Modellierung und nichtlineare Zeitreihenanalyse psychotherapeutischer Prozesse

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Inhaltsverzeichnis

TEIL I: Einleitende Zusammenfassung der zur Erlangung des Doktorgrades (Dr. phil.) an der Fakultät für Psychologie und Pädagogik der Ludwig-Maximilians-Universität München vorgelegten Publikationen (kumulative Dissertation)

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Publikationen

Folgende Fachartikel entstanden unter meiner Mitwirkung im Rahmen meines Promotionsstudiums:

Erst-Autorenschaft

[1] **Schöller, H.**, Viol, K., Aichhorn, W., Hütt, M.T., & Schiepek, G. (2018). Personality development in psychotherapy: a synergetic model of state-trait dynamics. *Cognitive Neurodynamics, 12(5), 441-459.* doi.org/10.1007/s11571-018-9488-y. Dieser Artikel ist veröffentlicht unter der Creative Commons Attribution 4.0 International License[1] und ist in dieser Arbeit unverändert abgedruckt.

[2] **Schöller, H.**, Viol, K., Goditsch, H., Aichhorn, W., Hütt, M.T., & Schiepek, G. A nonlinear dynamic systems model of psychotherapy: first steps toward validation and the role of external input. *Nonlinear Dynamics in Psychology and the Sciences 23(1):79-112, January 2019.* Dieser Artikel ist in der vorliegenden Arbeit unverändert abgedruckt mit freundlicher Genehmigung von *Nonlinear Dynamics, Psychology, and Life Sciences*.

Letzt-Autorenschaft

[3] Schiepek, G., Viol, K., Aichhorn, W., Hütt, M.T., Sungler, K., Pincus, D., & **Schöller, H.** (2017). Psychotherapy is chaotic—(not only) in a computational world. *Frontiers in Psychology for Clinical Settings, 8:479. doi: 10.4489/fpsyg.2017.00479.* Dieser Artikel ist veröffentlicht unter der Creative Commons Attribution 4.0 International License[1] und ist in dieser Arbeit unverändert abgedruckt.

[4] Schiepek, G., Aichhorn, W., & **Schöller, H.** (2018). Monitoring change dynamics – a nonlinear approach to psychotherapy feedback. *Chaos & Complexity Letters, 11(4),* 455-475. Dieser Artikel ist in der vorliegenden Arbeit unverändert abgedruckt mit freundlicher Genehmigung der Redaktion von *Chaos & Complexity Letters.*

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Ko-Autorenschaft

[5] Schiepek, G., Aichhorn, W., **Schöller, H.**, & Kronberger, H. (2018). Prozessfeedback in der Psychotherapie. Methodik, Visualisierung und Fallbeispiel. *Psychotherapeut, 64(4),* 406-414. doi.org/10.1007/s00278-018-0272-6. Dieser Artikel ist veröffentlicht bei Springer unter Open Access-Lizenz und ist in dieser Arbeit unverändert abgedruckt.

[6] Schiepek, G., **Schöller, H.**, Viol, K., Hütt M.T., Sungler, K., & Menning, H. (2016). Die Mathematik der Psychotherapie. *Psychoscope 5/2016*, 28-41. Dieser Artikel ist in der vorliegenden Arbeit unverändert abgedruckt mit freundlicher Genehmigung der Redaktion von *Psychoscope.*

[7] Stöger-Schmidinger, B., Aichhorn, W., **Schöller, H.**, Aas, B., & Schiepek, G. (2016). Systemische Fallkonzeption und State-Dynamik bei einer Patientin mit struktureller Dissoziation der Persönlichkeit. *Familiendynamik, 41(4),* 422-442. *doi: 10.21706/FD-41-4-422.*
Dieser Artikel ist in der vorliegenden Arbeit unverändert abgedruckt mit freundlicher Genehmigung der Redaktion von *Klett-Cotta*.

[8] Schiepek, G., Stöger-Schmidinger, B., Aichhorn, W., **Schöller, H.**, & Aas, B. (2016). Systemic case formulation, individualized process monitoring, and state dynamics in a case of dissociative identity disorder. *Frontiers in Psychology for Clinical Settings, 7:1545. doi: 10.4489/fpsyg.2016.01545.* Dieser Artikel ist veröffentlicht unter der Creative Commons Attribution 4.0 International License[2] und ist in dieser Arbeit unverändert abgedruckt.

[9] Michaelis, R., **Schöller, H.**, Höller, Y., Kalss, G., Zimmermann, G., Kirschner, M., Schmid, E., Trinka, E., & Schiepek, G. (2018). Integrating the systematic assessment of psychological states in an epilepsy monitoring unit: Concept and compliance. *Epilepsy & Behavior 88/2018, 5-14. doi: 10.1016/j.yebeh.2018.08.029.* Dieser Artikel ist veröffentlicht bei ScienceDirect und ist in dieser Arbeit unverändert abgedruckt mit freundlicher Genehmigung von Elsevier.

[10] Schiepek, G., **Schöller, H.**, Carl, R., Aichhorn, W., & Lichtwark-Aschoff, A. (in press). A nonlinear dynamic systems approach to psychological interventions. In S. Kunnen, M. van der Gaag, N. de Ruiter, & B. Jeronimu (Eds.), *Psychosocial Development in Adolescence: Insights from the Dynamic Systems Approach.* New York: Routledge. Dieser Beitrag ist zum Datum der Fertigstellung dieser Arbeit nicht veröffentlicht und darf nicht abgedruckt werden. Die Veröffentlichung erfolgt im Mai 2019 (ISBN-13: 978-1138055568, ISBN-10: 1138055565).

[11] Viol, K., Aas, B., Kastinger, A., **Schöller, H.**, Kronbichler, M., Reiter, E.-M., Said-Yürekli, S., Kronbichler, L., Kravanja, B., Stoeger-Schmiedinger, B., Aichhorn, W., & Schiepek, G. Individual OCD-provoking stimuli activate disorder-related and self-related networks in fMRI. *Psychiatry Research – Neuroimage 283/2019, 135-144e. doi: 10.1016/j.pscychresns.2018.12.008*
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Bedeutung der Arbeiten für das Fachgebiet

Das Bezugsparadigma der Arbeiten

Die für diese kumulative Dissertation eingereichten Publikationen stehen in einem inhaltlichen Zusammenhang und wurden in einem einheitlichen paradigmatischen Rahmen der Psychologie – insbesondere der Klinischen Psychologie und Psychotherapieforschung – angefertigt. Es handelt sich um das Paradigma der Synergetik und der Chaostheorie, welche von manchen Autoren unter der Bezeichnung „Nonlinear Dynamic Systems Approach" oder „Complexity Science" zusammengefasst werden (z.B. Gelo & Salvatore, 2016; Mainzer, 2007; Orsucci, 2006, 2015).

