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Running head: NONLINEAR DYNAMICS IN SUICIDOLOGY

Nonlinear Dynamics. Theoretical Perspectives and Application to Suicidology

Abstract

Despite decades of research, the prediction of suicidal behavior remains limited. As a result, searching for more specific risk factors and testing their predictive power is central in suicidology. We will demonstrate that this strategy may be of limited value because it assumes linearity to the suicidal process that is most likely nonlinear by nature and which can be more adequately described and analyzed with nonlinear dynamics. The goal of moving nonlinear dynamics from theory to practice and to real-world phenomena can now be realized with internet-based monitoring systems such as the Synergetic Navigation System.

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Key-words

Nonlinear dynamics, complexity science, real-time monitoring, ambulatory assessment, suicide, prediction, prevention, warning systems

Introduction

Despite decades of research, predicting suicides is still not possible with satisfying specificity and sensitivity (Goldney, 2000). If one accepts the claim that “If suicides cannot be predicted, they cannot be prevented” (Paris, 2007, p. 81) – remembering the statement of “savoir pour prévoir” by Auguste Comte – then it becomes obvious that challenging the prediction problem is of major importance to suicidology.

Traditionally, regression models or related statistical methods were used to predict suicides or suicide attempts/ideations as surrogates for suicides. Ideally, these were prospective studies, where risk factors were assessed at a certain time, and suicidal behavior was observed through a followup period. In a benchmark study (Pokorny, 1983), 4,800 psychiatric inpatients were followed up for 4 to 6 years. Discriminant analysis was run with the four variables that best distinguished between the 63 suicide completers and the other patients. The model was able to correctly identify 35 (56%) of the suicide completers, but at the cost of 1,206 false positives, i.e., patients that were classified by the model as suicide completers who actually did not complete suicides. In other terms, sensitivity was 56%, specificity 74%. For clinicians, missing near half of suicide completers would be too low a sensitivity and thus unacceptable. However, increasing sensitivity in prediction models leads to a drop in specificity, with even more false positives.

Using more specific risk factors may be one way out of the prediction dilemma, and many attempts have been made since Pokorny’s benchmark study. Hopelessness, for example, is known to be characteristic for a suicidal state and was sensitive in predicting future suicides. However, specificity was rather low (.42) (McMillan, Gilbody, Beresford, & Neilly, 2007). Using a combination of selected risk factors out of a large variety to predict repeated self-harm lead to a high sensitivity (94%), but again a low specificity of 25% (Cooper et al., 2006). The authors also found that the statistical model is more sensitive but less specific compared to clinicians ratings (Cooper, Kapur, & Mackway-Jones, 2007). Two biological markers known to be associated with suicide, 5-hydroxyindoleacetic acid in cerebrospinal fluid as a marker of the serotonergic system, and the dexamethasone suppression test as a marker for the hypothalamic-pituitary-adrenal axis dysfunction, were also meta-analytically investigated for their predictive power (Mann et al., 2006). Again, prediction models with a high sensitivity went hand in hand with low specificity. A view on the topics of the current literature suggests that suicidology is characterized by an ongoing search for risk factors (or combinations of them) that are more specific for the phenomenon of suicide. Recent examples are implicit cognitions (Nock et al., 2010), intense emotions (Hendin, Al Jurdi, Houck, Hughes, & Turner, 2010), psychological-interpersonal motives (Joiner, 2005), or psychophysiological markers (Thorell, 2009). Perhaps using a variety of predictors and theoretical constructs from quite different biological, mental, and social systems may increase the specificity and thus reduce false positives. Despite the obvious importance of finding more specific risk factors and their integration into models (e.g., O'Connor, 2011; Van Orden et al., 2010) this approach is inherently limited because these models are still linear, whereas the suicidal process is most likely nonlinear by nature, as we will outline in this paper. Adding more variables, even if they are more specific, will not help overcoming linearity.

In suicidological literature, the necessity of considering the process and process characteristics for risk assessment has been pointed out (e.g., Granello, 2010; Simon, 2006), but mostly without explicit referral to nonlinearity. There are only few examples where nonlinear dynamics was explicitly related to suicidal phenomena. It has often been observed, for example, that a seemingly unimportant stressor can trigger suicide. This corresponds to the well known "butterfly effect" of the chaos theory, or to discontinuous phenomena labeled as "catastrophes" in catastrophe theory (Thom, 1976). Ramsay (1997) applied this to crisis theory: "Knowledge about catastrophe transitions can help to provide a scientific explanation to the 'straw that breaks the camel's back' metaphor in crisis theory. In a 'fold' type catastrophe where the pressure of a single variable keeps increasing, the final straw is the last unpredictable amount of pressure that turns the ability to manage all previous pressure conditions into an unmanageable crisis. This triggers a correspondingly abrupt change from one 'functional' equilibrium state to another, more or less functional state. The stoic 'keep your chin up' woman in a battering relationship suddenly snaps' and takes murderous control or a suicidal escape" (Ramsay, 1997, p. 31).

