory where some event or change is typically sought within a short period of time. The imposition of a deadline raises the question as to whether the process or interaction observed (or not observed) would have occurred or occurred the same way in the natural world. Second, in the natural world, no treatments are imposed, leaving behavior to unfold as it normally does. In the laboratory, the imposition of a treatment may distort or reconstruct the chronological ordering of an interactive sequence between two or more variables. For example, when treatment X is applied and outcome Y is sought, a natural reverse ordering or bicausal relation between X and Y may be missed (42).

Process designs also open up possibilities for innovative data analysis and theory testing and construction, particularly when data in their original time-serial form are analyzed and interpreted. However, it is relatively common for process researchers to aggregate data. Such aggregation into single or a small number of values introduces theoretical and statistical problems. As Jaccard and Wan (53) describe, collapsing data into mean values ignores the rich data base available from laboratory or *in vivo* measurement; aggregation implicitly assumes, as with one-occasion measurement, that the variables manifest a constant level of frequency or intensity across conditions or situations. Thus, nonlinear behavior patterns cannot be explored. Second, when a treatment is involved, aggregation ignores the possibility that the treatment might have effects on a variable under some conditions but not others (e.g. at work but not at home). Third, averaging of scores across individuals into single group scores can introduce aggregation bias, in which group analyses yield conclusions that are misleading about the individuals composing the group. This can happen when there is substantial interindividual variability in the expression of a variable over time or when interindividual variability in independent–dependent variable relations is possible.

While the dynamics of behavior and general relations between different behaviors are best studied when data are analyzed in their original temporal form, splitting of the data into subsets can serve to highlight special features of the data or contingent relations between variables. For example, if interest were in establishing whether behavior manifests differently in home versus work versus recreational contexts, data could be grouped and analyzed according to the location where it was collected or observed. If there were multiple data points in each of these contexts, data could still be analyzed at an individual level and then used for interindividual comparison or group analysis (81).

The vast majority of process (and traditional design) research interested in the mind–body connection has been largely limited to the exploration of the one-way connection between psyche and soma. The idea that the body impacts upon cognitive and emotional processes is relatively foreign territory in most health research, and except for isolated pockets of activity, little research has been devoted to exploring the potential bidirectional communication between mind and body.

The relation between mind and body has been primarily explored through two paradigms (82). The first paradigm, exploring how the body is influenced by the mind, has been the primary guide for behavioral medicine and related disciplines. The second paradigm, which studies the influence of body on psychological processes, is still new in psychology and has primarily been explored by researchers in biofeedback and, more recently, by those working in psychoneuroimmunology. This latter work is interesting not only in demonstrating that somatic processes may impact upon thoughts, emotions, and overt behavior (45), but placed together with work grounded in the first paradigm, suggests that mind and body may interact with each other in some organized fashion as a system. Process research, when it collects data on both psychological and somatic variables intensively over time, is well-suited to the examination of several systemic phenomena, including bidirectional mind–body links and feedback loops in which variables interact so as to amplify or dampen the activity of each other (83). Research exploring only the mind-to-body relation may be missing important, perhaps essential, features of both healthy functioning and illness conditions.

CONCLUSION

In many fields of science as varied and diverse as physics, neuroscience, and economics, phenomena are studied intensively over time in order to make inferences and deductions about patterns of behavior and to allow for predictions of future change and stability. For example, in wildlife biology, field notes on a single animal or group of animals may cover months of regular and detailed observation in an attempt to accurately describe and explain behavior. The field of psychology often implicitly assumes that humans are capable of describing their behavior, the motivations for it, and the circumstances in which it does and does not occur. This may not, however, always be a valid assumption. For example, many core postulates about ourselves, others, and the world (e.g. our strivings or beliefs) cannot be articulated and so must be inferred from patterns of behavior (78). Anecdotally, participants in our event-sampling studies have often been surprised by the ways in which they act in social interactions and by how they feel day-to-day when they have been put into the position of observing such behaviors and experiences on a daily basis.