Die von dem mathematischen Physiker Hermann Haken ursprünglich zur Erklärung des LASERs – eines quantenoptischen Phänomens – entwickelte *Synergetik*, welche die Emergenz von Ordnungszuständen aus sogenannten Ungleichgewichts-Phasenübergängen erklärt (Haken, 2004), wurde bereits von ihm und seinen Mitarbeitern auf die Musterbildung in verschiedenen Systemen außerhalb der Physik generalisiert. Seit den 1980er Jahren erfolgten dann unterschiedliche Übertragungen – in der Sprache der strukturalistischen Theorienauffassung (z.B. Stegmüller, 1973): „intendierte Anwendungen" – auch auf psychologische Phänomene wie motorische Koordination, visuelle Wahrnehmung, Entscheidungsprozesse, Meinungsbildung in großen sozialen Kollektiven, schließlich auch auf klinisch-psychologische Themen und die Psychotherapie (Haken & Schiepek, 2006/2010; Schiepek et al., 2016; Schiepek & Tschacher, 1997; Tschacher et al., 1992).

Die *Chaostheorie* modelliert und analysiert das komplexe Verhalten nichtlinearer Systeme in unterschiedlichen Kontexten, wobei die begrenzte Vorhersehbarkeit von Dynamiken hervorgehoben wird, die aus nichtlinearen iterativen Prozessen entstehen, und auch die sensitive Abhängigkeit der Dynamik von Startbedingungen, minimalem Input und von Parameterwerten (z.B. Guastello et al., 2009; Heath, 2000; Ott, 1993; Strunk & Schiepek, 2006). Beide Ansätze (Synergetik und Chaostheorie) fokussieren auf die diskontinuierliche Veränderung dynamischer Muster, auf die Rolle von Kontrollparametern, auf die nichtlineare Eigendynamik komplexer Systeme (im Gegensatz zu linearen Input-Output-Mechanismen), oder auf Frühwarnzeichen („precursors") wie kritischen Instabilitäten vor dem Auftreten von Musterwandel (Phasenübergänge).

Damit erscheinen diese Ansätze für das Verständnis so wohl psychopathologischer Phänomene (z.B. die zeitlichen Muster von klinischen Störungsbildern), neuronaler Prozesse wie z.B. die hochdynamische Veränderung von Konnektivitätsmustern im Gehirn, menschlicher Entwicklung, oder auch psychotherapeutischer Veränderungsprozesse sehr geeignet. In meinen Arbeiten habe ich mich primär auf das Gebiet der Psychotherapie-Prozessforschung begeben und konnte mich dabei auf umfassende Vorarbeiten beziehen, in denen therapeutische Prozesse bereits auf unterschiedlichen Zeitskalen (z.B. Mikroprozesse der Therapeut-Klient-Interaktion: Schiepek et al., 1997; Kowalik et al., 1997; Ramseyer & Tschacher, 2008; täglich getaktete Dynamik: z.B. Haken & Schiepek, 2006/2010; Heinzel et al., 2014; Schiepek et al., 2014; Schiepek et al., 2015) oder unterschiedlichen Systemebenen (z.B. synchronisierte Ordnungsübergänge in neuronalen und psychischen Systemen, Schiepek et al., 2013) untersucht worden waren. Ein wichtiges und zugleich neues Arbeitsfeld waren mathematische Modellierungen und darauf aufbauende Computersimulationen, die der Erklärung therapeutischer Prozesse dienen. Neben der Modellierung der emotionalen Qualität von Therapeut-Patient-Beziehungen (Liebovitch et al., 2011; Peluso et al., 2012) fand ich einen Modellierungsansatz zum

Verständnis der intrapsychischen Dynamik von Patienten vor, der in der Arbeitsgruppe meines Erstbetreuers, Prof. Dr. Günter Schiepek, entwickelt und vorangetrieben wurde (Schiepek et al., 2016). Ein wichtiger Teil meiner Arbeiten bezieht sich auf dieses Modell und versteht sich als Beitrag zu dessen Weiterentwicklung, eingebettet in den kollegialen Kontext unseres Teams (Dr. Kathrin Viol, Institut für Synergetik und Psychotherapieforschung, PMU Salzburg; Prof. Dr. Marc Hütt, Department of Computational Systems Biology, Jacobs University, Bremen; Prof. Dr. Günter Schiepek, PMU Salzburg).

Motivation und Anspruch an die Modellierung von Psychotherapie

Das Interesse an derartigen mathematischen Modellierungen speist sich aus verschiedenen Quellen: Erstens wird in der Psychotherapieforschung seit längerem eine detaillierte Modellierung der Mechanismen von Veränderung eingefordert, da diese zwar in sehr heterogener Weise (nämlich von den vielen Therapieschulen) postuliert, aber noch nicht einheitlich erarbeitet wurden (Kazdin, 2005, 2009). Zweitens liegen in der Wirkfaktorenforschung (z.B. Duncan et al., 2010; Wampold & Imel, 2015) umfassende additive Auflistungen einzelner Faktoren vor, die mehr oder weniger substanziell zum Outcome von Psychotherapie beitragen können – meist unter Angabe entsprechender Prozentwerte der erklärten Outcome-Varianz –, aber keine konkrete (insbesondere formale) Vorstellung davon, wie das (v.a. nichtlineare) Zusammenwirken dieser Faktoren den Prozess generieren könnte. Eine Erklärung, die sich tatsächlich auf Prozesse und nicht nur auf den Effekt (Outcome) bezieht, kann nur in Form einer mathematischen Modellierung (in unserem Fall als System nichtlinearer gekoppelter Differenzengleichungen) erfolgen. Drittens liegen seit geraumer Zeit und in wachsendem Umfang engmaschig (z.B. täglich) erfasste Prozessdaten zu verschiedenen Störungsbildern und aus unterschiedlichen Behandlungskontexten vor, mit denen erstmals ein Einblick in die realen Verlaufsmuster von Psychotherapie möglich wurde. Da diese Daten vorwiegend mit dem internet- und app-basierten Synergetischen Navigationssystem (SNS) unter Verwendung des Therapie-Prozessbogens (TPB) erfasst wurden [4], konnte ich auf diese Daten zugreifen und sie zu Zwecken der Referenzbildung [10], der konkreten Modellvalidierung [2] und zur Prozessanalyse nutzen.