Mishara (1996) developed a simple mathematical model which was able to demonstrate how suicidal and life tendencies can develop nonlinearly over time and how slight changes in system states or parameters can cause substantial alterations in suicidal or life tendencies. Linear models are not able to explain such processes since they transform external input onto a system (e.g., life events or changes in the environment of an individual) or internal changes of a system into a *proportionally* related output. The explanatory advantage of nonlinear dynamics has also been suggested by Rogers, 2003 (p. 13): "These theories, described as nonlinear dynamic systems models, stand in strong contrast to the more typical linear and reductionist models employed in the social and behavioral sciences and may hold promise for the field of suicidology". However, he also stated that discussions have been theoretical and the applications to empirical data are still lacking. "It is time to move complexity theory from metaphors to mathematical models and apply them directly to the study of suicide if their promise is to be fulfilled."

In this paper we will summarize reasons for the application of nonlinear dynamics to the field of suicidology, the potential for risk assessment, prediction of suicides, and the development of early warning systems. We will also demonstrate that it is now possible to move nonlinear dynamics from theory to practice and to real-world phenomena by means of internet-based monitoring systems such as the Synergetic Navigation System.

Why Nonlinear Dynamics Could be an Appropriate Approach to Suicide Research

There are multiple reasons why a theoretical framework using complexity theory and nonlinear dynamics could be useful for understanding and – in a next step – for empirical assessment or even prediction of chronic as well as acute or crisis-induced suicidality.

1. Both chronic as well as crisis-induced suicidality are phenomena occurring in time. They are more or less impressing precursors of suicidal acts, and the suicidal acts as well as suicide-related thoughts and feelings (hopelessness, burdensomeness, loss of self-efficacy, depression, drug abuse, or others) show time-related patterns. Not only suicidal, but all mental and behavioral phenomena express specific *dynamic patterns* (e.g., Kelso, 1995), and their *gestalt* depends heavily on how these phenomena are conceptualized and measured, as well as on the time scale or measurement frequency we choose for signal detection (milliseconds, seconds, minutes, hours, days, months, or others).

2. The evidence of essential *unpredictability* we know from suicidal as well as other phenomena in psychopathology is a core feature of chaotic processes. Examples are the onset of depressive episodes, the transitions from depressive to manic periods and vice versa in bipolar disorders, the beginning of symptom exacerbations in schizophrenia, the manifestation of disruptive behavior or crimes in antisocial personality disorders, the relapses of addictive or substance abuse patients, the onset of epileptic seizures, and others. Here, the long-term unpredictability may be due to a deficit of our understanding of the systems under consideration; it may be a result of lacking measurement precision or data reliability, or a consequence of overwhelming complexity (e.g., heterogeneity of interacting components in a given system). But there is also a very fundamental reason for the limited predictability in complex systems – a necessary consequence of the *nonlinearity* of recursive and iterative processes between the interacting components (Guastello, Koopmans & Pincus, 2009; Ott, 1993; Schuster, 1989; Strunk & Schiepek, 2006). Even very simple and purely deterministic model systems including only one or a small number of recursively operating variables are able to produce very complex chaotic patterns. Examples are the discrete Verhulst system x_{n+1}

$= \mathrm{a}x_{\mathrm{n}} (1 - x_{\mathrm{n}})$ with a as the growth parameter, x as the only system variable (e.g., the bio mass of a population), and n as the number iterative steps, reproducing x by this map); or two-variable systems like the discrete Hénon map with $x_{\mathrm{n+1}} = y_{\mathrm{n}} + 1 - \mathrm{a}x_{\mathrm{n}}^{2}$ and $y_{\mathrm{n+1}} = \mathrm{b}x_{\mathrm{n}}$; or continuous three-variable systems like the Rössler or the Lorenz system. These systems are used to demonstrate basic qualities of chaotic behavior since they are very low-dimensional, completely deterministic, and realize well-known dynamic patterns. In the chaotic parameter regime, these patterns are very sensitive to small changes of the starting conditions, or to small interventions, or to changes of the parameters. Nonlinear equations cannot be solved analytically, but numerically, and therefore well known model systems are used to realize quite different computer experiments.

If we have a closer look at our living systems, especially at our brain (Haken, 2002), but also at psychological and social systems (Guastello et al. 2009; Haken & Schiepek, 2010), the nonlinearity of mixed feedback processes (positive and negative feedback, activation and inhibition working together) between system components or subsystems is an essential feature of all these systems.

3. Seemingly in contrast to commonsense thinking, chaos behaves like chance and randomness, but results from deterministic processes and realizes specific global *gestalts*. The specific *gestalt* of a given chaotic process is called "attractor" and can be made visible by means of so-called phase space embedding of the time series under consideration (Kantz & Schreiber, 2003; Strunk & Schiepek, 2006). A continuous shift of the relevant parameters of the generating system can result in a discontinuous jump of the attractor, which adds a second source of unpredictability. The first is the pseudo-randomness *within* a given attractor, the second is the switch *between* global patterns (attractors) of the system dynamics. The search for endogenous (intrinsic, input-independent) or exogenous (extrinsic, input-dependent) conditions of attractor transitions is an important issue in psychopathology, since it characterizes the qualitative shift from healthy to pathological states or vice versa, or from

one state of mind to another, or from unpleasant feelings to severe suicidality. Discontinuous changes and critical events are in the scope of theoretical considerations and modeling in nonlinear systems science.

