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Complex individual pathways or standard tracks? A data-based discussion on the trajectories of change in psychotherapy

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Abstract

Objective: Current approaches of routine outcome monitoring (session-by-session measures) expect that trajectories of change should move on a standard track. Patients moving out of standard tracks are assumed to be at risk of deterioration. From a nonlinear dynamic systems perspective, there is not any assumption regarding a supposed standard track a patient should follow. Individual trajectories should be more complex than averaged tracks, highly individual, and characterised by pattern transitions.

Method: We tested if high-frequency (daily) trajectories of change are moving on standard tracks, if there are different complexity levels of high- versus low-frequency time series, if 'not on track' dynamics will be correlated with poor outcome and if complexity peaks representing the critical instabilities of a process will be correlated with the outcome. The patients included in the data analysis ($N = 88$) used the Therapy Process Questionnaire (TPQ) for daily self-assessments and the ICD-10-based Symptom Rating (ISR) for outcome evaluation.

Results: High-frequency trajectories are not running on standard tracks and are not necessarily correlated with poor outcome. Locally increased complexity may be associated with good outcome.

Conclusion: It may be useful to move beyond the concept of standard tracks and expected treatment outcomes. Routine feedback procedures should use the information that is given by the nonlinear dynamics of multiple change criteria.

KEYWORDS
dynamic complexity, nonlinear dynamic systems, on track versus. not on track, process–outcome research, psychotherapy feedback

1 | INTRODUCTION

1.1 | The Hypothesis of standard tracks

Computer-assisted feedback on psychotherapy processes has been tested in many contexts and treatment settings with encouraging results, for example the enhancement of outcome (Lambert, 2015). It is considered to be a standard of practice (Lambert, 2017; Laska, Gurman, & Wampold, 2014) and is recommended as a part of good practice (Lambert, 2010, 2013; Wampold, 2015), with a main focus on outcome routine monitoring (e.g. Lambert, 2010, 2015). There are different technologies available and different ways of realising feedback. Today, it seems no more to be the question *if* feedback should be used, but *how* it should be implemented (Wampold, 2015).

One common approach is outcome monitoring based on patient's self-ratings at treatment sessions. The most frequently used assessment tool is the Outcome Questionnaire-45 (OQ-45), developed by Lambert and co-workers (Lambert et al., 2004). The assumption is that the treatment progress should run on a 'standard track' with patients developing out of this track being at risk of deterioration (Hannan et al., 2005; Hansen, Lambert, & Forman, 2002). Standard tracks are generated by averaging the trajectories of patients with a specific diagnosis. Postsession assessments usually are taken once per week or less frequently with varying sampling rates. As a result of averaging many trajectories, the shape of standard tracks is linear or slightly exponentially damped (decreasing in case of symptom reduction and increasing in case of treatment progress). The recommended way of improving treatments at risk of deterioration is to look at a 'traffic light' which indicates trajectories moving 'not on track' and to apply so-called 'clinical support tools'. These tools try to optimise unfavourable goals, difficult social contexts of a patient or an insufficiently supporting therapeutic working alliance (Lambert, Harmon, Slade, Whipple, & Hawkins, 2005; Lambert et al., 2002).

1.2 | The nonlinear dynamic systems approach and the question of sampling rates

Another approach was developed in the context of complexity science and the paradigm of *nonlinear dynamic systems* (de Felice, Giuliani, et al., 2019; de Felice et al., 2018; Gelo & Salvatore, 2016; Haken, 2004; Haken & Schiepek, 2006; Halfon et al., 2016; Hayes & Strauss, 1998; Orsucci, 2002, 2016; Strunk & Schiepek, 2006). Some important terms of the nonlinear dynamic systems approach are explained in a short glossary (see Box 1). When they are firstly noted in the text, the terms that are explained in the glossary are written in italics. Within this paradigm, the perspective on processes is based on a continuous high-frequency assessment (equidistant time sampling, once per day) of change trajectories that are not limited to specific tracks, but instead will show irregular ('*chaotic*') and individualised patterns. Based on the hypothesis that successful psychotherapies realise cascades of *order transitions* (i.e. transitions

of patterns; de Felice, Orsucci, et al., 2019; Gelo & Salvatore, 2016; Haken & Schiepek, 2006; Hayes, Feldman, et al., 2007), there should be at least one period of critical instability during the process. Given the complexity and the occurrence of order transitions during a change process, the nonlinear approach to psychotherapy feedback does not assume that moving out of any specific track would be associated with deterioration.

Individualised *trajectories* are much more complex than 'standard tracks'. In practice, psychotherapists can use this complexity as a source of information for reflecting the process together with their patients. Therapists and patients regularly (almost at each session) have a look at the time series and their dynamic patterns. Monitoring technologies like the Synergetic Navigation System (SNS) were developed for the online data acquisition, visualisation and analysis of these patterns and provide feedback on *self-organised pattern transitions* (Schiepek, Aichhorn, & Schöller, 2018; Schiepek, Eckert, Aas, Wallot, & Wallot, 2015). Not only when threatening deteriorations are identified, but continuously, that is in most of the sessions, patients and therapists discuss the current dynamics and, based on this, decide on the next steps of the process (continuous cooperative process control; Schiepek, Aichhorn, et al., 2016; Schiepek, Aichhorn & Schöller, 2018).

The theoretical background for the importance of locally increased dynamic complexity is that *critical instabilities* precede *far-from-equilibrium phase transitions* in complex, self-organising systems (Haken, 2004). Critical fluctuations also characterise therapeutic order transitions (Gelo & Salvatore, 2016; Haken & Schiepek, 2006; Hayes, Feldman, et al., 2007; Heinzel, Tominschek, & Schiepek, 2014; Olthof, Hasselman, Strunk, Aas, et al., 2019; Olthof, Hasselman, Strunk, Rooij, et al., 2019; Schiepek et al., 2014). Therapists should be aware of upcoming destabilisations during the process and make use of it for precisely placing interventions. Procedures of *deviation-amplifying feedback* (e.g. interventions which help to explore cognitions, emotions and behaviour beyond the stable pathological patterns or schemata) which are implemented during these periods need to be counterbalanced by taking care of the stability a patient experiences during periods of instability (see the generic principles of psychotherapy; Haken & Schiepek, 2006; Schiepek et al., 2015).