Der Anspruch des Modells war es, wichtige Ergebnisse der Prozess-Outcome- und der Wirkfaktorenforschung zu berücksichtigen, unter anderem

- Patientenfaktoren wie Veränderungsmotivation, kognitive und behaviorale Fertigkeiten, Kompetenzen von Mentalisierung und Emotionsregulation sowie andere Ressourcen spielen eine bedeutende Rolle
- Symptomausprägung, therapeutischer Fortschritt und Veränderungsmotivation sollten funktional aufeinander bezogen sein
- Es sollte klar werden, über welche Variablen die Veränderungsdynamik von Patienten beeinflusst werden kann (Eingangsrand für Interventionen)
- Die Rolle der Therapeutischen Beziehung sollte berücksichtigt werden
- Die wechselseitige Abhängigkeit von Emotionen, Einsicht und Konfrontation mit traumatischen Erfahrungen und inneren Konflikten sollten modelliert werden.
- Die Rolle der Problemaktualisierung (Aktivierung negativer Schemata) und die Notwendigkeit einer klärenden Perspektive auf Probleme (Grawe, 1998, 2004) sollten berücksichtigt werden
- Psychodynamische, kognitiv-behaviorale und ressourcenorientierte Beiträge zum Verständnis der Psychotherapie sollen verbunden werden

Die mathematische Modellierung psychotherapeutischer Prozesse

Ausgehend von der in Schiepek et al. (2016) dokumentierten Vorarbeit konnte ich mich ab dem Eintritt in das Institut für Synergetik und Psychotherapieforschung (Leitung: Prof. Dr. Günter Schiepek; Paracelsus Medical University, Salzburg) mit der weiteren Ausarbeitung der in dem Modell enthaltenen Funktionen befassen [3]. Die Funktionen beschreiben die Wirkung folgender Variablen aufeinander:

- E (*emotions*) Emotionen sind als bipolare Variable berücksichtigt, welche sich zwischen dysphorischen Emotionen (z.B. Angst, Schuld, Scham) und positiven Emotionen (Freude, Glück, im weiteren Sinn auch Selbstwertgefühl) aufspannt
- P (*problem intensity*) Problemausprägung/Intensität der Symptomatik, Erfahrung von inneren Konflikten oder Inkongruenzen
- M (*motivation*) Motivation zur Veränderung, Bereitschaft zum Engagement für therapiebezogene Aktivitäten
- I (*insight*) Einsicht, Erwerb neuer Perspektiven auf Probleme und Verhaltensmuster
- S (*success*) Erfolg, erlebter therapeutischer Fortschritt, Grad der Zielerreichung, Vertrauen in den Erfolg der Therapie

Die genaue Form der 16 Funktionen, die die Wirkungen der Variablen aufeinander beschreiben (Abb. 1), ist im Modell abhängig von folgenden Modulatoren:

- *a* (*alliance and attachment disposition*) Qualität der therapeutischen Beziehung, Fähigkeit zur vertrauensvollen Zusammenarbeit mit dem Therapeuten. Einerseits repräsentiert *a* die persönliche Disposition eines Patienten, sich in einer vertrauensvollen Beziehung zu engagieren, andererseits den Grad der realisierten Qualität der therapeutischen Beziehung.
- *c* (*cognitive competencies*) Kognitive Kompetenzen, Fähigkeiten zur Mentalisierung und Emotionsregulation, mentale Fähigkeiten zur Selbstreflexion
- *r* (*behavioral resources and skills*) Verhaltensressourcen, Verfügbarkeit von Strategien zur Problemlösung
- *m* (*motivational disposition, self-efficacy*) Motivationsbereitschaft als Persönlichkeitsmerkmal. Grad der erlernten Selbstwirksamkeit. Positive Erwartungen zur persönlichen Entwicklung, Grad der Belohnungserwartung

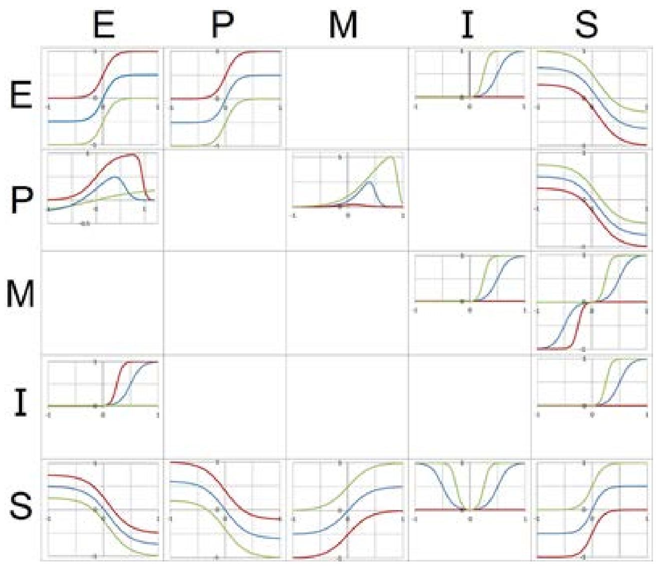

Abb. 1: Die nichtlinearen Funktionen des Modells. Die Variablen am linken Rand der Matrix (Zeilen) sind als Inputgrößen, die Variablen am oberen Rand der Matrix (Spalten) als beeinflusste Größen zu verstehen. Die obere Zeile zeigt zum Beispiel an, in welcher Weise E auf E, P, I und S wirkt.

Die Funktionen des Modells (Abb. 1) wurden nach im Vergleich zur ersten Modellstufe erweiterten psychologischen Erkenntnissen, basierend auf systematischer Literarturrecherche modifiziert, spezifiziert (z.B. die Funktion E(P) unter Berücksichtigung des Kenntnisstandes zur Emotionsregulation, insbesondere im Bereich der Borderline-Störung) und dem bestehenden Modell angepasst. Auch wurde mit Hilfe von Bifurkationsdiagrammen geklärt, in welchen Wertebereichen der Parameter das System chaotisches oder komplex periodisches Verhalten aufweist [3].