Discontinuous changes of the shape of an attractor refer to what is called “phase transitions” in physics. Phase transitions are qualitative changes of the dynamics or structure of a system (temporal and/or spatial patterns) which are triggered by changes of one or more control parameters. These parameters mediate the internal coupling of system components. In many cases this has to do with the energy input in thermodynamically open (dissipative) systems. Discontinuous or “sudden” changes in patterns are related to continuous shifts of the control parameters and often accompanied by critical instabilities of the system dynamics.

4. Chaos and other nonlinear dynamic phenomena like attractor shifts are, at first, the result of *intra-systemic* processes. They are not passive reactions to an external, errative driving input, and consequently, nonlinear complex systems like human brains or mental processes do not follow simple stimulus-reaction-mechanisms. However, in a second step, we can investigate the changes of endogenous system behavior in reaction to external input or to internal fluctuations. One important characteristic of chaotic processes is its sensitivity to small changes of an ongoing systems trajectory (metaphorically called the “butterfly effect”), which is especially pronounced at the transition from one attractor to the other. A second characteristic is its capacity of getting in resonance and causing new dynamic qualities to emerge by the transient or continuous coupling of nonlinear systems (Osipov, Kuhrts & Zhou, 2007; Pikovsky, Rosenblum & Kuhrts, 2001). This is important for the understanding of many psychopathological phenomena, including suicide attempts. Their pronounced *eigendynamics* do not seem to be a simple and linear reaction to external events.

Eigendynamics refers to processes that a given system will produce on its own, e.g. certain rhythmic or chaotic behavior. Such processes are initially independent of any external input to the system. Thus, eigendynamics is, in a sense, similar to the brain’s default mode, i.e., its immanent activity without any specific external stimuli. In this particular instance, a given system's response represents a complex interaction between input, eigendynamics, and resonance with other coupled systems.

5. The nonlinear interaction of system components as well as the nonlinear coupling of dynamic systems creates emergent phenomena. *Emergence* means the appearance of new qualities at a macroscopic level of systems-functioning which do not occur at the microscopic level of components or subsystems (Haken, 2004). Suicidality may have such an emergent quality, since it seems to be different from intensive depressive feelings, thoughts, or self-related information processing. Going beyond the evolutionary founded desire to survive and the need to avoid life-threatening behaviors and situations, suicidality has a different motivational quality which is hard to understand.

6. Nonlinear dynamics and chaos theory have proven to be *empirically useful*. Concepts and methods left their initial states of only metaphorical transfer to psychiatric or psychological phenomena. Measurement procedures were developed in order to get time-series data which were appropriate for an application to nonlinear time-series analysis methods. First applications applied to EEG data (Duke & Pritchard, 1991; Elbert, Ray, Kowalik, Skinner, Graf & Birbaumer, 1990; Iasemidis, Sackellares, Zaveri & Williams, 1990; Kowalik & Elbert, 1994; Lehnertz, Arnhold, Grassberger & Elger, 2000), or the coding of client-therapist-interactions (Kowalik et al., 1997; Schiepek et al., 1997). An important methodological step was the development of mathematical algorithms which allowed to detect *nonstationarities* like phase transitions or attractor jumps. Nonstationarity means the change of dynamic qualities like mean, variance, frequency distribution or fractal dimensionality during a process. Those nonstationarities are crucial for learning and adaptation by living and mental systems. For example: Methods for estimating the fractal dimensionality (Grassberger & Procaccia, 1983a,b) or the exponential divergence of nearby trajectories of system states in phase spaces (Largest Lyapunov Exponents, indicating the degree of unpredictability of a

process, Ott, 1993; Schuster, 1989) were upgraded to *measures of changes* of fractal dimensionality (Pointwise D2, Skinner, Molnar & Tomberg, 1994) or of Lyapunov Exponents (Local Largest Lyapunov Exponents, Kowalik & Elbert, 1994; Kowalik, Schiepek, Kumpf, Roberts & Elbert, 1997; Rosenstein, Collins & de Luca, 1993) – to mention only two of them. Nonstationarity could explain, for example, why an individual suddenly becomes suicidal after a stable phase without an external trigger, and the detection of nonstationarity is thus of obvious clinical importance.

7. During the last decade, psychotherapy research has made some important progress. Processes were examined very closely and data were published which reflect not only some selected time samples but the entire change process (e.g., by daily self-ratings of patients). One important feature of such change processes seem to be *sudden gains* or *sudden losses* (Hayes, Laurenceau, Feldman, Strauss & Cardaciotto, 2007a; Stulz, Lutz, Leach, Lucock & Brkham, 2007), which correspond to the discontinuous order transitions we know from the dynamics of nonlinear, self-organizing systems (Haken & Schiepek, 2010; Schiepek, 2009). Interestingly, such discontinuous gains often emerge *before* the relevant interventions were applied. Examples are: Cognitive restructuring before cognitive techniques (like disputation of irrational beliefs or re-assessments) were imposed, and a significant reduction of compulsions and obsessions before exposure/response prevention was applied to patients with obsessive-compulsive disorder (Hayes, Feldman, Beevers, Laurenceau, Cardaciotto & Lewis-Smith, 2007b; Ilardi & Craighead, 1994). Such findings are surprising, given a linear input-output-model of psychotherapy, but correspond to an increasing number of reports on nonlinear changes and nonstationarity in human development (Haken & Schiepek, 2010; Hayes et al., 2007a,b; Kowalik et al., 1997; Lewis & Granic, 2000; Schiepek & Perlitz, 2009). All these findings encourage the development of nonlinear dynamic system models of suicidal behavior.