A crucial question concerns the sampling rates of the assessment. There is no international norm of how to do this, but it is evident that different sampling rates create different results. Time series based on daily measurements (continuous equidistant time sampling) reveal patterns that cannot be identified by slower and irregular measurement frequencies (Schiepek, Aichhorn, et al., 2016). Figure 1 shows the time series of 'self-esteem' as experienced by a patient diagnosed with borderline personality disorder. The emotional instability characterising the first third of the process stops and changes to a more stable and less volatile dynamics. This is a sudden change that does not manifest in the mean level of the dynamics (e.g., symptom severity, cf. the criterion of Tang & de Rubeis, 1999), but in the complexity and volatility of the dynamics. Different sampling rates produce different observed time courses. Compared

Box 1 Terms of nonlinear dynamic systems theory: A short glossary

Attractor: The pattern, or 'gestalt', which can be seen if the trajectory of a system dynamics is embedded in a phase space (see 'trajectory').

Butterfly effect: Sensitive dependency of the system dynamics ('trajectory') on its initial conditions or on small aberrations of the dynamics, for example by intrinsic fluctuations or by any kind of input from the environment. This kind of sensitivity limits any long-term predictability of the system dynamics, and it is a basic characteristic of nonlinear 'chaotic' systems.

(Deterministic) chaos: Irregular dynamics that are characterised by a complex order. Although chaotic dynamics may be created by deterministic mechanisms (e.g. coupled nonlinear equations), their (long-term) predictability is limited.

Control parameter: The control parameter(s) of a dynamic system determine the dynamic pattern that is realised by the system. In thermodynamically open (dissipative) systems, these parameters refer to the energy flow through the system. In a more general sense, control parameters modulate the interaction between the components of a system and, once critical thresholds are passed, can change the qualitative state of the system.

Critical instability: Fluctuations that are precursors of an order transition in self-organising processes.

Deviation-amplifying feedback: Feedback, sometimes also called positive feedback, that intensifies or 'amplifies' deviations from a stable state or attractor state. Deviation-amplifying is contrary to restabilising, or negative, feedback, which reduces and dampens deviations away to keep a stable state in place.

Dynamic complexity: This complexity measure of time series combines the amplitude and frequency of fluctuations with the distribution of measurement values over the scale range. Usually, it is calculated within a running window that allows for the representation of the complexity dynamics of a time series.

Far-from-equilibrium phase transition: Spontaneous emergence of a pattern or discontinuous jump between patterns emerging in a complex system. In physics or chemistry, phase transitions occur in dissipative (energy consuming) thermodynamically open systems by specific changes of control parameters.

Generic principles: The generic principles are derived from synergetics and based on principles of self-organisation. The principles describe conditions that should be realised in order for self-organisation in human change processes to take place.

Nonlinear dynamics: Dynamics that are produced by a nonlinear system. In many cases, nonlinear dynamics are chaotic in a strict sense. Nonlinear dynamics are different from nonstationary dynamics which implicate a qualitative transition of the pattern (e.g. concerning the level of a time series, from regularity to chaoticity, from a fix point to any kind of rhythm).

Order parameter: Measure or concept that allows for the description of the global behaviour of many components or subsystems of a system. In terms of synergetics, order parameters are patterns emerging from the interaction of many components and the other way round, constraining or 'enslaving' the behaviour of the components (circular causality between bottom-up and top-down effects). An example is convection cells in fluids which are created by many molecules of the fluid and—the other way round—enslave the behaviour of the molecules.

Order transition: Spontaneous emergence of a pattern or discontinuous jump between patterns in a complex system. Given that we usually do not have access to the control parameters in psychological systems and phase transitions require particular (manipulated) changes in control parameters, we prefer to use the softer term order transition, when we refer to clinical change phenomena.

Self-organisation: Spontaneous emergence of order or discontinuous jumps between modes of order in complex systems.

Trajectory: The sequence of system states over time. System states are defined by the variables that define the system or that are used to describe it. By using these variables to define the axes of a phase space, the trajectory can be embedded in this phase space.

with daily measures, weekly measures reveal different shapes of trajectories missing most of the information of *dynamic complexity* and on the pattern of change.

The question of sampling rates was addressed in other articles of our group (e.g. Schiepek et al., 2018; Schiepek et al., 2019). In addition to the methodological reasoning in these papers, here we focus on the question of whether the widely used concept of standard tracks may be valid, empirically supported and practically useful, which depends—besides other criteria—on the definition of sampling rates.

1.3 | Assessment criteria

Besides sampling rates and the role of complexity, another difference between feedback approaches is given by the focus on the criteria to be assessed. Is it only outcome (e.g. symptom severity, social functioning) or is it a diversity of factors and mediators which may contribute to therapeutic progress? A widely used process questionnaire that was designed for daily self-ratings (Therapy Process Questionnaire, TPQ; Schiepek et al., 2019) includes aspects like experienced progress, self-efficacy and
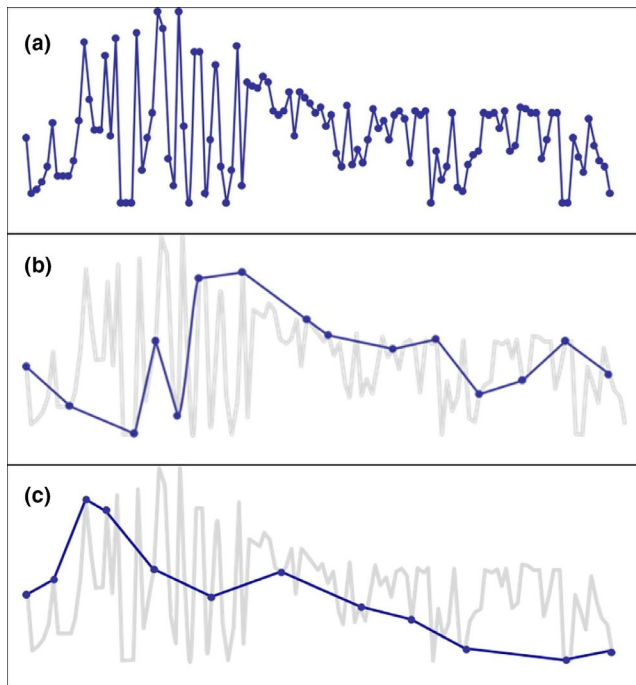
FIGURE 1 Down-sampling of measurement frequencies changes the features of the resulting dynamic pattern. (a) Time series of 'self-esteem', assessed by daily self-ratings (visual analogue scale) of a patient diagnosed with borderline personality disorder. There is a period of high volatility which disappears after about one-third of the therapy process. (b) and (c) A reduced number of measurement points was selected at a rhythm of about one week. On the average, every 7th day from the complete time series was respected with a variability of ± some days around this sampling rate. Although the measurement values remain unchanged, the overall impression of the change process is completely different and the impression of the complex pattern is lost

confidence in a successful process, motivation for change, emotions, insight and development of new perspectives, or mindfulness and body awareness.