The research approach described in this article examines behavior embedded in its original temporal context. In contrast, when changes in behavior are not explored and accounted for, the emergent picture may represent a gloss of what is actually happening in individuals' lives. Examination of what behavior is generally like—its structure (84)—whether it be expressed in personality traits, coping styles, health behavior, or any other component of the human psyche, is unquestionably important. It would be unwise to ignore the stable and consistent aspects of behavior. However, such stability usually does not imply static equilibrium. Many kinds of fluctuation and change in the natural world occur such that the integrity of the organism's structure is maintained. Indeed, these fluctuations continually test the stability of the structure (30). Order and coherence come not through inflexibility and the preservation of static equilibrium but through fluctuation and dynamic change. Recent research suggests that such variability is, far from reflecting disorder, associated with health and adaptability to the ever-changing circumstances of life (23,85).

We have outlined a number of benefits to the process approach: first, the temporal and, in some instances, situational generality of the behavior can be taken into account (cf. 16,86). Relatedly, contextual correlates and determinants of the behavior of individuals (or groups) can be described. Second, causal inferences can be made or made more precisely with detailed temporal information. Individual differences in the patterning of behavior over time can be explored. Finally, interactions between different behaviors or between behaviors and events can be studied as they unfold over time. All such information is important to both describing nonlinear behavior and predicting its future course. Further, the knowledge gained from the study of process can be implicated in both clinical decision-making and in acquiring a more detailed theoretical understanding of behavior phenomena.

The idea that many forms of behavior are in perpetual flux suggests that such dynamics are not only meaningful but central to the organization of the individual. As such, the process approach is not simply a new methodology to study existing questions and problems. As research progresses on various fronts, new ways of thinking about mind–body phenomena are coming to the fore.