Ambulatory Assessment and Real-Time Monitoring

Looking for dynamic patterns in human suicidality may be important theoretically and an intellectual challenge as well, but on the other hand, it seems to be discouraging in practical terms. The message is that limits of predictability are not only a consequence of empirical and methodological shortcomings, but also have their principal reasons. If this holds true, even the most exact measurements of the most important variables will not allow for sensitive and specific long-term predictions of single case dynamics. In consequence, long-term prediction cannot be the final goal of suicidology, but the development of *early warning systems* based on indicators occurring early enough to act before a rare and extreme event (recently conceptualized as so-called “Xevent”, see Albeverio, Jentsch & Kantz, 2006 and below) such as a suicide attempt. The need for warning signs as proximal indicators, implying immediate risk, in contrast to more distal risk factors, has already been pointed out (Rudd et al., 2006) and has also been viewed with pessimism (Simon, 2006), but the established list of warning signs, again, does not refer to nonlinear dynamics of the suicidal process.

The Synergetic Navigation System and Its Application to Psychotherapy

The core technology for building such warning systems is the internet. It is available at any time at almost any place in the world, even through cell phones. Consequently, real-time monitoring systems used in psychotherapy – such as the Synergetic Navigation System (SNS) – are based on internet technology, and by means of this, make data from patients’ self-ratings or interpersonal assessments available to therapists with very little delay. Repeated equidistant assessments result in time series which can be visualized and analyzed by methods specific to the identification of nonlinear qualities and their transient changes (nonstationarities) in time signals. By this, we get data, and only a data-driven approach can be a serious application of nonlinear dynamics and complexity science to psychology, psychiatry, or in this case, to suicidology. This is the big and promising difference to the first enthusiastic wave of absorbing chaos theory into psychology in the 1980ies: At these times, interest remained mostly metaphorical, since researchers had – except for EEG data – no or very small samples of time series data available. Another difference was that concepts of nonstationarity, i.e. the inherent change of nonlinear qualities, and of synchronization and coupling were not yet elaborated. Although the SNS is perhaps the first and most promising data source and data analyzer, other ways of data mining will be developed, but it should be noted that only a data driven approach will add a surplus value to new words or concepts applied to well-known phenomena. The SNS has implemented the measures of dynamical complexity (a measure for natural coarse grained real world data which integrates aspects of amplitude and frequency of fluctuations as well as of scattering characteristics of the measurements over the scale range; Schiepek & Strunk, 2010), recurrence plots (a visualization of existing or not existing "recurrent" or repeated measurement sequences during a time series, which is sensitive to transients and dynamic jumps [phase transitions] within a process; Webber & Zbilut, 1994), permutation entropy (a complexity measure even for ordinal scaled real world data based on the Shannon information of probability distribution of value permutations; Bandt & Pompe, 2002), and synchronization pattern analysis by visualization of the degree and sign of correlations between individual items of a questionnaire (sign and degree of correlation coefficients are calculated in a matrix and the then transformed into colors). All measurements are then calculated in gliding temporal windows (the width of the window is a matter of free choice), thus making them sensitive to transient changes of the qualities (complexity, entropy, recurrence, synchronization) that are to be identified. A complexity resonance diagram allows for the visualization of changing degrees of dynamic complexity, calculated from the time series corresponding to the different questionnaire items. Complexity values are transformed into colors or significance levels (made visible through gray or black dots in the complexity resonance diagram). Figure 1 provides an example of the synopsis of different methods and their co-visualization.

Fig. 1 about here

In everyday psychotherapy practice, the SNS is implemented by using a Therapy Process Questionnaire (Haken & Schiepek, 2010) for in-patient treatment (42 items) or for day-treatment centers (47 items). A factor analysis of the questionnaire resulted in a 7-factors solution, explaining 59.6% of variance. The factor loadings of the items differentiated very well and allowed for a clear-cut item classification. The internal consistency of the factors ranged from .83 to .94.

Patients are to fill out the questionnaire daily in the evening and are also given the possibility of adding comments about their experiences during the day. Once a week and at the beginning and the end of the treatment, symptom ratings such as the Depression-Anxiety-Stress-Scale (DASS) (Lovibond & Lovibond, 1995) or the ICD-10-Based Symptom Rating (ISR) (Tritt, von Heymann, Zaudig, Zacharis, Söllner & Löw, 2008) are administered. The results are also visualized by means of the SNS. In the meantime, hundreds of therapeutic change processes are completely monitored and analyzed. Experience has shown a very high compliance and validity level of the data, with a very small rate of missing data during assessment periods of mostly 50 to 200 days (Schiepek, Zellweger, Kronberger, Aichhorn & Leeb, 2011). Therapists make use of the measurement results in order to reflect on and discuss the ongoing process repeatedly in a collegial supervision setting or directly with the patient.

