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State-Space Grid Analysis: Applications for Clinical Whole Systems Complementary and Alternative Medicine Research

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Summary

This paper presents state space grids (SSGs) as a mathematically less intensive methodology for process-oriented research beyond traditional qualitative and quantitative approaches in whole systems of complementary and alternative medicine (WS-CAM). SSGs, originally applied in developmental psychology research, offer a logical, flexible, and accessible tool for capturing emergent changes in the temporal dynamics of patient behaviors, manifestations of resilience, and outcomes. The SSG method generates a two-dimensional visualization and quantification of the inter-relationships between variables on a moment-to-moment basis. SSGs can describe dyadic interactive behavior in real time and, followed longitudinally, allow evaluation of how change occurs over extended time periods. Practice theories of WS-CAM encompass the holistic health concept of whole-person outcomes, including nonlinear pathways to complex, multidimensional changes. Understanding how the patient as a living system arrives at these outcomes requires studying the process of healing, e.g., sudden abrupt worsening and/or improvements, 'healing crises', and 'unstuckness', from which the multiple inter-personal and intra-personal outcomes emerge. SSGs can document the indirect, emergent dynamic effects of interventions, transitional phases, and the mutual interaction of patient and environment that underlie the healing process. Two WS-CAM research exemplars are provided to demonstrate the feasibility of using SSGs in both dyadic and within-patient contexts, and to illustrate the possibilities for clinically relevant, process-focused hypotheses. This type of research has the potential to help clinicians select, modify and optimize treatment plans earlier in the course of care and produce more successful outcomes for more patients.

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Introduction

Clinical researchers are challenged to identify theories as well as methods from scientific fields other than conventional pharmaceutical research that might better accommodate the practice theories and clinical observations of whole systems of complementary and alternative medicine (WS-CAM). As other papers in this issue have outlined, complexity science, nonlinear dynamical systems (NDS) and network science offer a variety of methodological approaches to capture holistic patterns of change in patients as living dynamic systems. This paper introduces one such set of methods. State space grids (SSGs) were originally developed for clinical research in developmental psychology but have potential applicability to WS-CAM research [1].

A dynamic system (DS) is a collection of elements that change over time [2]. The person as a DS functions in constant interaction and relationship with his/her environment. Each person as a DS exhibits recurring patterns of behavior as time passes. These patterns occur within a state space, which is a set of all possible states through which the system can pass with his/her dynamics. At certain critical points in time, as inner conditions change (e.g., puberty, aging, acute illness, changes in nutrition, emotional trauma, or organ dysfunction) or environmental demands and circumstances fluctuate, the system can break out of the usual pattern into other types of dynamics with different attractors. Attractors are recurrent states that occur more frequently than other states and require much more energy to transition into a different state. Depression, for example, has been conceptualized as an attractor, a recurring state from which it is difficult for an individual to escape [3]. As figure 1 illustrates, some dynamic patterns reflect instability and phase transitions of the system; others reflect the relatively stable behavioral patterns that the person exhibits in typical interactions with his or her world. The quality of the attractor dynamics in terms of rigidity versus flexibility or adaptability in the face of change provides valuable information on the relative health of the person as a living system [4, 5].

The holistic goals of WS-CAM interventions, such as Traditional Chinese Medicine (TCM), classical homeopathy, and Ayurveda, exert complex local and global effects that require innovative evaluative approaches [6]. Traditional qualitative methods provide a starting point for describing the complex effects of treatment [7–9]. However, there are few quantitative methods that examine these multidimensional, whole-person outcomes and the processes of healing that lead to the emergence of well-being over time. The SSG is an innovative analytical tool with graphical, quantitative, and qualitative features with potential for WS-CAM research. This type of research has potential to help clinicians select, modify and optimize treatment plans earlier in the course of care and produce more successful outcomes for more patients.