State-Trait-Interaktion

Eine substanzielle Erweiterung des Modells bestand in der Kopplung der Parameterdynamik an die Variablendynamik, womit eine kreiskausale Verbindung zwischen Ordnungsparametern und Kontrollparametern hergestellt wurde [1]. Auch wurde damit eine doppelte (komplementäre) Interpretation des Modells eingeführt: Die Variablen des Modells sind einerseits als Ordnungsparameter der Psychotherapie zu verstehen, andererseits als States, die relativ kurzfristiges Erleben und Verhalten eines Patienten repräsentieren. Die Modulatoren der Funktionen sind einerseits als Kontrollparameter im Sinne der Synergetik, andererseits als Kompetenzen, Dispositionen oder Traits, somit als langfristig veränderliche Größen zu verstehen. Die Dynamik von Ordnungsparametern (States) und von Kontrollparameters (Traits) entfaltet sich also auf verschiedenen Zeitskalen. Ordnungsübergänge entstehen aus der zeitverzögerten, langsamen Veränderung der Traits durch die Dynamik der States (konkrete Erfahrungen, Emotionen, Verhalten) über eine selbstorganisierte Schwelle (Kritikalität). Kritische Instabilitäten entstehen, wenn diese Schwelle erreicht wird – es ist dann sowohl möglich, dass ein Ordnungsübergang zu einem höheren Trait-Niveau und in eine veränderte State-Dynamik stattfindet, es ist aber auch möglich, dass die Trait-Dynamik unter der Schwelle bleibt und kein Übergang stattfindet. Damit ist zudem eine Bedingung für langfristige Stabilität der therapeutischen Effekte gegeben, nämlich eine Verschiebung des Trait-Niveaus über eine bestimmte Schwelle. Die formale Realisation dieses State-Trait-Modells besteht in der Kopplung der vier Kontrollparameter-Gleichungen für *a, c, r, m* an die fünf Ordnungsparameter-Gleichungen von E, P, M, I, S.

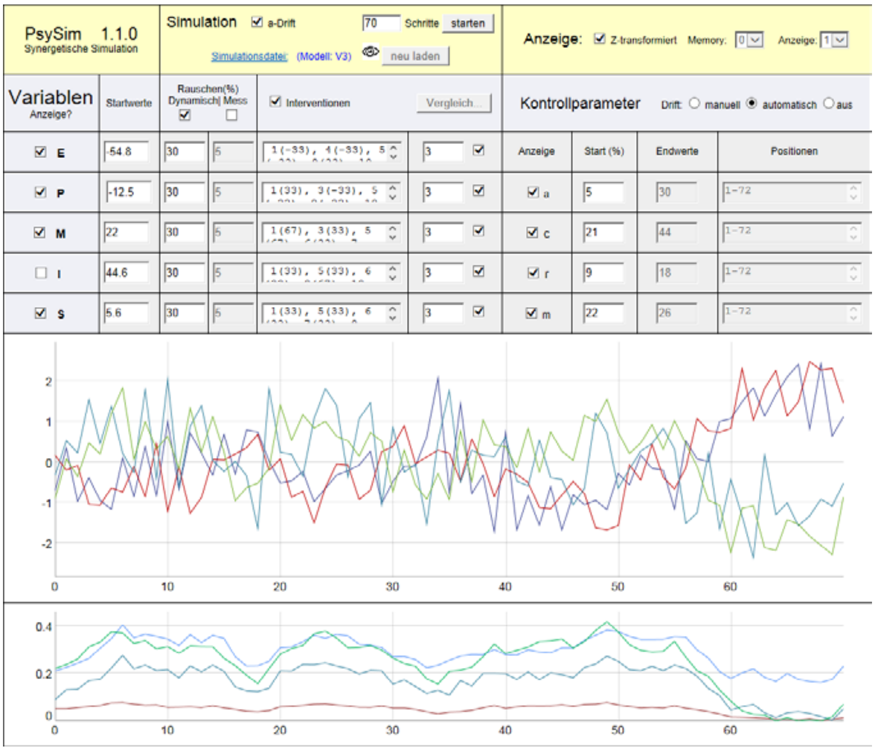

Abb. 2: Benutzeroberfläche des PsySim Simulationstools für Therapieprozesse. Dargestellt wird die Dynamik der Variablen (Ordnungsparameter oder States) und die Dynamik der Kontrollparameter (Traits).

Therapie spielen: Das PsySim-Tool

Ein wesentlicher Schritt, der in den Publikationen nicht repräsentiert ist, bestand in der Realisation eines Simulationstools für das Therapiemodell. Der Benutzer des Simulationstools (https://PsySim.at) kann unterschiedliche Startwerte wählen (womit z.B. unterschiedliche Symptom- und Problembelastungen oder Ausprägungen der Therapiemotivation am Beginn einer Therapie ausgedrückt werden), dynamisches oder Messrauschen ein- oder ausschalten, unterschiedliche Parameterausprägungen zu Therapiebeginn wählen (höhere oder niedrigere Kompetenzen, Bindungsfähigkeiten oder Motivationsniveaus, „Strukturniveau" im Sinne der OPD), oder eine konstante (lineare) oder eine dynamische Trait-Entwicklung (simulierte Kontrollparameter-Dynamik) wählen. Auch können unterschiedliche Interventionen (punktuell oder kontinuierlich über einen bestimmten Zeitraum, auf eine oder mehrere Variablen (States) gerichtet) vorgenommen werden. Das PsySim-Tool ermöglicht es, unterschiedliche Verhaltensmuster des Modells zu erkunden (z.B. die Simulation von Langzeiteffekten von Psychotherapien) und „Therapie" zu spielen. Es kann Psychologen und Psychotherapeuten durch die Interaktion mit einem simulierten „Patienten" verdeutlichen, wie komplexe Systeme funktionieren und mit welchen Besonderheiten man – anders als in linearen Systemen – in der nichtlinearen Dynamik solcher Systemen rechnen muss (z.B. zeitlich verzögerte Wirkungen, begrenzte Vorhersehbarkeit der Dynamik, Null-Effekte von Interventionen in stabilen Attraktoren oder sprunghafte Veränderungen bei minimalen Interventionen, diskontinuierliche Übergänge, Unterschiede zwischen punktuellen oder kontinuierlichen Interventionen, sudden gains, sudden losses). Das PsySim-Tool hat also vorwiegend didaktische Funktion zum Erwerb von „Systemkompetenz" (Verständnis und Handlungsfähigkeit in komplexen nichtlinearen Systemen) von Psychologen und Therapeuten. In Zukunft könnte ein solches System unter Vorbehalt entsprechender Modellvalidierungen und verfügbarer Daten (Startwerte der Variablen, Initial- und Prozessinformation zu den Kontrollparametern, Erfassung von Interventionswirkungen von Seiten des Patienten, aktueller Stand der Dynamik) auch dazu dienen, Interventionen am Modell zu testen, bevor sie real appliziert werden.