1.4 | Different conjectures from the linear and the nonlinear approach

One reason for supposing that deviations from any standard track will not necessarily be associated with poor outcome is that chaotic trajectories are complex, unpredictable and individualised. Another reason is the necessity of order transitions and its precursors (critical instabilities, transient relapses) emerging in successful therapies (Haken & Schiepek, 2006; Hayes, Feldman, et al., 2007; Hayes, Laurenceau, Feldman, Strauss, & Cardaciotto, 2007; Olthof, Hasselman, Strunk, Aas, et al., 2019; Olthof, Hasselman, Strunk, Rooij, et al., 2019; Schiepek et al., 2014). However, in one point the predictions of the linear and the nonlinear model are in agreement: better dynamics compared with the standard track will result in better outcome (in this context, 'better' refers to, for example, reduced

symptom severity or worrying emotions, or increased experienced progress, mindfulness or body awareness). Besides the trivial assumption that better dynamics will produce better outcomes, for example running under the global average of a symptom severity standard track, it can be hypothesised that dynamic patterns ('problem attractors'; Grawe, 2004) placed in the upper range of, for example, a symptom severity scale will produce fluctuations in the direction of a new *attractor* which should be characterised by lower values of symptom severity. Additionally, early order transitions will shift the dynamics to another attractor which is placed under the standard track (Figure 2). This corresponds to the finding that sudden gains that occur during the process are correlated with better outcome at the end of the treatment (Hardy et al., 2005; Kelly, Roberts, & Ciesla, 2005; Wucherpfennig, Rubel, Hollon, & Lutz, 2017).

Crucial points of the discussion between the linear and the nonlinear paradigm refer to the following questions: (a) Are trajectories of change moving on standard tracks? (b) Are there different degrees of complexity in time series which were produced by high-frequency sampling compared to standard tracks based on low-frequency assessment? (c) Are 'not on track' dynamics correlated with poorer outcome than 'on track' dynamics? (d) Are complexity peaks representing critical fluctuations or transient instabilities correlated with better outcome?

2 | METHODS AND MATERIALS

2.1 | Subjects

The patients of this study were treated at two psychotherapy centres, the Department of Inpatient Psychotherapy at the University Hospital of Psychiatry, Psychotherapy and Psychosomatics (Paracelsus Medical University Salzburg, Austria) and the Department of Psychotraumatology at the St. Irmingard Rehabilitation Center (Prien am Chiemsee, Germany). Time series of 150 patients were available, and out of these patients, the time series of at least 80 patients (>50%) were used for the calculation of the 'standard tracks' (see Section 2.3). For 88 patients, ISR-based outcome assessments were available. The correlations between time-series characteristics (squared deviations from standard tracks, dynamic complexity) and outcome were calculated on these 88 patients. The characteristics of these patients are as follows: female: 63 (71.6%); male: 25 (28.4%); mean age: 40.9 (*SD* = 11.6). ICD-10 diagnostic categories are as follows: F2 (schizophrenia, schizotypal and delusional disorders): 2 (2.3%); F3 (mood disorders): 32 (36.4%); F4 (neurotic, stress-related and somatoform disorders): 48 (54.5%); F6 (disorders of adult personality and behaviour): 5 (5.7%); and F9 (behavioural and emotional disorders with onset usually occurring in childhood and adolescence): 1 (1.1%). The most frequent specific diagnoses are F33 (major depressive disorder, recurrent): 25 (28.4%); and F43 (reaction to severe stress and adjustment disorders): 30 (34.1%). The mean number of additional diagnoses is 1.3. The mean time-series length is 73 measurement days (*SD* = 22.6); the mean number of missing data is 0.2 (0.3%). Written informed consent was

obtained from every patient. Due to the retrospective nature of our investigation, a formal consent of the local ethics committee was not required. A general approval for using the SNS in clinical settings was stated by the ethics commission of the Salzburg government (No. 415-E/1068/3-2009). All procedures were in accordance with the Helsinki Declaration as revised in 2013.

2.2 | Questionnaires and monitoring technology

The psychotherapeutic change processes were assessed by the Therapy Process Questionnaire (TPQ; Schiepek et al., 2019), which was further developed from the original version that was used in former applications and studies (Haken & Schiepek, 2006; Schiepek, Aichhorn, & Strunk, 2012). This process questionnaire was developed for daily multidimensional self-assessments of inpatient treatments. The TPQ as it was used in this study included 47 items using visual analogue scales clustered into eight subscales. Here, we refer to the subscales 'therapeutic success/progress/self-efficacy' (S), 'emotions (high values refer to dysphoric/worrying emotions and low values to positive emotions)' (E), 'insight/creating new perspectives' (I), 'motivation for change' (M), 'problem/symptom severity' (P) and 'mindfulness/body awareness' (Mind).[1] The subscales 'working alliance' and 'relationship to fellow patients' were not included because they can be seen as boundary conditions of the change dynamics but not as indicators of it. Usually, these conditions are much more stable than the factors S, E, I, M, P and Mind.

The outcome was assessed at admission to and at dismissal from the hospital by the ICD-10-based Symptom Rating (ISR; Tritt et al., 2008, 2013). The subscales are 'depression', 'anxiety', 'obsessive-compulsive disorder (OCD)', 'somatoform disorder', 'eating

disorder' and an additional scale with problems not related to the other subscales. The total score averages the items of all subscales by a weight of 1, except for the items of the additional scale which are weighted by 2. Both questionnaires, the TPQ and the ISR, were administered by an Internet-based monitoring system, the Synergetic Navigation System (SNS), which was developed for the assessment of processes and outcomes in naturalistic settings (Schiepek, Aichhorn, et al., 2016; Schiepek Aichhorn & Schöller, 2018).