State Space Grids

The SSG approach was developed as a middle road between NDS methods that are mathematically demanding (and often inaccessible or inappropriate for clinical research) and those that are purely descriptive [10, 11]. SSGs permit researchers to capture if and when bifurcations or unsticking points in systems dynamics occur. These transition periods involve a temporary increase in variability in the dynamics of the system, a variability that is measurable with the proper observational tools, including computation of measures of entropy and dispersion [1]. Once the nonlinear change occurs, the system is likely to restabilize for extended periods of time in a new, healthier attractor if a therapy has been effective. Ineffective therapy could leave the system in an unstable condition or lead to a restabilization back into a more rigid dynamic associated with poorer health.

The grids are a graphical approach that quantifies ordinal data according to two dimensions defining the state space for the system (fig. 2). Instructions for how to assess the parameters of the state space and the appropriateness of a dataset for SSG analysis are available [1, 12]. To date, these dimensions have been most typically been based on two-person systems [1, 13–17], but can be adapted to within-person system studies.

With the SSG method, the system’s behavioral trajectory (i.e., the sequence of behavioral states) is plotted as it proceeds in time on the two-dimensional grid representing all possible behavioral combinations, much like a temporal scatter plot of moment-to-moment states. Researchers can use this method with any two variables in a system, e.g., not only patient and practitioner behaviors, but also patient and family member behaviors or patient behavior and physiology. As WS-CAM patients often report changes in interpersonal relationships in everyday life as an outcome of successful treatment [8, 9, 18], changes in two-person dynamics are as relevant as are intra-personal changes for fully assessing holistic outcomes.

Each cell of the grid represents the simultaneous intersection of the categories within each dimension or axis. For analysis of dyadic interactions (e.g., patient and practitioner), the patient’s behavioral categories may form the x-axis and the same behavioral categories form the practitioner y-axis (fig. 2). Any time there is a change in either person’s behavior, a new point is plotted in the cell representing that joint behavior and a line is drawn connecting the new point and the previous point.

Thus, what is left is a representation of the dyad’s course during the conversation, indicating where and how much time they spent in different sections of the grid space. Various attractor types exist [19], but SSGs enable the identification of fixed-point attractors and, if systems have ‘multi-stability’, where multiple fixed points are in proximity to one another (as in the left-hand panel of fig. 2). Using the SSG software GridWare [20], measures can then be derived indexing the content and structure of the system behavior. Each of these parameters can serve as independent variable included in multivariate statistical models designed to test how the patterns relate to differential treatment outcomes. In addition, the visual inspection of the grids can be used to increase the qualitative information about a system, help explain the patterns that emerge in a system and visualize how the system reorganizes following a period of disruption. There are multiple modeling techniques well suited for assessing system flexibility, and a number of quantitative strategies for identifying attractor-like patterns on an SSG [21, 22].

Conceptually Translating WS-CAM into SSGs

Many WS-CAM practitioners report clinical observations that may represent the nonlinear dynamics, emergent behaviors, and/or self-organization of the healing process. For example, early in treatment, some patients report improvements in the sense of general well-being as well as temporary sudden worsening of more organ-specific symptoms. The usual pattern of symptoms appears to go into flux in what TCM providers might term a ‘healing crisis’ or homeopaths an ‘aggravation’. Other patients undergo an abrupt shift in usual symptoms with dramatic improvements. CAM researchers have described similar phenomena which they have labeled as ‘unstuckness’ [7, 9, 23].

This type of wider amplitude changeability could reflect a temporary system-wide destabilization of dynamics. Abrupt qualitative changes in dynamics could be a form of phase transition (see middle section of fig. 1), also termed a bifurcation in NDS terminology [19]. These changes are not limited to WS-CAM treatments. Other types of clinical intervention, such as cognitive-behavioral and psychodynamic therapies, frequently involve increasing symptoms and general dysregulation prior to improvements in the course of depression [24–29]. The flexibility of SSG methodology allows researchers to utilize various design strategies (e.g., within-person over time, as in fig. 1; between-person relationship comparison as in fig. 2) to capture these types of changes in dynamics and to reveal new patterns as outcomes.