Monitoring of Suicide-related Cognitions and Emotions

Initial data experience is now available in applying SNS technology in monitoring chronic suicidal patients. Some patients were monitored during an extended suicidal crisis; during their stay at a specialized hospital ward (Suicidal Prevention Program at the Christian Doppler University Hospital, Salzburg); and/or in a home setting. The most impressive results came during a mountain hiking project, which offered 3 guided hikes per week in the Alps near Salzburg. In a cross-over design, 10 and 7 chronic suicidal patients respectively took part in 9 weeks of guided hikes and 9 weeks of no treatment (before or after the "intervention" period, respectively) (Sturm et al., forthcoming). It was shown that a continuous monitoring device (daily self-ratings of mood, cognitions, and behavior) can be applied to chronic suicidal and depressive patients in a continuous day-to-day setting. Missing data were rare, compliance in filling the questionnaires was high, and the application of the system was rated as beneficial and useful by most of the participants of the study (for examples of the time series produced by the study see Figure 2). For applications in monitoring of suicidality, our research group developed a process monitoring questionnaire containing suicide-specific items related to suicide-specific theoretical constructs (like burdensomeness, hopelessness, wish to die, wish to live, rating suicide proneness). This questionnaire will continue to be validated in ongoing studies with daily applications during several months. In the chronically suicidal patients we studied so far, we were able to observe substantial variations in all of the assessed risk factors and also critical instabilities over the course of observation. So far, one patient attempted suicide after discharge from the hospital. This attempt was preceded by a significant complexity on several items of the questionnaire (Plöderl et al., 2011). In other chronically suicidal patients we observed critical instabilities before phases of well-being, suggesting that the "suicidal mode" of such patients may be a very strong attractor. Having the process visible to both therapist and patient was helpful in discovering what behavior or events preceded such critical instabilities. From our experience, having feedback of the process visible by the SNS time series and the qualitative descriptions given by patients on daily basis enrich the understanding of individual suicidality; thus, SNS provides valuable additional information for the ongoing psychotherapeutic and psychiatric treatment.

Fig. 2 about here

A written informed consent is given by all patients included into the SNS-based monitoring of suicidal risk factors. The monitoring corresponds to the guidelines of the ethics committee of Salzburg, Austria. One important issue was to clarify that the monitoring system does not replace any face-to-face communication with clinicians for the communication of suicidal impulses. Other issues were data safety of all electronically collected data. The informed consent includes this and other topics (e.g., the purpose of SNS) in great detail.

Limitations of using SNS include, for example, a lack of compliance by patients with paranoid tendencies. However, this was only observed in rare cases and data from applications of the SNS to inpatient treatment showed no correlation between users' compliance and diagnoses, symptom severity or degree of impairment (Schiepek et al., 2011). In our experience, compliance is clearly dependent on the quality and frequency of feedback sessions integrating the results into a patient's change process. Fill-out compliance not only depends on SNS-related motivation, but conversely, SNS can enhance treatment compliance in a substantial way. Compliance Problems seem to be related less to SNS technology and more to a lack of treatment motivation in general. As results from ambulatory assessment make evident, validity of data resulting from repeatedly used electronic devices in the field is at least equivalent to the validity of data from paper-and-pencil questionnaires or from interviews (Bussmann, Ebner-Priemer & Fahrenberg, 2009; Ebner-Priemer & Trull, 2010; Wenze & Miller, 2010). Actually, data are based on self-reports, but could easily be extended to third-party reports or to physiological data.

Is It Realistic to Create an Early Warning System of Suicidal Xevents?

It is a big challenge for an interdisciplinary community of scientists to model, predict, and manage Xevents. Examples of such Xevents are earthquakes, volcanism, floods, turbulent wind gusts, but also financial crashes, terrorist attacks, social shocks, and on an individual level, heart attacks or epileptic seizures. A textbook on "Extreme Events in Nature and

Society" (Albeverio et al., 2006) offers many examples, but it does not mention suicides or suicidal crises. However, without any doubt, suicides and suicide attempts fulfill the criteria of Xevents. They are rare, difficult to predict and irregular, and in most cases, associated with severe consequences for nature, societies, or individuals. Kantz et al. (2006, pp. 70) characterizes Xevents as "… large deviations from the average behavior in temporally evolving systems". By this, classical statistics is difficult to apply to such phenomena.