Interventionen in komplexen Systemen

Das Modell macht deutlich, welche Rolle Interventionen für die State-Dynamik spielen können und wie sich diese dann in die Trait-Dynamik übersetzt. Das Modell hat somit zu einem erweiterten Verständnis der Funktionsweise von Interventionen in der Psychotherapie beigetragen und diese auch am Simulationsmodell illustriert [10]. Entscheidend ist dabei, dass „erlebte" Interventionen, wie sie der Patient für sich subjektiv als bedeutsam und wirksam (im Sinne einer Veränderung der fünf States des Modells) erlebt, mittels täglicher Selbsteinschätzungen direkt erfasst werden können. Hierzu wurde der bei vielen Patienten in der Routine mitlaufende Therapie-Prozessbogen (vorgelegt und beantwortet mit Hilfe des SNS) um entsprechende fünf Items erweitert (erlebte Wirkung von Erfahrungen auf S, E, I, M, P). Auch die Variablen (States) des Modells können im Therapieverlauf kontinuierlich (täglich) erfasst werden; sie entsprechen fünf Faktoren des TPB (Haken & Schiepek, 2006/2010). Schließlich sind die Traits (Kontrollparameter) des Modells bekannte psychologische Konstrukte, für die es übliche und verbreitete Fragbögen gibt [1,2].

Modellvalidierung

Diese Datenbasis schafft die Voraussetzung für eine umfassende Validierung des Modells, die in Publikation [2] ausgearbeitet wurde. Das Vorgehen wurde in dieser Arbeit an einem Einzelfall illustriert, soll aber in Zukunft an einer großen Stichprobe realisiert werden. Unter Vorgabe bestimmter Bedingungen und des empirischen Inputs von außen (subjektiv erlebte Interventionseffekte) findet sich eine hohe Übereinstimmung der simulierten Modelldynamik mit dem realen (d.h. empirisch erfassten) Therapieverlauf des Klienten. Die Bedingungen sind: Nutzung der Startwerte der Variablen und der Parameter, Simulation der kompletten State-Trait-Dynamik, Berücksichtigung der empirischen (kontinuierlich vom Patienten eingeschätzten) Dynamik der Therapiebeziehung, welche in die Dynamik des Parameters *a* als empirische Komponente eingeht, und schließlich die subjektiv erlebten Interventionen auf die States (Variablen). Besonders letztere führten zu Korrelationen bis zu .60 zwischen simulierten und empirischen Verläufen (Abb. 3).

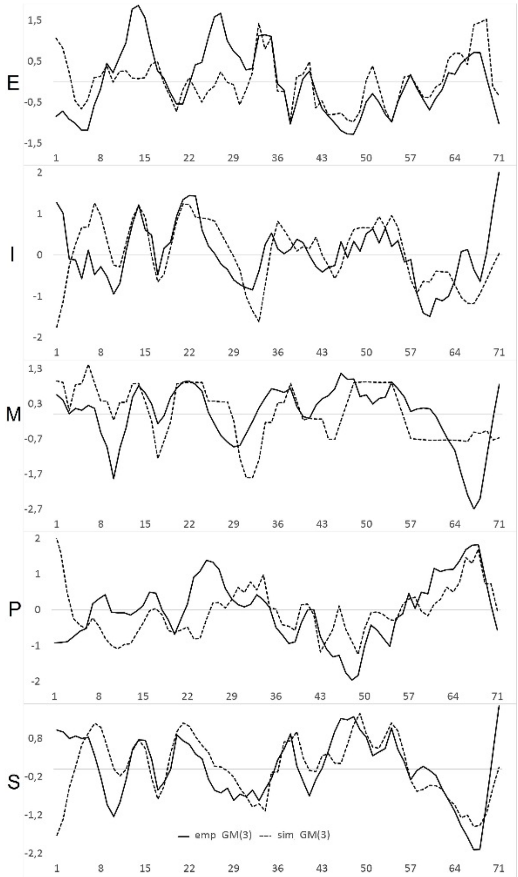

Abb. 3: Übereinstimmung zwischen empirischem (durchgezogene Linie) und simuliertem (gestrichelte Linie) Verlauf der fünf Variablen des Modells.

Ein wichtiger und zugleich schwieriger Punkt in der Entwicklung des Validierungsalgorithmus bestand darin, die gemessenen Kontrollparameter (Traits) aufgrund der vor und nach der Therapie beantworteten Fragebögen auf die modellspezifischen Werte zu kalibrieren. Ein Wert von 50% (bzw. 0.5) auf einer psychologischen Skala muss nicht unbedingt 0.5 im Wertebereich eines Modellparameters entsprechen. Es ist anzunehmen und scheint auch so zu sein, dass es ein modellspezifisches Sensitivitätsprofil für Kontrollparameter gibt, in welches die mittels Fragebögen gemessenen Parameterwerte übersetzt werden können.

„Not on Track“

Neben der Entwicklungs- und Validierungsarbeit am mathematischen Modell des psychotherapeutischen Prozesses [1,2,3,6] konnte ich zur Aufbereitung eines Großdatensatzes aus dem SNS zu Zwecken weitreichender Prozess-Outcome-Analysen von im Vergleich mit bisher üblichen Prozessdaten hochfrequent erfassten Zeitreihen beitragen. Eine aktuelle Studie konnte deutlich machen, dass therapeutische Verläufe keineswegs „Standard-Tracks“ folgen, sondern hochkomplex, individuell und nur sehr begrenzt vorhersehbar verlaufen – ganz im Sinne von Chaostheorie und Synergetik. Abweichungen von einem durch üblicherweise schlichte Mittelung von Verläufen gewonnen Standard-Track müssen keineswegs zwangsläufig mit schlechtem Outcome assoziiert sein. Auch das Phänomen des „Schmetterlingseffekts“ (sensitive Abhängigkeiten der Dynamik von den Ausgangsbedingungen) lässt sich in erstaunlich präziser Weise finden.