2.3 | Construction of Standard Tracks

Referring to the usual procedure of defining standard tracks by session-based measures (Finch, Lambert, & Schaalje, 2001), we assumed that sessions would take place about once per week. In consequence, every 8th measurement point out of the daily assessed time series was taken for the construction of the standard tracks. These 'weekly' measurement points were linearly interpolated, and the resulting lines were averaged over the included patients. With increasing length of the time series, the number of patients who realised these time series decreases, resulting in instable tracks based on fewer and fewer patients whose time series contribute to the track (Figure 3). For this reason, we defined a criterion of including at least 50% of the sample for the construction of the standard tracks, one track for each subscale of the TPQ. Following the criterion of >50% of the sample, the calculation of standard tracks includes all 150 patients at the beginning and 80 patients at the end of the tracks. In consequence, at least 80 patients cover a treatment length of 71 days.

2.4 | The dynamic complexity measure

The measure of dynamic complexity (for mathematical details, see Haken & Schiepek, 2006; Schiepek & Strunk, 2010) allows for the identification of critical instabilities and for the quantification of the irregularity and volatility of time series. It combines the amplitude, the frequency and the distribution of the values of a time series over the available range of a scale. All of these features (amplitude, frequency and distribution) are calculated within a gliding window that runs over the complete time series (given daily measures, the usual window width is 7 days).
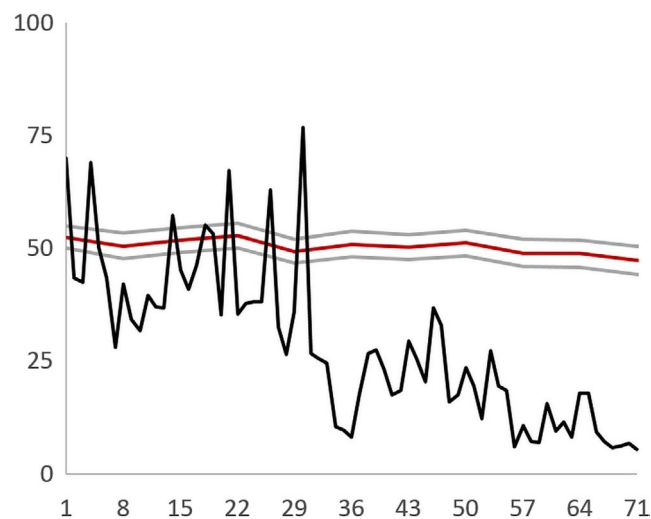
3 | RESULTS

3.1 | Standard tracks based on 95% confidence intervals

The percentage of measurement points placed out of a standard track depends on the confidence interval which is defined around the mean track. If a 95% confidence interval (±1.96 standard deviations) is used, almost all measurement points of the time series lie within
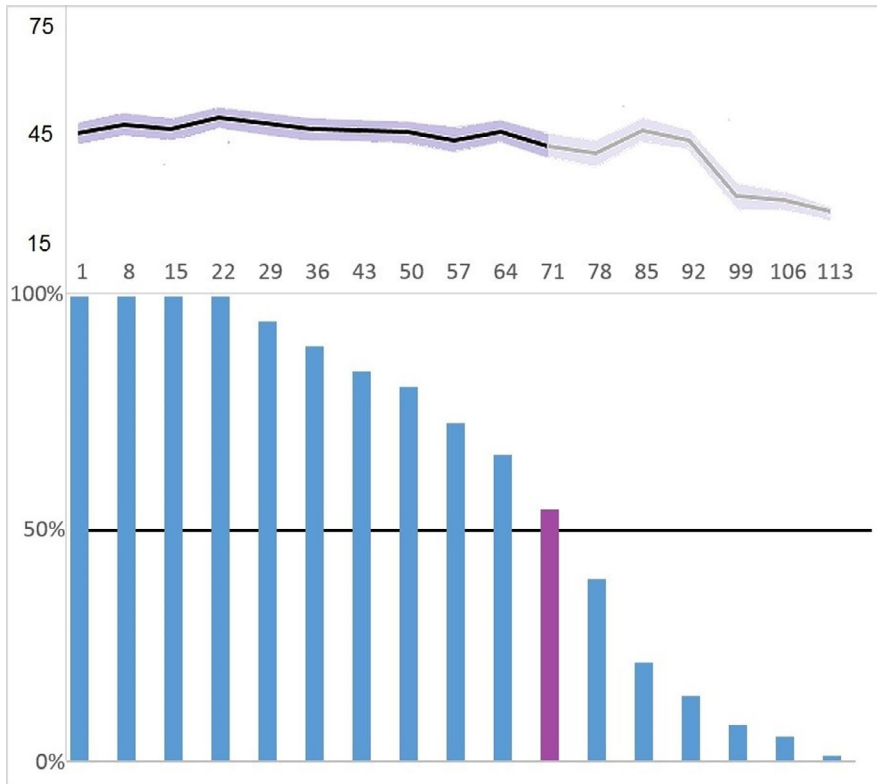
FIGURE 2 Dynamics of the variable 'problem/symptom severity'. High-level dynamics changes to low-level dynamics, which implicates that after the order transition, the dynamics moves under the averaged trajectory ('standard track'). Usually, order transitions implicate that after this, the trajectories are moving under (for problem intensity or worrying emotions) or over (for therapeutic success, motivation to change or mindfulness) the mean track

the confidence bands of the standard tracks. Figure 4 illustrates that standard tracks based on 95% confidence intervals (light grey bands in Figure 4) fill almost the complete area spanned by factor values (*y*-axis: normalised intensity from 0% to 100%) to treatment time (*x*-axis: 71 measurement points). If the standard criterion of a 95% confidence interval would be applied, any hypothesis of treatments running on or out of standard tracks could not be falsified. This is the reason why for testing hypotheses on the relationship between change dynamics and outcome we will use a narrower band of a ±5% confidence interval (dark grey bands in Figure 4). The ±5% confidence band around the standard track allows for a substantial amount of measurement points to be placed outside of the confidence band.

3.2 | Complexity of standard tracks and low-frequency measures compared with high-frequency measures

Comparing the mean dynamic complexity of the factor dynamics as it was measured day by day (high-frequency time sampling) with the mean of the down-sampled time series (weekly measures at measurement points 1, 8, 16, …) and the dynamic complexity of the mean tracks (mean line of the standard tracks), it becomes evident that the complexity of the original high-frequency dynamics is almost completely lost if time series were generated by weekly assessments. The complexity of the low-frequency dynamics is about 30–40 times lower than the complexity of the high-frequency dynamics (Table 1). Compared with the averaged standard tracks, the complexity is reduced by a factor of about 2 or 3×10^{-3}. Standard tracks are almost

straight lines, and by this, any complexity vanishes (Table 1; Figure 5). It should be noted that even the complexity of the high-frequency dynamics of the subscales (factors) is reduced compared to the complexity of the raw data dynamics of the items which are assessed by visual analogue scales (0–100). Raw data complexities usually vary between 0.05 and 0.7.