Deviations of this kind can result from irregular external events or inputs such as meteoritic impacts in the geological past (Herget, 2006) or – on a different time scale – books or other product's sale shocks after TV promotions (Sornette, 2006). If the *exogenous origins* of such "crises" (which in the case of sale shocks are very useful to authors and editors) are not selfmade or not known (e.g., from models of asteroid movements in the case of meteoritic impacts), prediction is nearly impossible. But in the case of temporally evolving systems there are *endogenous origins* of more or less extreme dynamic behaviors. In systems and interacting systems, data are statistically dependent since components and systems are related to each other and states evolve in iterative steps. For example, if a system is constituted by interacting people, it is possible to create epidemic cascade models of social interactions in order to predict extreme acts of violence during a political demonstration, or the popularity of products in a user society. The shape of time evolution in sales per day of a product will be different if the "shock" is caused exogenously, as opposed to an endogenous development (which could be modeled by interacting autonomous agents or master equations) (Sornette, 2006). In real-world systems there will be a complex interaction between endogenous and exogenous causes because a system's capacity for resonance and synchronization with external systems creates a specific "vulnerability" for getting in contact with systems in the environment and also makes systems sensitive to impacts from external events. This is the case when we look for the psychological impact of life events where similar events can have quite different consequences for different systems (individuals, couples, families, organizations) at any given time.

One reason for believing in the success of early warning systems for suicidal Xevents is the nature of endogenous system dynamics before manifesting critical events such as phase transitions or dramatic changes of system behavior. One of these phenomena is the occurrence of large fluctuations and critical instabilities, which take place before order transitions are initiated. Measurements such as dynamic complexity (Schiepek & Strunk, 2010), permutation entropy (Bandt & Pompe, 2002), or Local Largest Lyapunov Exponents (Kowalik & Elbert, 1994; Rosenstein et al., 2003) are sensitive to such fluctuations in time signals. The Synergetic Navigation System allows for “real-time” calculation of measures such as dynamic complexity and permutation entropy in a gliding window.

Another characteristic phenomenon is the large scale synchronization of components or subsystems. Order states in complex multi-component systems are generally characterized by collective behavior and large scale correlations (Haken, 2004; Kelso, 1995), and such collective dynamics increase especially before transitions take place (Kantz et al., 2006). Our own results from process-outcome-studies in psychotherapy indicated a significantly increased inter-correlation of the time-series created by the items of the Therapy Process Questionnaire during critical instabilities and related order-transitions of the therapeutic change-process (Haken & Schiepek, 2010). Different aspects of experiencing, emotioning, and self-related cognitions of an individual seem to be more synchronized during order transitions than during other change processes.

Clear-cut examples of increased synchronization can be seen in healthy and in an even more pronounced manner in pathological systems. Before epileptic seizures occur, the fractal dimensionality as well as the chaoticity of the EEG signal and, in consequence, the dynamics of involved brain regions, are reduced (Iasemidis et al., 1990; Lehnertz, 2006). This seems to be precursor to a pathologically increased synchronization of those cell assemblies and populations of neurons generating the epileptic seizure. Pathological synchronization is also a hallmark of other neurological diseases such as Parkinson's disease or essential tremor (Alberts, Wright & Feinstein, 1969; Nini, Slovin, Feingold & Bergmann, 1995). Parkinsonian resting tremor is caused by a pacemaker-like population of neurons which fire in a synchronized and periodical manner (Alberts et al., 1969; Tass, Smirnov, Karavaev, Barnikol, Barnikol, Adamchic, Hauptmann, Pawelcyzk, Maarouf, Sturm, Freund & Bezruchko, 2010). In contrast, in healthy subjects these neuronal populations fire in an uncorrelated, i.e. desynchronized manner (Nini et al., 1995). In addition to neurological diseases, psychiatric diseases are also characterized by an oversynchronization of neural cell assemblies involved in pathophysiological circuits of the disease (Tass & Majtanik, 2006; Tass & Hauptmann, 2007). This could be the case for obsessive-compulsive spectrum disorders, for depression, or even for suicidality. Since in the case of tinnitus a therapeutic reorganization of oversynchronized neuronal populations was successful by applying a non-invasive (acoustic) brain stimulator based on coordinated reset technology (coordinated reset is the triggering of healthy, desynchronized, and chaotic activity of neurons by short electrical bursts at different sites of an electrode placed in a target population of oversynchronized neurons; ANM, 2010), a similar stimulation might perhaps support psychotherapeutic efforts in working with chronically suicidal patients.

In chronic suicidality the search for abnormal synchronization patterns of specific neural circuits may be promising. It could provide new therapeutic approaches by combining non-invasive desynchronizing brain stimulation and psychotherapy. However, this does not implicate that in any case suicides would be a necessary consequence of brain or mental disorders. There may be cases of voluntary decisions to commit suicide unrelated to any psychopathology or abnormal brain functioning. But even if the more or less blurred line between free choice and pathology will remain an enduring issue and also a paradigmatic ambiguity in suicidology, there could be precursors to suicidal attempts or suicides irrespective of the underlying motivation. Like the readiness potentials in the motor cortex that precede action and can predict motor actions, quite independent of being part of normal or abnormal processes, suicide may have its precursor in the dynamic patterns of neural or mental processing. The message of this contribution is that it may be a worthy and realistic endeavor to concentrate on the (nonlinear) qualities of these precursors in time-series data.