WS-CAM Research Examples Using SSG

Two exemplars highlight the potential use of SSGs in WS-CAM research. The first is an interpersonal, patient-practitioner model examining interpersonal interactions and exploring how the patient process unfolds over time. The second example demonstrates how SSG analysis can capture the relationship of system components within a single person as he/she evolves over the period of WS-CAM treatment.

Interpersonal Emergent Behavioral Systems

To illustrate the use of SSGs in interpersonal WS-CAM research, we present a pilot project underway of a patient consultation with a homeopathic practitioner. The patient/practitioner encounter is hypothesized to have a significant therapeutic effect on the outcomes of homeopathic intervention [30–32]. Possible explanations include the confidence practitioners unconsciously project when they believe they have either found the ‘right’ remedy for a given patient, the accuracy of the assessment-remedy selection process, or their assessment competency to elicit sufficient information to find an appropriate remedy for a given patient. Similarly, assessing the amount and quality of engagement between patients and practitioners is important as there is an increasing evidence base that actively engaging with patients through empathy may enhance patient satisfaction and outcomes [33–35]. Traditional qualitative content analysis [18, 36–38] has not enabled researchers to understand specifically how the patient-practitioner interaction changes and unfolds over time, how changes in practitioner confidence are reflected in the flow of the interview, or how different patterns in the flow of the interaction may be related to patient outcomes. SSG analysis procedures can be used to explicate this emerging therapeutic relationship.

To rate the practitioner's level of engagement, audio recordings are made of the patient-practitioner encounter, and all audible behavior of both the practitioner and the patient are categorized by two synchronized streams of codes. These behavioral categories are 'Listen', 'Short Response', 'Ask Question', and 'Elaboration'. Because code categories need to be mutually exclusive and exhaustive for SSG analyses, an 'Off Topic' code is included to capture any behavior that occurs that cannot be adequately captured by the other four categories.

SSGs are constructed for each patient-practitioner dyad using these categories arranged in a nominal fashion. Figure 2 displays two examples of patient-practitioner dyads in the GridWare program alongside the measures window that displays the values for each SSG. Theoretical attractor regions are highlighted. The left-side grid shows an idealized interaction in which the exchange is a reciprocal pattern of asking questions and providing elaborate responses. The right-side grid shows a less optimal pattern in which the dyad spends less time in the attractor states. Measures derived from these SSGs include the total amount of variability across the whole state space (e.g., number of transitions, number of cells visited by the trajectory, or overall dispersion) and indices that reflect behavior in the attractor regions (e.g., frequency, total duration, and mean duration in each of these regions, return time).

Given this arrangement of the state space, we would focus on the dynamics in and out of the regions that reflect high levels of engagement – reciprocal exchanges of questions and elaborated answers. The left-side SSG in figure 2 reflects a high degree of this pattern of engagement and the SSG in the right-hand panel of figure 2 a more disrupted and disjointed pattern. Research questions can include: (i) What are the practitioner-patient dynamics of those who improve with treatment compared with those who do not? (ii) Do improvers spend more time in, and return more rapidly to, the Ask/Elaborate attractors than the non-improvers? (iii) Is dyadic engagement a better predictor of treatment outcome than either patient engagement or practitioner engagement separately? (iv) What are the session-to-session changes in practitioner-patient dynamics associated with improvement? Is there a phase transition of low-high-low variability for the best improvers? Data from psychotherapy research suggests that patients with early sudden changes may maintain longer-lasting improvements up to 2 years later, compared to linear incremental improvers [28, 29]. Do homeopathy patients with evidence of analogously variable patterns have better long-term outcomes, compared with those who show more linear incremental improvements?