3.3 | Chaotic dynamics: The 'butterfly effect'

If we have a closer look at the dynamics of specific factors, we find trajectories that realise the so-called '*butterfly effect*'. This notion illustrates the sensitive dependency of the dynamics on small differences in the initial conditions, which is an essential feature of chaotic dynamics realised by nonlinear systems, and it is one reason for the limited predictability of chaotic processes (Schuster, 1989; Strogatz, 2014; Strunk & Schiepek, 2006). Figure 6 represents the dynamics of the factor 'problem/symptom severity' (P) of three patients in each diagram. The trajectories were selected by the criterion of the first three to five measurement values lying very close to each other.

3.4 | Correlations between the deviation from the standard tracks and the outcome

The relationship between the deviation from the standard tracks and the outcome was defined by the correlation of the averaged squared differences between the measurement values and the standard tracks as defined by a ±5% confidence interval around the mean tracks, and
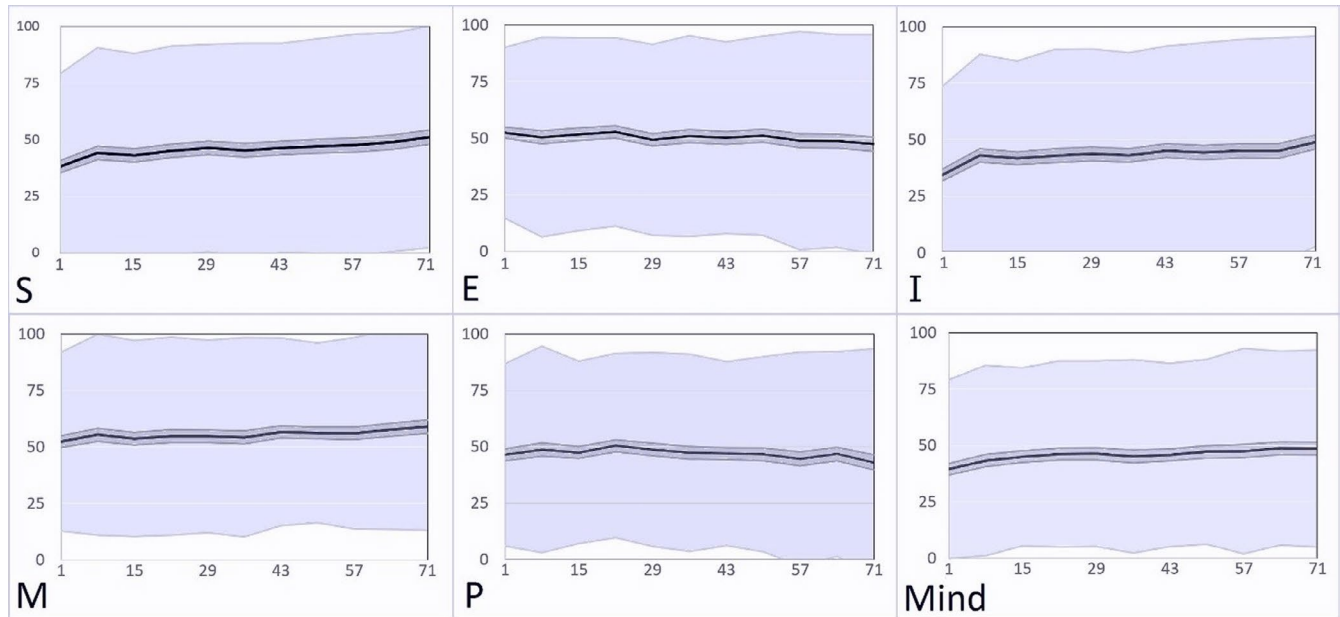
FIGURE 4 Standard tracks defined by a 95% confidence interval (light grey band) around the mean track (black lines). The dark grey line around the mean track represents a ±5% confidence interval. x-axis: time (71 measurement points = treatment days); y-axis: normalised intensity of the factors from 0% to 100%. 'Therapeutic success/progress' (S), 'emotions' (high values refer to dysphoric/worrying emotions and low values to positive emotions) (E), 'insight/creating new perspectives' (I), 'motivation for change' (M), 'problem/symptom severity' (P) and 'mindfulness/body awareness' (Mind)

the scales of the ISR. Table 2 shows the correlations of the squared deviations and the subscales of the ISR independent of the direction of the deviations. Most of the correlations are not significant, and the significant correlations are positive (positive correlations indicate an association between the averaged squared deviations and positive outcome, i.e. symptom reduction as assessed by the ISR). This reveals that deviations from a standard track do *not* predict poor outcome and, on the contrary, are associated with better outcome (Figure 7).

Tables 3 and 4 differentiate for the direction of the deviations. As it was expected, the existing significant correlations indicate a positive association between deviations from the ±5% standard tracks in the direction of increased values and a positive outcome for the subscales S (success/therapy progress), M (motivation for change) and Mind (mindfulness/body awareness), and a negative association for deviations in the direction of increased values and positive outcome for P (problem/symptom severity) and

E (dysphoric emotions) (Table 3). Table 4 shows some significant correlations that indicate a positive association between deviations from the standard track in the direction of decreased values and positive outcome for the subscales P (problem/symptom severity) and E (dysphoric emotions), three negative correlations for Mind (mindfulness/body awareness) and one for M (motivation for change) (Figures 8 and 9).