Conclusion

In summing up, let us quote the noted psychotherapy researcher, Michael J. Lambert: "Yes, it is time for clinicians to routinely monitor treatment outcome" (see his contribution in the textbook of Duncan, Miller, Wampold and Hubble "The Heart and Soul of Change", 2010). Slightly modifying this quotation we would like to say: "Yes, it is time to routinely monitor risk factors of suicidal patients by ambulatory assessment devices". By this, (i) the important dimension of time comes into the focus of suicide science, and (ii) theories and methodologies from the spectrum of complex, nonlinear dynamic systems will be introduced into the field. By collecting data sets on processes we will learn about dynamic markers of increased suicidal risks, thus approaching the modest goal of making *short term predictions* of suicidal ideation or suicidal behavior with varying lethality. This way, prevention programs could be optimized and emergency treatment or even self-help strategies for patients could be applied in due time. In addition, simply the regularity function of self-monitoring of important items and writing diaries by using devices such as the Synergetic Navigation System could have protective effects. With the available technical means, suicide prevention programs can now integrate continuous monitoring programs and apply the results, including nonlinear analysis, in regular contacts with patients by phone, internet or in person. In addition, the Synergetic Navigation System offers the possibility to create customized questionnaires that cover an individual's risk and protective factors as well as resources and coping strategies. Individual risk factors as well as protective factors can be identified by the work on idiographic system models (Schiepek, 2003), which visualize the interdependencies of the most important variables (processes) constituting the "problem system" of a patient. The variables included in an individual network can be transferred to the items of an individual questionnaire. By this, SNS technology helps to search for specific risk and protective factors, and also identifies appropriate times (compare the Greek concept of "kairos") and psychological contexts for applying therapeutic interventions.

In a next step we ought to go from patterns of suicide-specific dynamics to models of those dynamics. This way can achieved by applying more inductive, boot-strap techniques or by more deductive and theory oriented work. Either way, in taking the necessary steps towards valid modeling, there is a need for appropriate psychological, brain related, and biochemical constructs, but also for data on their dynamics. Dynamic models can be visualized as system networks and can then be written as a set of coupled nonlinear difference or differential equations. A certain type of pre-decision on the future design of those models is made by the monitoring approach we have presented in this paper as far as the monitoring of and modeling constructs of suicidal crises as self-organized criticalities of complex, nonlinear systems are concerned. Theoretical modeling is a matter of the near future, but scientific as well as practice-oriented projects involving real-time monitoring and developing early warning systems of suicidal behavior should and can start now.

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Figure Captions

Figure 1. (a) Time series of 2 out of 7 factors of the Therapy Process Questionnaire (TPQ): "progress/confidence in treatment success/self-efficacy" (blue line) and "symptom intensity/impairment" (red line). The time series result from daily ratings of a patient during hospital treatment. The "factors" were identified by a factor analysis of the TPB. The factor values result from a z-transformation and averaging of all items constituting the factor (subscale). Arrays: SNS-based feedback-interviews with the patient.

(b) The dynamic complexity (for mathematical algorithms see Schiepek & Strunk, 2010) of the factor dynamics of „intensity of therapeutic work / motivation to change" (blue line), „quality of the therapeutic relationship/openness/confidence in the therapist" (red line) and „symptom intensity/impairment" (green line). Increases of dynamic complexity indicate periods of critical instabilities in a change process. The dynamic complexity is calculated in a gliding window with window width of 7 points.

(c) Complexity-Resonance-Diagrams of the therapy process of a patient. The abscissa represents time. In the ordinate the items are grouped to the factors of the TPQ. In the upper diagram only the significant complexity values are marked. The complexity signal is z-transformed and classified to significance levels (gray: 5%-level, black: 1% level). The histograms at the top of the diagram sum up the gray and black cells. The columnlike structure indicates resonating complexities of items during the phases of critical instability.

Figure 2. Time series of psychological items, rated once per day (in the evening, reflecting the status of the past day). The items shown are (a) restlessness/arousal, (b) desire to live, (c) quality of sleep. These items are 3 out of 38 items constituting a Suicide Process Questionnaire, which is tested in a greater sample of patients. The length of the time series produced in the hiking study is about 180 measuring points (= days). The gray area indicates the mountain hiking period of group 1.