REFERENCES

(1) Lao Tzu: *Tao Te Ching*. New York: Bantam, 1990.
(2) Folkman S, Lazarus RS: If it changes it must be a process: A study of emotion and coping during three stages of a college examination. *Journal of Personality and Social Psychology.* 1985, *48:*150–170.
(3) Derogatis LR, Spencer PM: *The Brief Symptom Inventory.* Baltimore, MD: Clinical Psychometric Research, 1982.
(4) McNair DM, Lorr M, Droppleman LF: *Manual: Profile of Mood States.* San Diego, CA: Educational and Industrial Testing Service, 1971.
(5) Menaghan E: Measuring coping effectiveness: A panel analysis of marital problems and efforts. *Journal of Health and Social Behavior.* 1982, *23:*220–234.
(6) Aldwin C, Folkman S, Schaefer C, Coyne JC, Lazarus RS: Ways of coping: A process measure. The annual meeting of the American Psychological Association. Montreal, Canada: 1980.
(7) Pearlin LI, Schooler C: The structure of coping. *Journal of Health and Social Behavior.* 1978, *19:*2–21.
(8) Folkman S, Lazarus RS, Gruen RJ, DeLongis A: Appraisal, coping, health status, and psychological symptoms. *Journal of Personality and Social Psychology.* 1986, *50:*571–579.
(9) Glass AL, Holyoak KJ: *Cognition* (2nd Ed.). New York: Random House, 1986.
(10) Stone AA, Schiffman S: Ecological momentary assessment (EMA) in behavioral medicine. *Annals of Behavioral Medicine.* 1994, *16:*199–202.
(11) Beese A, Morley S: Memory for acute pain experience is specifically inaccurate but generally reliable. *Pain.* 1993, *53:*183–189.
(12) Larsen RJ: Neuroticism and selective encoding and recall of symptoms: Evidence from a combined concurrent–retrospective study. *Journal of Personality and Social Psychology.* 1992, *62:*480–488.
(13) Turk DC: Potentials of process measurement: Motion pictures versus snapshots. *Annals of Behavioral Medicine.* 1994, *16:*198.
(14) Ramsay JO, Silverman BW: *Functional Data Analysis.* New York: Chapman-Hall, 1997.
(15) Combs A: Psychology, chaos, and the process nature of consciousness. In Abraham FD, Gilgen AR (eds), *Chaos Theory in Psychology.* Westport, CT: Praeger, 1995, 129–137.
(16) Larsen RJ: A process approach to personality psychology: Utilizing time as a facet of data. In Buss D, Cantor N (eds), *Personality Psychology: Recent Trends and Emerging Directions.* New York: Springer-Verlag, 1989, 177–193.
(17) Brown KW, Moskowitz DS: Does unhappiness make you sick? The role of affect and neuroticism in the experience of common physical symptoms. *Journal of Personality and Social Psychology.* 1997, *72:*907–917.
(18) Melzack R: The tragedy of needless pain. *Scientific American.* 1990, *262:*27–33.
(19) Emmons RA: Personal strivings, daily life events, and psychological and physical well-being. *Journal of Personality.* 1991, *59:*453–472.
(20) Koerner J: Nonlinear dynamic systems in behavioral psychology. Unpublished doctoral dissertation. University of Minnesota, 1993.
(21) Larsen RJ, Kasimatis M: Individual differences in entrainment of mood to the weekly calendar. *Journal of Personality and Social Psychology.* 1990, *58:*164–171.
(22) Brown KW, Moskowitz DS: Dynamic stability of behavior: The rhythms of our interpersonal lives. *Journal of Personality.* 1998, *66:*105–134.
(23) Goldberger AL, Rigney DR, West BJ: Chaos and fractals in human physiology. *Scientific American.* 1990, *262:*43–49.
(24) Heiby EM: Chaos theory, nonlinear dynamical models, and psychological assessment. *Psychological Assessment.* 1995a, *7:*5–9.
(25) Abraham FD, Abraham RH, Shaw CD: *A Visual Introduction to Dynamical Systems Theory for Psychology.* Santa Cruz, CA: Aerial Press, 1990.
(26) Abraham FD, Gilgen AR: *Chaos Theory in Psychology.* Westport, CT: Praeger, 1995.
(27) Glass L, Mackey MC: *From Clocks to Chaos: The Rhythms of Life.* Princeton, NJ: Princeton University Press, 1988.
(28) Waldrop MM: *Complexity: The Emerging Science at the Edge of Order and Chaos.* New York: Simon & Shuster, 1992.
(29) von Bertalanffy L: *General System Theory.* New York: Braziller, 1968.
(30) Jantsch E: *The Self-Organizing Universe: Scientific and Human Implications of the Emerging Paradigm of Evolution.* Oxford, England: Pergamon Press, 1980.
(31) Sabelli HC, Carlson-Sabelli L, Patel MK, et al: Psychocardiological portraits: A clinical application of process theory. In Abraham FD, Gilgen AR (eds), *Chaos Theory in Psychology.* Westport, CT: Praeger, 1995, 107–125.
(32) Stone AA, Neale JM, Cox DS, et al: Daily events are associated with a secretory immune response to an oral antigen in men. *Health Psychology.* 1994, *13:*440–446.
(33) Reidbord SP, Redington DJ: Psychophysiological processes during insight-oriented therapy: Further investigations into nonlinear dynamics. *Journal of Nervous and Mental Disease.* 1992, *180:*649–657.
(34) Reidbord SP, Redington DJ: Nonlinear analysis of autonomic responses in a therapist during psychotherapy. *Journal of Nervous and Mental Disease.* 1993, *181:*428–435.
(35) Redington DJ, Reidbord SP: Chaotic dynamics in autonomic nervous system activity of a patient during a psychotherapy session. *Biological Psychiatry.* 1992, *31:*993–1007.
(36) Wood C, Magnello ME, Sharpe MC: Fluctuations in perceived energy and mood among patients with chronic fatigue syndrome. *Journal of the Royal Society of Medicine.* 1992, *85:*195–198.
(37) Haynes SN: *Models of Causality in Psychopathology.* New York: Macmillan, 1992.
(38) Haynes SN, Blaine D, Meyer K: Dynamical models for psychological assessment: Phase space functions. *Psychological Assessment.* 1995, *7:*17–24.

(39) Larsen RJ, Kasimatis M: Day-to-day physical symptoms: Individual differences in the occurrence, duration, and emotional concomitants of minor daily illnesses. *Journal of Personality.* 1991, *59:*387–423.

(40) Goerner S: Chaos and deep ecology. In Abraham FD, Gilgen AR (eds), *Chaos Theory in Psychology.* Westport, CT: Praeger, 1995, 3–18.

(41) West SG, Hepworth JT: Statistical issues in the study of temporal data: Daily experiences. *Journal of Personality.* 1991, *59:*609–662.