3.5 | Correlations between locally increased dynamic complexity and the outcome

A last result refers to the hypothesis that successful psychotherapies are characterised by cascades of order transitions. Order transitions are assumed to be a basic mechanism creating sudden gains or sudden losses and should be associated with positive outcome. In many

TABLE 1 The dynamic complexity (DC) of the TPQ factors ('therapeutic success/progress/self-efficacy' (S), 'dysphoric emotions' (E), 'insight/creating new perspectives' (I), 'motivation for change' (M), 'problem/symptom severity' (P) and 'mindfulness/body awareness' (Mind))

	S	E	I	M	P	Mind
DC high-frequency measures	0.02296	0.02578	0.02503	0.02695	0.03559	0.02005
DC down-sampling to weekly measures	0.00074	0.00071	0.00066	0.00077	0.00101	0.00054
DC mean tracks	0.00001	0.00001	0.00002	0.00001	0.00001	0.00000

Note: 'DC high-frequency measures' refers to the daily measures of the factors (arithmetic mean of 88 patients which were available for the process–outcome analysis), 'DC down-sampling to weekly measures' refers to the time series that were generated by taking only every 8th value and an interpolation of the missing values in between (arithmetic mean over 88 patients), and 'DC mean track' refers to the mean line of the standard tracks (black lines in Figure 4).
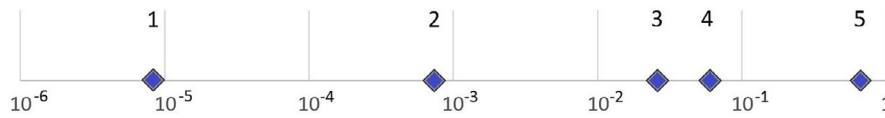
FIGURE 5 The values of the dynamic complexities of different types of time series presented in a logarithmic scale ($\log_{10}$). (1) Dynamic complexity mean of the standard tracks of the factors S, E, I, M, P and Mind (DC = 0.0000083). (2) Dynamic complexity of the factors as generated by the down-sampling procedure of 'weekly' assessments (1, 8, 16, … measurement point), averaged on 88 patients (DC = 0.0007402). (3) Dynamic complexity of the factors as originally generated by daily self-ratings (high-frequency sampling), averaged on 88 patients (DC = 0.0260596). (4) Illustration of the mean dynamic complexity of the items (visual analogue scales from 0 to 100) as originally generated by daily self-ratings (high-frequency sampling), averaged on 88 patients (DC = 0.0602851). (5) Illustration of the maximum dynamic complexity of the items (visual analogue scales from 0 to 100) as originally generated by daily self-ratings, averaged on 88 patients (DC = 0.6636508)
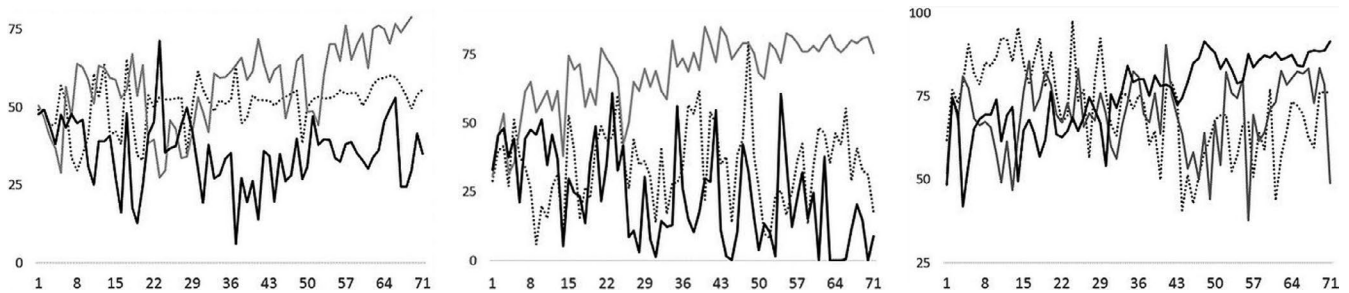

FIGURE 6 The 'butterfly effect' (sensitive dependency of the dynamics on its initial conditions) realised by the empirical dynamics of the factor 'problem/symptom severity' (P). Each diagram represents the trajectories of three different patients (black, grey, dotted lines). y-axis: normalised intensity of the factor (0%–100%); x-axis: time (71 days)

	Dep	Anx	OCD	Som	Eat	Add	Total
S	0.20	0.01	0.21*	−0.05	−0.06	0.07	0.09
E	0.24*	0.12	0.18	0.09	−0.05	0.12	0.17
I	−0.05	−0.1	0.15	−0.12	−0.09	−0.05	−0.06
M	0.22*	0.07	0.29**	−0.05	−0.15	0.07	0.11
P	0.28**	0.08	0.2	0.21*	0.12	0.15	0.24*
Mind	0.03	−0.02	0.09	−0.06	−0.27*	−0.14	−0.09

TABLE 2 Correlations between the subscales of the ISR (pre minus post) and the averaged squared differences of time-series points from the respective standard track of the factors S, E, I, M, P and Mind of the TPQ as defined by a ±5% confidence interval around the mean track

Note: As illustrated, the differences do not respect the direction of the deviation from the standard track. Subscales of the ISR: 'depression' (Dep), 'anxiety' (Anx), 'obsessive-compulsive disorder' (OCD), 'somatoform disorder' (Som), 'eating disorder' (Eat), additional scale (Add) and total score (Total).
*Significant at $p<.05$.
**Significant at $p<.01$.

cases, critical fluctuations of the system dynamics are a precursor of order transitions and a necessary, but not yet sufficient, condition for order transitions and therapeutic success. Periods of critical instabilities manifest in locally increased dynamic complexity. The difference of the overall mean of the dynamic complexity and its highest peak (maximum) should be a measure of the intensity of the critical instability and an indicator for order transitions. The correlations of the maximum–mean complexity differences of the TPQ factors and the subscales of the ISR are shown in Table 5. All correlations are positive with significant correlations in Mind, P and M. In the time series of these factors, the occurrence of critical instabilities is significantly associated with symptom reduction in some, but not all, of the subscales of the ISR.

4 | DISCUSSION

4.1 | Loss of complexity-related information in standard tracks

Following the usual procedure of how standard tracks or dose–outcome curves are defined (averaging measures of patients which were taken at sessions, i.e. at low and irregular sampling rates), the resulting lines are flat and lose almost any complexity. The trajectories of high-frequency measures as realised in routine process monitoring with the SNS are far away from these tracks. This is proven by the fact that 95% confidence bands around the mean
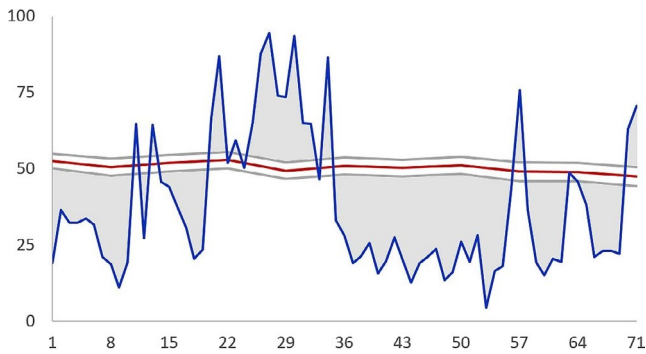
FIGURE 7 Illustration of the deviations from the standard track in both directions. The mean of the squared deviations is correlated with the outcome (Table 2)

produce it (irregular and low-frequency assessment times, averaging over patients, perhaps even smoothing the trajectories before averaging) correspond to a linear perspective on human change processes. Nonlinear trajectories will have no chance to be detected because they were eliminated by the procedure. If therapists and researchers are interested in dynamic patterns, pattern transitions, dynamic complexities, critical instabilities and other precursors of sudden transitions, or synchronisation and desynchronisation of multiple process indicators, monitoring procedures should be used which are able to detect and visualise this kind of information. Whether standard tracks are seen as useful or as doubtful artefacts, missing any information on important features of change strongly depends on the theoretical perspective applied on understanding psychotherapy.