Das Synergetische Navigationssystem in Praxis und Forschung

Das speziell zur Erfassung, Analyse und Visualisierung von nichtlinearen Dynamiken entwickelte Synergetische Navigationssystem (SNS, s. die Darstellung der Funktionalitäten in [4]) liefert die Möglichkeit, die Veränderung von dynamischen Mustern in Psychotherapien detailliert und quasi in Echtzeit darzustellen. Es entspricht dem klinischen und therapeutischen Eindruck dieser Verläufe in erstaunlicher Weise, sodass es sich zur quantitativen wie qualitativen Illustration von Kasuistiken sehr gut eignet. Therapeutische Selbstorganisationsprozesse (Ordnungsübergänge, begleitet von kritischen Instabilitäten und sich verändernden Synchronisationsmustern) konnten in einigen Fallstudien sehr klar nachgezeichnet werden [5,7,8]. Nicht zuletzt wurden dabei einige störungsspezifische Muster, z.B. „rumination“ [5] oder das Oszillieren zwischen Ego-States im Falle einer Patientin mit dissoziativer Persönlichkeitsstörung [7,8] unmittelbar erkennbar.

Anwendungen des SNS gab es auch im Bereich des Epilepsie-Monitorings (5 Selbsteinschätzungen pro Tag), mit der Intention, subjektive Stressmarker und Coping-Strategien der Patienten in einem speziellen Setting zu erfassen, in dem epileptische Anfälle mit erhöhter Wahrscheinlichkeit auftreten können. In weiteren Schritten sollte es möglich sein, psychologische Frühwarnindikatoren epileptischer Zustände auch im Lebensalltag zu erfassen [9]. Eine wissenschaftliche Anwendung des SNS gab es auch in einem Forschungsprojekt zur Identifikation von Ordnungsübergängen in der Psychotherapie von Patienten mit Zwangsstörungen, wobei es um die Synchronisation von Übergängen in der subjektiven Dynamik (erfasst mit dem TPB-R), in der neuronalen Aktivierung und Konnektivität (wiederholte fMRI-Scans im Prozess) und in Immun- sowie Endokrin-Parametern ging [11].

Ausblick und weitere Entwicklungen

In Bezug auf die mathematische Modellierung psychotherapeutischer Prozesse ist eine Vereinfachung des Modells geplant, welche ohne bzw. mit einer reduzierten Anzahl von Zusatzparametern auskommt, wie sie bisher als Form- und Lageparameter der Funktionen eingeführt werden mussten. Damit soll das Modell sowohl eleganter als auch leichter prüfbar werden. Die Modellvalidierung soll unter Nutzung zahlreicher weiterer Fälle weitergeführt und optimiert werden. Die hierfür notwendigen Therapieverläufe werden in einem aktuell laufenden Projekt im Moment erhoben und analysiert. Ein Ziel besteht darin, reale Verläufe tatsächlich simulieren zu können, um unter Nutzung empirischer Vorgaben (z.B. bisheriger Verlauf, Parameterwerte, subjektiv erlebte Interventionswirkungen) Interventionen vor ihrer Realanwendung testen zu können.

Ein anderes Ziel ist die Einsetzung des Modells im Rahmen von Aus- und Weiterbildung von Studenten und Psychotherapeuten. Da Komplexität und Dynamik zentrale Themen des 21. Jahrhundert sind – in Bereichen wie Klimaforschung, Wirtschaft, Politik, Neurowissenschaft, aber natürlich auch Psychologie und Psychotherapie –, sollten entsprechende Qualifikationen (Systemkompetenz) in Studium und Ausbildung vermittelt werden. Unser Modell und die Simulation im PsySim können für ein Verständnis von komplexen, nichtlinearen Systemen geeignete didaktische Instrumente liefern.

Schließlich können die Anwendungen des SNS, insbesondere die Möglichkeit, gemeinsam mit den Patienten aus umfassenden Fallkonzeptionen individualisierte Prozessfragebögen zu entwickeln, einen wesentlichen Schritt hin zu einer personalisierten Psychotherapie leisten. Die Personalisierung und Individualisierung von Psychotherapie ist eine konsequente Folgerung aus dem Verständnis komplexer, nichtlinearer Dynamiken in Psychotherapien, wie sie im Rahmen von Chaostheorie und Synergetik verstehbar und mit dem SNS messbar werden.

Mit den Arbeiten im Rahmen dieser kumulierten Dissertation hoffe ich, einen Beitrag zu diesen Entwicklungen geleistet zu haben.

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Mein Beitrag zu den einzelnen Publikationen

[1] **Schöller, H.**, Viol, K., Aichhorn, W., Hütt, M.T., & Schiepek, G. (2018). Personality development in psychotherapy: a synergetic model of state-trait dynamics. *Cognitive Neurodynamics, 12(5), 441-459.* doi.org/10.1007/s11571-018-9488-y.

1. Planung, Durchführung und Auswertung aller Simulationen, die der Veröffentlichung zugrunde liegen
2. Schreibtätigkeit:
    - Entwurf für den Abstract
    - *The Functions*
    - *Model extension on parameter dynamics*
    - *A synergetic interpretation of states and traits*
    - *Model Testing*
    - Beschreibungen für die Abbildungen
    - einzelne Passagen in anderen Texten
3. Arbeiten zur State-Trait-Dynamik:
    - Übersetzung der psychologischen Vorgaben zur State-Trait-Dynamik in die mathematische Formelsprache
    - Einführung und Implementierung des Sättigungsverhaltens der State-Trait-Dynamik
    - Einführung und Implementierung des Abklingverhaltens der Einflüsse von Zustandsvariablen auf Kontrollparameter
    - Implementierung der gewonnenen Formeln in das Simulations-Framework, sowohl in *MS-Excel* als auch im Simulationstool *PsySim*
    - Implementierung einer automatischen Datensicherung und des Datenexports von Berichtsdateien aus *PsySim* in ein Serververzeichnis, Linkerstellung und Mailversand zur wissenschaftlichen Dokumentation
    - Implementierung der halbautomatischen Übernahme klinischer Messdaten (a-Vektor, Interventionen) in die Simulationen
    - Übernahme der klinischen Daten als Input für die Simulation („Interventionen“)
    - Implementierung von Routinen zur automatischen Darstellung von Berichtsdateien in *PsySim* via Email-Link
    - Durchführung von Testläufen zur Validierung des realen zum geplanten Simulationsverhalten (Inklusive Vergleich *MS-Excel*- und Web-Implementierung)
    - Planung und Durchführung der Simulationen, Auswahl der Parameter zur Visualisierung
    - Beschreibung und Interpretation der Simulationen und der Simulationsergebnisse
    - Formulierung neuer Fragestellungen und Einwände für die Diskussion
    - Interpretation und Bericht der Simulationsergebnisse als Basis für den Ergebnisteil der Veröffentlichung
4. Übernahme von eigenen Arbeiten zu früheren Veröffentlichung:
    - Abbildung 2:
        - Visualisierung aller Funktionen inklusive Variation von Kontrollparametern zur Validierung und Veranschaulichung des Modells
        - Implementierung der Ableitungen der Funktionen und Cross-Checking mit den Formeln und Routinen zur Ableitungssimulation