Intrapersonal Emergent Behavioral Systems

When examining processes of change within a person, SSGs can help focus on the interaction between two subsystems, similar to what occurs in clinical practice during treatment or outcomes evaluation. WS-CAM predicts multidimensional change within an individual in response to treatment. WS-CAM practitioners expect that physical, emotional, and mental symptoms change simultaneously in response to individually effective treatments. Further, psychology, nursing, and integrative medicine practice theory posits that healing occurs across levels of human experience, i.e., levels of organizational scale in complex systems terminology, in response to intervention. Behavioral and emotional experiences are believed to have underlying physiological components, powered by feedback loops between component systems [39], such that as a person's experience evolves, subtle shifts occur in the relationships between components. SSG analysis can facilitate measurement and understanding of these complex and emergent physiological and behavioral responses, providing valuable tools for clinical researchers.

To illustrate the use of SSG in intrapersonal WS-CAM research, a proposed study using an NDS model for TCM acupuncture and back pain hypothesizes that the relationship between the physical experience of back pain measured by back electromyography (EMG), heart rate variability (HRV), or electrodermal responses (EDR) [40, 41] and its relation to the amount of behavioral distress (e.g., pain behaviors) displayed by the patient will evolve during the course of treatment. Thus, patients at pretreatment baseline will exhibit relatively rigid behavioral patterns on SSGs [15, 16, 42]. After successful treatment, SSGs should reveal a different attractor pattern with significantly greater flexibility and adaptability. After unsuccessful treatment, however, SSGs should show little change from the original rigid behavioral pattern.

This intrapersonal study would combine the use of physiological recordings, patient self-report, and video recordings of the patient's behaviors during a standardized situation in the laboratory. For instance, patients would be videotaped discussing their chief back pain complaint with the CAM practitioner, e.g., acupuncturist, for 5–15 min during one segment of the typical clinical assessment before, during, and after treatment. Physiological data can be collected during the interview. The video recordings will be reviewed by trained coders rating behavioral distress during the interview, and physiological data will be synchronized with the time scale of the behavioral codes.

SSGs can be generated for a 12-week course of acupuncture, plotting the physiological variable on the x-axis, with the observer-coded videotaped behavioral states of the patient on the y-axis. SSGs require that coding be mutually exclusive and exhaustive, such that for each time point, e.g. every 30 s, there is a code for both behavioral and physiology data. Physiological data is generally recorded at a much faster rate (e.g., 200, 500 Hz), requiring the experimenter to average sections of the data for use with the grids, essentially converting the continuous data stream into ordinal categories. Averaging continuous, physiological data has some analytic consequences [43], but the advantage here is to capture the moment-to-moment relationship between the changes in the body and the behavior of a person over the course of treatment and follow-up.

Gridware measures of entropy and dispersion will be computed for each laboratory visit and compared over time. It is hypothesized that the relationship between a patient's EMG recording and behavioral distress while discussing their pain will be characterized by rigidity at baseline, followed by periods of fluctuation during treatment, and eventual stabilization in a different attractor space following successful treatment (similar to the process described in fig. 1). Also, the patterns during the treatment course will differ between those with improved clinical outcomes and those patients exhibiting little to no improvement following treatment.

Discussion and Conclusions

The flexibility of the SSG methodology holds great promise not only for WS-CAM outcomes research but for many types of health-related research as a whole. The examples shown here could be used in most patient-practitioner contexts, particularly when the meta-theory underpinning the research proposes that healing occurs multidimensionally and that therapeutic response is emergent and nonlinear. While both examples use behavioral coding schemes to assess patient behavior, this is not a requirement for SSGs. Data can include a number of sources, such as patient self-report ratings, clinical notes, or daily diary entries, for example.