(42) Kelly JR, McGrath JE: *On Time and Method.* Newbury Park, CA: Sage, 1988.

(43) Reichardt CS: Comments on "The application of time series methods to moderate span longitudinal data." In Collins LM, Horn JL (eds), *Best Methods for the Analysis of Change: Recent Advances, Unanswered Questions, Future Directions.* Washington, DC: American Psychological Association, 1991, 88–91.

(44) Schwartz GE: Biofeedback and physiological patterning in human emotion and consciousness. In Beatty J, Legewie H (eds), *Biofeedback and Behavior.* New York: Plenum, 1977, 293–305.

(45) Maier S, Watkins LR, Fleshner M: Psychoneuroimmunology: The interface between behavior, brain, and immunity. *American Psychologist.* 1994, *49:*1004–1017.

(46) Mackey MC, Milton JG: Dynamical diseases. *Annals of the New York Academy of Sciences.* 1987, *504:*16–32.

(47) James W: *The Principles of Psychology.* Cambridge, MA: Harvard University Press, 1890/1981.

(48) Fischer KW, Rose SP: Concurrent cycles in the dynamic development of brain and behavior. In Dawson G, Fischer KW (eds), *Human Behavior and the Developing Brain.* New York: Guilford Press, 1994, 3–66.

(49) Schwartz JE, Warren K, Pickering TG: Mood, location and physical position as predictors of ambulatory blood pressure and heart rate: Application of a multi-level random effects model. *Annals of Behavioral Medicine.* 1994, *16:*210–220.

(50) Affleck G, Tennen H, Urrows S, Higgins P: Individual differences in the day-to-day experience of chronic pain: A prospective study of rheumatoid arthritis patients. *Health Psychology.* 1991, *10:*419–426.

(51) Gottman JM: *Time Series Analysis: A Comprehensive Introduction for Social Scientists.* Cambridge, England: Cambridge University Press, 1981.

(52) Bowerman BL, O'Connell RT: *Forecasting and Time Series: An Applied Approach* (3rd Ed.). Belmont, CA: Duxbury Press, 1993.

(53) Jaccard J, Wan CK: Statistical analysis of temporal data with many observations: Issues for behavioral medicine data. *Annals of Behavioral Medicine.* 1993, *15:*41–50.

(54) Vallacher RR, Nowak A: The emergence of dynamical social psychology. *Psychological Inquiry.* 1997, *8:*73–99.

(55) Levor RM, Cohen MJ, Naliboff BD, McArthur D, Heuser G: Psychosocial precursors and correlates of migraine headache. *Journal of Consulting and Clinical Psychology.* 1986, *54:*347–353.

(56) Halford WK, Cuddihy S, Mortimer RH: Psychological stress and blood glucose regulation in Type I diabetic patients. *Health Psychology.* 1990, *9:*516–528.

(57) Duncan AD: Self-application of behavior modification techniques by teenagers. *Adolescence.* 1969, *16:*541–556.

(58) Suls J, Martin RE: Daily recording and ambulatory monitoring methodologies in behavioral medicine. *Annals of Behavioral Medicine.* 1993, *15:*3–7.

(59) Wheeler L, Reis HT: Self-recording of everyday events: Origins, types, and uses. *Journal of Personality.* 1991, *59:*339–354.

(60) Affleck G, Urrows S, Tennen H, Higgins P: Daily coping with pain from rheumatoid arthritis: Patterns and correlates. *Pain.* 1992, *51:*221–229.

(61) Bolger N: Coping as a personality process: A prospective study. *Journal of Personality and Social Psychology.* 1990, *59:*525–537.

(62) Stone AA, Kennedy-Moore E, Neale JM: Association between daily coping and end-of-day mood. *Health Psychology.* 1995, *14:*341–349.

(63) Gallant SJ, Hamilton JA, Popiel DA, Morokoff PJ, Chakraborty PK: Daily moods and symptoms: Effects of awareness of study focus, gender, menstrual-cycle phase, and day of the week. *Health Psychology.* 1991, *10:*180–189.

(64) McFarlane JM, Williams TB: Placing menstrual syndrome in perspective. *Psychology of Women Quarterly.* 1994, *18:*339–373.