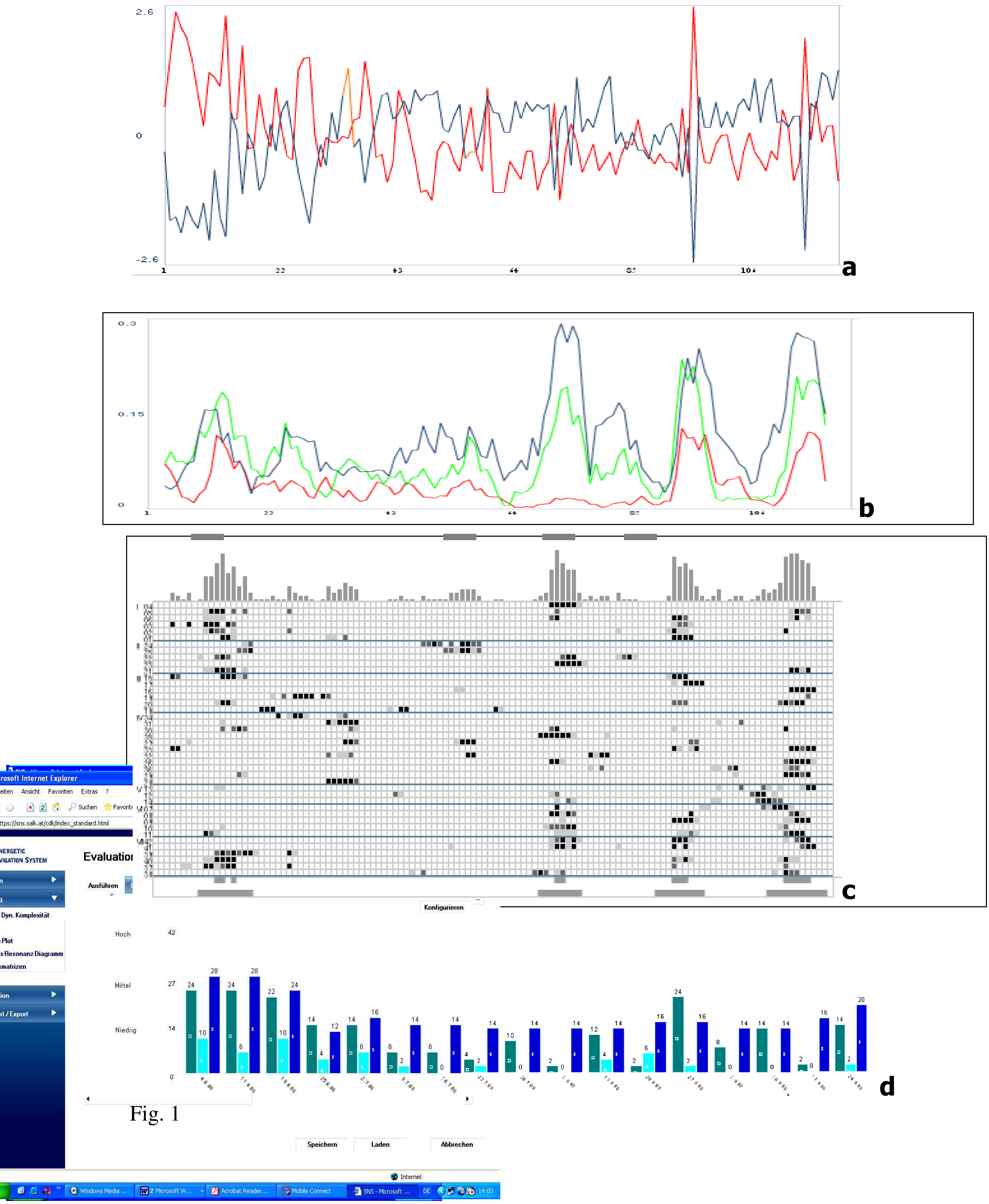
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Fig. 1

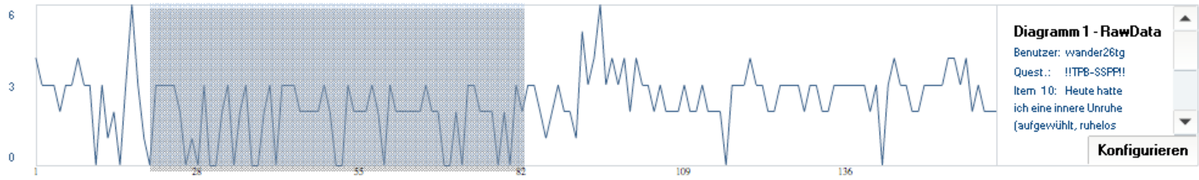
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Diagramm 1 - RawData
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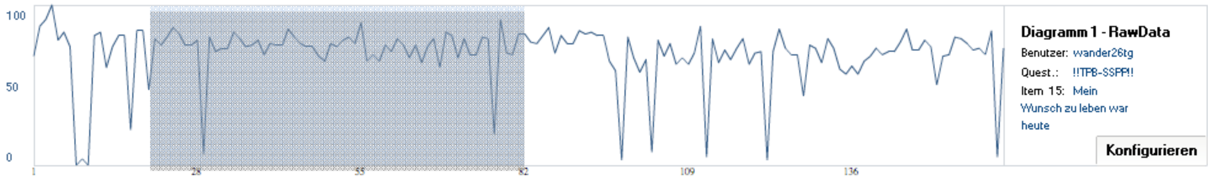
a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Item 15: Mein Wunsch zu leben war heute
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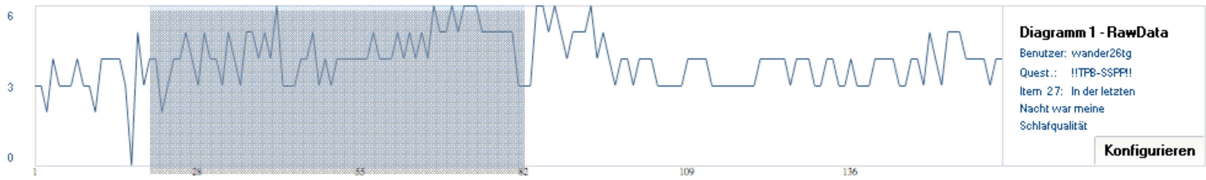
b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Benutzer: wander26tg
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Item 27: In der letzten Nacht war meine Schlafqualität
Konfigurieren

c

Fig. 2