- Abbildung 3:
    - Konstruktion von Attraktoren durch Einbettung und ihre Darstellung in MS-Excel
    - Simulation von Phasenübergängen durch Variation von Kontrollparametern
5. Erstellung und Aufbereitung aller Graphiken
6. Erstellung und Testen aller Formeln
7. Dokumentation der verwendeten Literatur

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2. Entwurf der Strategie zur Validierung des Simulationssystems an klinischen Daten und zur Trennung von klinischer Dynamik und autonomer Dynamik durch Berücksichtigung von „Interventionsvektoren“ aus dem klinischen Monitoring
3. Planung, Durchführung und Auswertung aller Simulationen, die der Veröffentlichung zugrunde liegen
4. Entwurf der Strategie zur Kalibrierung von Ordnungsparametern im Simulationssystem
5. Definition qualitativer und quantitativer Messwerte zum Vergleich von klinischen mit simulierten Verläufen
6. Anpassung des Simulationssystems *PsySim* zur Übernahme exportierter Interventionsdatenreihen
7. Datenexport, Datenimport aus dem klinischen Monitoring ins Simulationssystem,
8. Übernahme von gemessenen „Interventionswerten“ aus dem klinischen Monitoring
9. Berechnen der Korrelationen zwischen den simulierten und den klinischen Verläufen, um das Ergebnis zu bewerten
10. Schreibtätigkeit:
    - Entwurf für den Abstract
    - *The variables*
    - *The parameters*
    - *The functions*
    - *Methodological steps to validation*
    - Bildbeschreibungen
11. Formulierung der Ergebnisse und neuen Fragestellungen für die Diskussion
12. Aufbereitung der Referenzen
13. Erstellen und Bearbeiten aller Graphiken

[3] Schiepek, G., Viol, K., Aichhorn, W., Hütt, M.T., Sungler, K., Pincus, D., & **Schöller, H.** (2017). Psychotherapy is chaotic—(not only) in a computational world. *Frontiers in Psychology for Clinical Settings, 8:379. doi: 10.3389/fpsyg.2017.00379.*

1. Regulatorische Vorgaben für Verbesserung und Standardisierung der Simulationsfunktionen
2. Implementierung aller Funktionen im Simulationssystem (*MS-Excel*)
3. Planung, Durchführung und Auswertung von Simulationen, die der Veröffentlichung zugrunde liegen
4. Bericht der Simulationsergebnisse

5. Erzeugen von 3D-Darstellungen von Attraktoren zu ausgewählten Simulationen
6. Berechnung von Bifurkationsdiagrammen zur Veranschaulichung des Verhaltens im Parameterraum der Kontrollparameter
7. Erstellen und Bearbeiten aller Abbildungen
8. Beschreibung der Simulationsergebnisse zu den Abbildungen

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2. Planung, Durchführung und Auswertung von Simulationen, die der Veröffentlichung zugrunde liegen, z.B. in *Irregular vs. Frequent and Equidistant Time Sampling* und zu Abbildung 17., bzw. zur Zirkularität der State-Trait-Dynamik in *Theoretical Modelling Psychotherapeutic Processes.*
3. Schreibtätigkeit:
    - *Irregular vs. Frequent and Equidistant Time Sampling*
    - *Linear vs. Nonlinear Dynamics*
    - *Theoretical Modelling Psychotherapeutic Processes*
4. Aufbereitung der Referenzen
5. Erstellen und Bearbeiten aller Graphiken

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1. Arbeiten zur Anpassung des Modells und Implementierung der Simulationsumgebung wie in [3]
2. Übernahme und Visualisierung klinischer Daten (Abbildung 1a)
3. Planung, Durchführung und Auswertung von Simulationen, die der Veröffentlichung zugrunde liegen (Abbildung 1b)
4. Planung der Entwicklung eines Therapiespiels (S. 31), später realisiert als *PsySim* (www.*PsySim*.at, www.*PsySim*.de)
5. Erstellen und Bearbeiten der Graphiken

[7] Stöger-Schmidinger, B., Aichhorn, W., **Schöller, H.**, Aas, B., & Schiepek, G. (2016). Systemische Fallkonzeption und State-Dynamik bei einer Patientin mit struktureller Dissoziation der Persönlichkeit. Familiendynamik, 41(4), 322-332. doi: 10.21706/FD-41-4-322.

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1. Beratung zur Planung der Studie
2. Planung und Kontrolle der statistischen Auswertung der Daten
3. Mitwirkung an der statistischen Auswertung und Bewertung der Daten
4. Erstellen und Bearbeiten von Graphiken und Tabellen
5. Mitwirkung an der inhaltlichen Gestaltung des Abschnitts *Discussion*

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1. Planung, Durchführung und Auswertung von Simulationen, die der Veröffentlichung zugrunde liegen (Abbildungen 3, 4, 5, 6)
2. Erstellen und Bearbeiten von Graphiken und ihrer Beschreibungen
3. Schreibtätigkeit, Mitwirkung:
   - *Chaos and Self-Organization in Human Change Dynamics*
   - *Critical instabilities and order transitions*
   - *Psychotherapy as Dynamic Support of Clients' Self-Organizing Processes*

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1. Automatisierung der Aufbereitung individuellen Bildmaterials für die FMRI-Untersuchungen
2. Durchführung von Untersuchungen bei Kontrollpersonen
3. Beratung zur statistischen Auswertung der Daten