(65) McMillan MJ, Pihl RO: Premenstrual depression: A distinct entity. *Journal of Abnormal Psychology.* 1987, *96:*149–154.

(66) Rubinow DR, Roy-Byrne P, Hoban MC, Gold PW, Post RM: Prospective assessment of menstrually related mood disorders. *American Journal of Psychiatry.* 1984, *141:*684–686.

(67) James GD, Pickering TG: Ambulatory blood pressure monitoring: Assessing the diurnal variation of blood pressure. *American Journal of Physical Anthropology.* 1991, *84:*343–349.

(68) White WB, Schulman P, McCabe EJ, Dey HM: Average daily blood pressure, not office blood pressure, determines cardiac function in patients with hypertension. *Journal of the American Medical Association.* 1989, *261:*873–877.

(69) Cowdry RW, Gardner DL, O'Leary KM, Leibenluft E, Rubinow DR: Mood variability: A study of four groups. *American Journal of Psychiatry.* 1991, *148:*1505–1511.

(70) DiPietro L, Gyulai L, Stunkard AJ, Whybrow PC: Mood and body weight in a woman with rapid cycling bipolar disorder: A case report. *Psychosomatic Medicine.* 1993, *55:*7–10.

(71) Stone AA, Broderick JE, Porter LS, et al: Fatigue and mood in chronic fatigue syndrome patients: Results of a momentary assessment protocol examining fatigue and mood levels and diurnal patterns. *Annals of Behavioral Medicine.* 1994, *16:*228–234.

(72) Affleck G, Tennen H, Urrows S, Higgins P: Person and contextual features of daily stress reactivity: Individual differences in relations of undesirable daily events with mood disturbance and chronic pain intensity. *Journal of Personality and Social Psychology.* 1994, *66:*329–340.

(73) Olsen NJ, Brooks RH, Furst D: Variability of immunologic and clinical features in patients with rheumatoid arthritis studied over 24 hours. *Journal of Rheumatology.* 1993, *20:*940–943.

(74) Stone AA, Cox DS, Valdimarsdottir H, Jandorf L, Neale JM: Evidence that secretory IgA antibody is associated with daily mood. *Journal of Personality and Social Psychology.* 1987, *52:*988–993.

(75) van Eck MM, Nicolson NA: Perceived stress and salivary cortisol in daily life. *Annals of Behavioral Medicine.* 1994, *16:*221–227.

(76) Pickering TG: Ambulatory monitoring: Applications and limitations. In Schneiderman N, Weiss SM, Kaufmann P (eds), *Handbook of Research Methods in Cardiovascular Behavioral Medicine.* New York: Plenum, 1989, 261–272.

(77) Heiby EM: Assessment of behavioral chaos with a focus on transitions in depression. *Psychological Assessment.* 1995b, *7:*10–16.

(78) Tennen H, Suls J, Affleck G: Personality and daily experience: The promise and the challenge. *Journal of Personality.* 1991, *59:*313–337.

(79) Block J: Studying personality the long way. The annual meeting of the American Psychological Association. San Francisco, CA: 1991.

(80) Lazarus RS: Coping theory and research: Past, present, and future. *Psychosomatic Medicine.* 1993, *55:*234–247.

(81) Moskowitz DS, Coté S: Do interpersonal traits predict affect? A comparison of three models. *Journal of Personality and Social Psychology.* 1995, *69:*915–924.

(82) Haruki Y: Does the concept of embodiment offer us something new in psychology? The 26th International Congress of Psychology. Montreal, Canada: 1996.

(83) Brown KW: Emotional body, physical mind: An exploration of the psychosomatic system through the lens of day-to-day experience. Unpublished doctoral dissertation, McGill University, 1997.

(84) Epstein S: Trait theory as personality theory: Can a part be as great as the whole? *Psychological Inquiry.* 1994, *5:*120–122.

(85) Mischel W: Personality dispositions revisited and revised: A view after three decades. In Pervin LA (ed), *Handbook of Personality: Theory and Research.* New York: Guilford Press, 1990, 111–134.

(86) Nesselroade JR, Ford DH: P-technique comes of age: Multivariate, replicated, single-subject designs for research on older adults. *Research on Aging.* 1985, *7:*46–80.