Using the SSG methodology, practitioners can bridge NDS-based concepts with clinical observations and explore research questions that have been elusive with traditional quantitative and qualitative methods. Is change during treatment gradual and incremental or does it involve sudden extreme gains (or symptom spikes), extreme worsenings, and plateaus? When does the improvement begin? How do relationships with practitioners and significant others interact with other components of the treatment? Does the pattern of change matter for clinical outcomes? By what process do novel structures (e.g., engaged clinical interaction and alliance) or patient skills (e.g., coping, mobility, pain regulation) emerge during the treatment?

In summary, the advantages of the SSG method are:

- accessibility for clinical researchers to apply NDS concepts using patient self-report and/or physiological readings collected in a clinical laboratory setting;
- ability to visualize two-dimensional inter-relationships between variables on a moment-to-moment basis;
- flexibility of the grid methodology to multiple system structures.

By understanding the temporal dynamics of the healing process facilitated by WS-CAM practitioners, we can come closer to understanding the processes and mechanisms of change, treatment dynamics, and positive and negative treatment outcomes.

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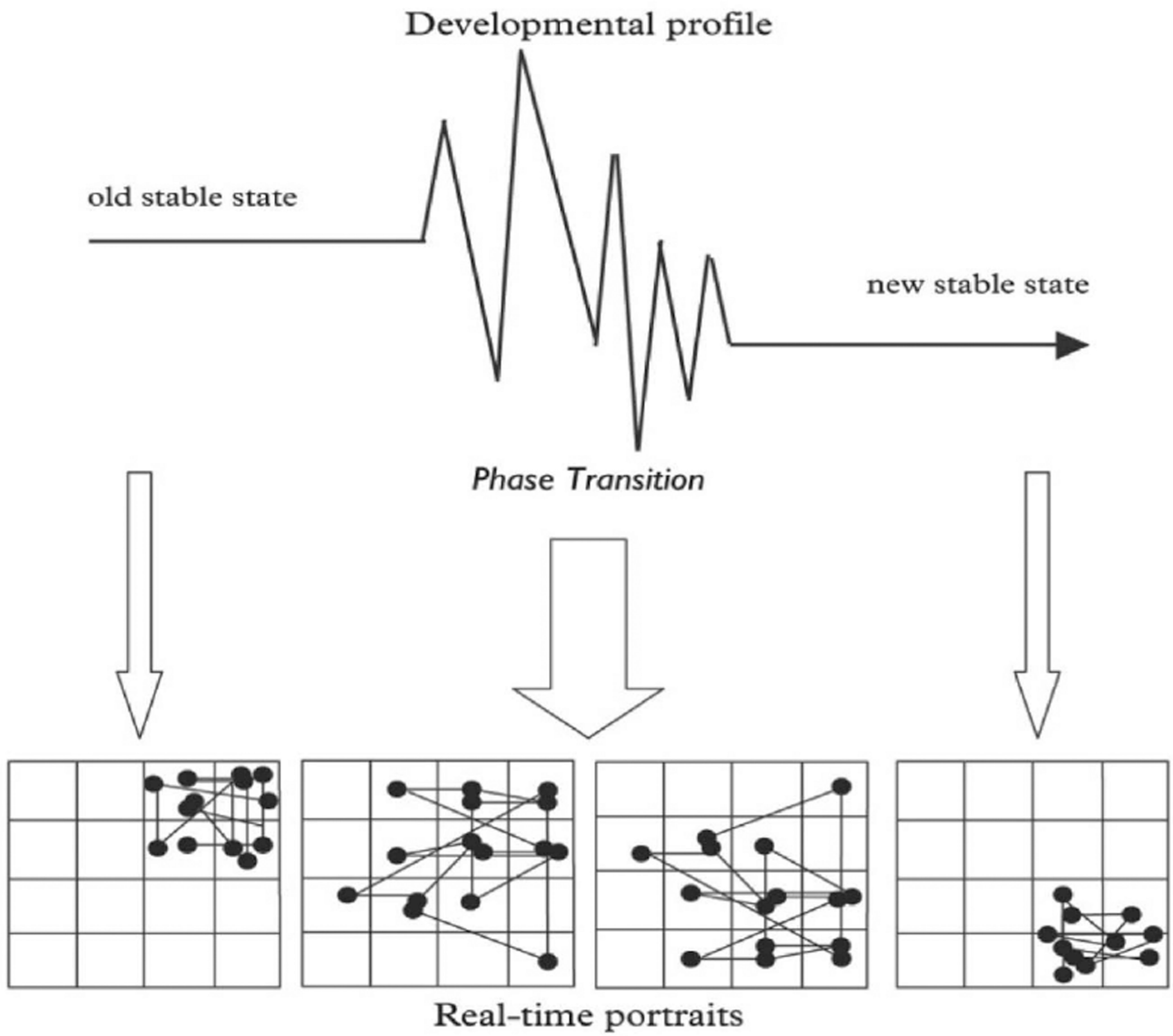