tracks which usually are taken for defining standard tracks cover almost the complete area of the measurement scale to treatment time. If we would accept this confidence band as the standard track, there would be no chance for empirical measures to exist outside of any standard track.

The construct of standard tracks only makes sense for low-frequency outcome monitoring using questionnaires like the OQ-45 for the assessment of change. The construct and the procedures to

4.2 | Deviation from standard tracks does not necessarily implicate poor outcome

The finding that 'not on track' trajectories are not necessarily associated with poor outcome corresponds to the conjecture that nonlinear features like critical instabilities or order transitions are moving far away from linear tracks. Fluctuations out of 'problem

TABLE 3 Correlations between the subscales of the ISR (pre minus post) and the averaged squared differences of time-series points from the respective standard track of the factors S, E, I, M, P and Mind of the TPQ as defined by a ±5% confidence interval around the mean track

	Dep	Anx	OCD	Som	Eat	Add	Total
S	0.38**	0.32**	0.34**	0.18	0	0.26*	0.35**
E	−0.14	−0.17	−0.14	−0.11	−0.14	−0.22*	−0.22*
I	0.13	0.17	0.18	−0.03	−0.06	0.13	0.13
M	0.28**	0.24*	0.31**	0.07	0.01	0.18	0.26*
P	−0.26*	−0.21*	−0.17	−0.1	−0.04	−0.29**	−0.26*
Mind	0.31**	0.34**	0.29**	0.14	0.01	0.25*	0.32**

Note: As illustrated, the correlations only respect differences from the standard track in the positive direction (increased values). Subscales of the ISR: 'depression' (Dep), 'anxiety' (Anx), 'obsessive-compulsive disorder' (OCD), 'somatoform disorder' (Som), 'eating disorder' (Eat), additional scale (Add) and total score (Total).
*Significant at $p < .05$.
**Significant at $p < .01$.

TABLE 4 Correlations between the subscales of the ISR (pre minus post) and the averaged squared differences of time-series points from the respective standard track of the factors S, E, I, M, P and Mind of the TPQ as defined by a ±5% confidence interval around the mean track

	Dep	Anx	OCD	Som	Eat	Add	Total
S	−0.06	−0.17	−0.01	−0.17	−0.09	−0.09	−0.14
E	0.31**	0.22*	0.27*	0.16	0.06	0.24*	0.29**
I	−0.12	−0.17	0.02	−0.11	−0.11	−0.11	−0.14
M	0.03	−0.06	0.05	−0.13	−0.28**	−0.05	−0.1
P	0.40**	0.21*	0.27*	0.24*	0.12	0.29**	0.36**
Mind	−0.14	−0.19	−0.05	−0.12	−0.30**	−0.26*	−0.25*

Note: As illustrated, the correlations only respect differences from the standard track in the negative direction (decreased values). Subscales of the ISR: 'depression' (Dep), 'anxiety' (Anx), 'obsessive-compulsive disorder' (OCD), 'somatoform disorder' (Som), 'eating disorder' (Eat), additional scale (Add) and total score (Total).
*Significant at $p < .05$.
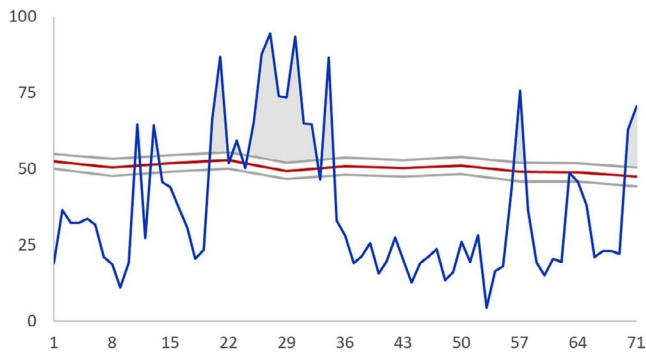**Significant at $p < .01$.

FIGURE 8 Illustration of the deviations from the standard track in the direction of increased values. The mean of the squared deviations is correlated with the outcome (Table 3)
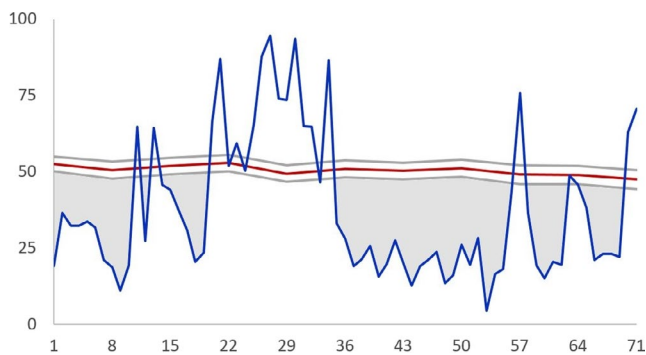

FIGURE 9 Illustration of the deviations from the standard track in the direction of decreased values. The mean of the squared deviations is correlated with the outcome (Table 4)

to better outcome. Taking different perspectives on the finding that 'better' dynamics may result in 'better' outcome, therapists referring to the concept of standard tracks will use this result in a different way than therapists working with concepts of self-organisation and nonlinear dynamics. With reference to standard tracks, therapists would look for deviations as precursors of deteriorations in order to apply clinical support tools; on the contrary, with reference to nonlinear dynamics and order transitions, therapists would look for critical instabilities and other precursors of transitions to apply the generic principles of change (the *generic principles* define the conditions for order transitions to occur) and to fit interventions to the process precisely.