Fig. 1.
Diagram of sudden dynamic bifurcation, leading to instability and eventually a new attractor [1].

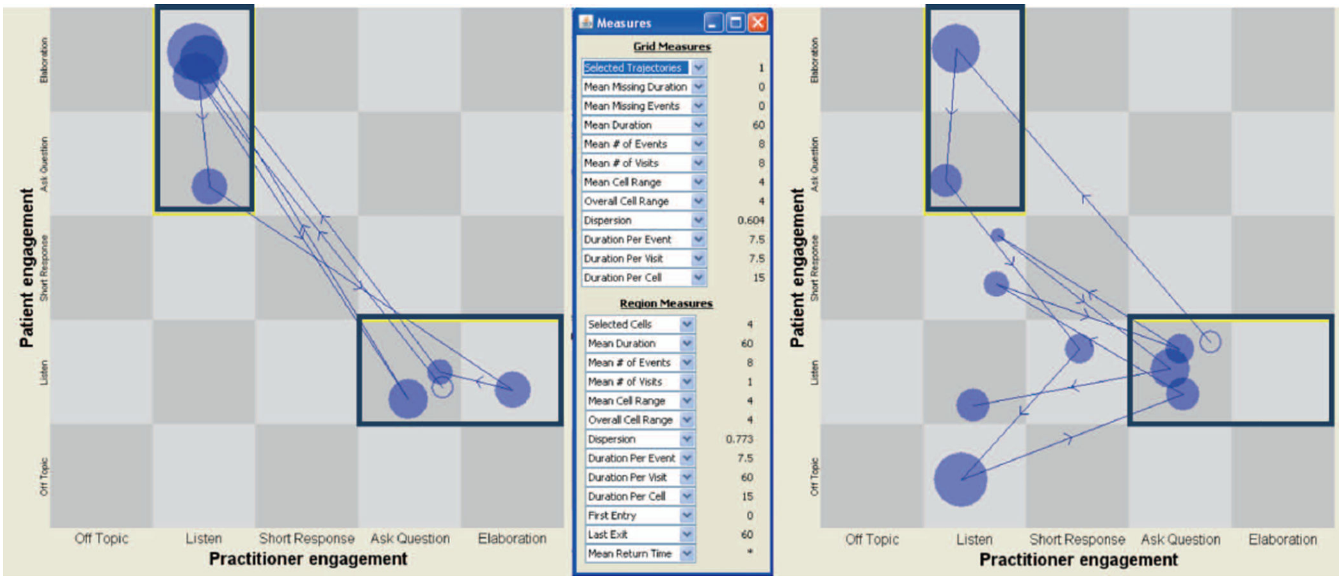

Fig. 2.

Two SSG examples of practitioner-patient engagement during a treatment session. Verbal behaviors are coded with mutually exclusive and exhaustive categories, then plotted in sequence. Theoretical fixed-point attractors are highlighted, and sample grid and region measures are displayed. The pair on the left exhibit more stable engagement dynamics (highlighted regions) than the pair on the right.