4.3 | Limitations

There are some limitations of this study. One is a limited number of patients with ISR-based pre and post measures and time-series data available for analysis. In a replication of the present study, more patients from different treatment centres will be included. A second limitation is that the ISR was the only available outcome measure. Future studies should try to replicate the findings by using more and different outcome criteria. Third, the source of deviations from the standard tracks should be differentiated. One is critical fluctuations that appear at restricted periods of the process, another is changed attractors emerging during the process, and a third is unspecified dynamics simply moving at the 'better' or the 'worse' side of the mean tracks. This differentiation could help to test hypotheses derived from the linear or the nonlinear perspective.

attractors' (Grawe, 2004) explore new subspaces of a phase space and thereby potential new 'healthy attractors'. The fact that order transitions to the better—corresponding to sudden gains—are an essential characteristic of therapeutic self-organisation implicates that deviations from the mean track to the 'better' correspond

4.4 | Personalisation of psychotherapy

The implications that can be derived from the results of the present study also concern the individualisation and personalisation

	Dep	Anx	OCD	Som	Eat	Add	Total
S	0.21	0.05	0.15	0.10	−0.07	0.13	0.14
E	0.19	0.07	0.11	0.08	−0.11	0.19	0.14
I	0.19	0.12	0.11	0.00	0.06	0.20	0.17
M	0.22*	0.07	0.12	0.03	−0.02	0.13	0.14
P	0.38**	0.17	0.21*	0.12	−0.11	0.22*	0.25*
Mind	0.42**	0.27*	0.22*	0.17	−0.07	0.28**	0.31**

TABLE 5 Correlations between the subscales of the ISR (pre minus post) and the differences of the maximum and the mean of the dynamic complexity

Note: The maximum–mean difference is calculated on the dynamics of each factor S, E, I, M, P and Mind of the TPQ and indicates the highest intensity of the dynamic complexity during a process related to the mean of the dynamic complexity. The course of the dynamic complexity is calculated by a gliding window of 7 measurement points which runs over the complete time series of the respective factor. Subscales of the ISR: 'depression' (Dep), 'anxiety' (Anx), 'obsessive-compulsive disorder' (OCD), 'somatoform disorder' (Som), 'eating disorder' (Eat), additional scale (Add) and total score (Total).

*Significant at $p<.05$.

**Significant at $p<.01$.

of psychotherapy (Fisher, 2015; Schiepek, Stöger-Schmidinger, Aichhorn, Schöller, & Aas, 2016), including tailored treatments and an optimised fit of therapeutic procedures to the process. Personalised treatments require monitoring technologies that combine high-frequency assessment with nonlinear time-series analysis, and in consequence, also a different conceptualisation of so-called 'traffic lights'. Traffic lights are general indicators of important features of a process. From a nonlinear perspective, these features do not refer to standard tracks but to critical instabilities and other precursors of pattern transitions. The traffic lights that are implemented in the SNS show the actual state of system-related indicators. These indicators can be defined by the user, for example the current state of some of the generic principles or the risk of suicide attempts. The definition of a traffic light is based on the combination of specific items of a questionnaire whose values are summed up respecting different weights by which items contribute to the indicator. The current state of an indicator is shown by a bagel. It also shows whether a certain threshold is exceeded or undershot. A second type of traffic lights indicates whether the dynamic complexity of a process increases or decreases compared to the level of the immediate last period.

Time-series data representing change processes can be used for testing hypotheses derived from the nonlinear dynamic systems approach (synergetics and chaos theory). The most concrete reference of the data is a theoretical model of therapeutic change dynamics which includes the factors 'success/therapeutic progress' (S), 'emotions' (E), 'insight' (I), 'motivation for change' (M) and 'problem intensity' (P) as its order parameters (Schiepek et al., 2017; Schöller, Viol, Aichhorn, Hütt, & Schiepek, 2018). The option to measure the order parameters of the model allows for testing this nonlinear theory of change and to realise short-term predictions of the process (including critical instabilities) which could help to optimise treatments.

- Beyond the focus of 'on track' versus 'not on track' dynamics, high-frequency feedback and process reflection is a continuous process that becomes part of routine practice (continuous cooperative process control). Patients and therapists refer to the dynamics not only when patients are moving 'not on tracks'.
- There are different routines of using traffic lights (see Section 4.4). The linear way is to use them as indicators of being 'not on track', and the nonlinear way is to indicate the current level of motivation for change, stable boundary conditions, the quality of the therapeutic relationship, or upcoming critical instabilities and other precursors for sudden changes.
- Clinicians become sensitive to critical instabilities and use it for applying interventions at qualified moments ('kairos').
- Therapists and patients learn that all kinds of dynamic patterns carry information that can be used for understanding pathological patterns and/or mechanisms of coping, change and learning.
- Daily measures (including electronic diaries) incorporate everyday life experiences much more than session-by-session measures do.
- Accepting all kinds of change dynamics—also trajectories that are moving slowly or are characterised by crises or relapses—avoids normative restrictions, gives regard to the individual and is more realistic than imposing normative trajectories.
- High-frequency measurement triggers processes of self-reflection, self-regulation and mentalisation. In consequence, measurement is intervention.

Methodologically, high-frequency monitoring opens the door to a nonlinear dynamic systems perspective on change processes and, by this, to an empirically based understanding of the dynamics of psychotherapy. Given a widespread use of this technology in naturalistic real-world settings (inpatient and outpatient), we get big data pools for testing models on a much broader base than is possible by limited studies.

4.5 | Conclusions

The clinical significance of the results is given by the fact that the trajectories of human change processes are individual, complex and characterised by critical periods and order transitions. Advanced Internet- and app-based technologies like the SNS can assess, analyse and visualise such nonlinear dynamics if the time series are sampled at high frequency and equidistant rates. Daily self-assessments by multidimensional questionnaires autocatalyse and support the therapeutic process (e.g. by mechanisms of mentalisation, self-regulation and self-motivation). Both the patient and the therapist can focus on important information from the time signals and their analysis (dynamic complexity, synchronisation patterns, ups and downs of values). In this way, time series contribute to the procedures of case formulation, to the insight into the problem dynamics and to the control of processes.

For summing up, the practical implications are as follows:

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NOTE

[1]These subscales (factors) are based on a former factor analysis of the TPQ and were valid during the application of the TPQ in the study period (2016–2018). A recent explorative and convergent factor analysis (Schiepek et al., 2019) revealed a slightly modified factor structure.

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