TEIL II: Die Fachartikel

Cognitive Neurodynamics
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RESEARCH ARTICLE

Personality development in psychotherapy: a synergetic model of state-trait dynamics

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Abstract

Theoretical models of psychotherapy not only try to predict outcome but also intend to explain patterns of change. Studies showed that psychotherapeutic change processes are characterized by nonlinearity, complexity, and discontinuous transitions. By this, theoretical models of psychotherapy should be able to reproduce these dynamic features. Using time series derived from daily measures through internet-based real-time monitoring as empirical reference, we earlier presented a model of psychotherapy which includes five state variables and four trait variables. In mathematical terms, the traits modulate the shape of the functions which define the nonlinear interactions between the variables (states) of the model. The functions are integrated into five coupled nonlinear difference equations. In the present paper, we model how traits (dispositions or competencies of a person) can continuously be altered by new experiences and states (cognition, emotion, behavior). Adding equations that link states to traits, this model not only describes how therapeutic interventions modulate short-term change and fluctuations of psychological states, but also how these can influence traits. Speaking in terms of Synergetics (theory of self-organization in complex systems), the states correspond to the order parameters and the traits to the control parameters of the system. In terms of psychology, trait dynamics is driven by the states—i.e., by the concrete experiences of a client—and creates a process of personality development at a slower time scale than that of the state dynamics (separation of time scales between control and order parameter dynamics).

Keywords Psychotherapy processes · Personality development · State-trait dynamics · Computer simulation · Synergetics · Mathematical modeling · Computational systems psychology

Introduction

There are some basic assumptions in psychotherapy which seem to be evident: psychotherapy is a process evolving in time and psychotherapy intends to change personality. At second sight both assumptions are everything but trivial. The fact that human development is a dynamic process requires time series data in order to get an idea on what these processes look like. There is empirical evidence that doubts the linearity of human change processes and instead suggests discontinuity and nonlinearity (chaoticity) of the processes (Haken and Schiepek 2010; Hayes et al. 2007; Kowalik et al. 1997; Lutz et al. 2013; Schiepek et al. 1997, 2016a; Stiles et al. 2003; Strunk et al. 2015). In consequence, the challenge for the development of theoretical models on change processes is to explain nonlinear dynamics and discontinuous pattern transitions. Acknowledging that the explanandum should be both, the outcome and the process, mathematical algorithms are required which are able to create dynamics, e.g., computer simulations based on coupled nonlinear difference equations. Conceptually, this approach of modeling change dynamics is embedded in a meta-theoretical framework of nonlinear dynamic systems and self-organization (Haken 2004; Gelo

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and Salvatore 2016; Haken and Schiepek 2010; Orsucci 2006, 2015; Pincus 2009; Salvatore and Tschacher 2012; Schiepek et al. 1992, 2016a; Strunk and Schiepek 2006).

The second assumption on personality development is just as challenging as the nonlinear dynamics conjecture. The term 'personality' is a fuzzy psychological construct with different definitions, conceptualizations, and ways of operationalization. Early behavior therapists therefore neglected this construct and focused on observable (overt) behavior. In psychoanalysis, personality was part of the unconscious and its drive dynamics, based on early childhood experiences and only partially accessible to conscious experience and reflection. In psychology, personality is usually defined by traits in the sense of habitual patterns of behavior, thought, and emotion. According to this perspective, traits are relatively stable over time, differ across individuals, and influence behavior. States, in contrast, are conceptualized as transitory and fluctuating. The trait approach was based on Allport and Odbert's work who clustered terms taken from an English dictionary that could be used to distinguish the behavior of one human being from that of another (Allport 1937). They differentiated between terms that represented general characteristics that determine personality—consistent and stable modes of an individual's adjustment to his environment (traits)—and terms that referred to temporary experiences, moods, and activities (states). Cattell (1943) distilled Allport and Odbert's trait terms into a useful taxonomy, and some decades later, the Big Five (Costa and McCrae 1992; Goldberg 1992) or the Big Six (Thalmayer et al. 2011) tried to capture the principal dimensions of human personality. Other models included the dynamics of personality development and the trans-situational variability of human's thinking, feeling, and behavior (Magnusson and Endler 1977; Mischel and Shoda 1995). For example, Fleeson's Whole Trait Model (Fleeson and Jayawickreme 2015) combines the evidence for interindividual differences in average global traits with the evidence that people also vary substantially around these averages. Consequently, they conceptualized personality traits as density distributions of momentary states. Based on this model, Wilson et al. (2016) tested, if fluctuations in affect and/or situational triggers account for fluctuations in personality states—measured in a sample of students by momentary ecological assessment—, finding that affect accounted for most, but not all of the within-person variance of states.

Other than in the Fleeson approach, the model of psychotherapeutic change we refer to in this article (Schiepek et al. 2017) differentiates in a classical sense between traits and states. The intention of the model is to reproduce some basic features of psychotherapy dynamics, like the variability of states, the evolution of state dynamics, but also the evolution of traits and the interaction between states and traits—in other words: the development of personality. The results we presented in previous publications focused on the dynamics of the model, e.g., nonlinear features and deterministic chaos, and on the dependency of the dynamic patterns (attractors) on the parameters—which can be interpreted as traits (Schiepek et al. 2016b, 2017)—, but did not consider the dynamic interaction between traits and states. Closing that gap is the aim of this article.

The model

This model takes for serious that one of the most robust findings in common factors research is the importance of the client contributing to the course and outcome of psychotherapy (Bohart and Tallman 2010; Duncan et al. 2004; Orlinsky et al. 2004; Sparks and Duncan 2010; Wampold and Imel 2015). For this reason the model focuses on psychological mechanisms which have repeatedly been shown to be important within the "client system" both empirically and theoretically (e.g., Grawe 2004; Orlinsky et al. 2004). Another reason for focusing on these variables is their correspondence to the factors (subscales) of the Therapy Process Questionnaire (TPQ, Haken and Schiepek 2010), which is used in the routine practice of psychotherapy feedback (Schiepek et al. 2016c).

The model includes five variables which are connected by 16 functions, mediated by four parameters (Fig. 1). A detailed description of the constructs and the psychological mechanisms were given in Schiepek et al. (2017) and will be explained in more detail in a book which currently is in preparation. For a better understanding, a short description of the variables, parameters and functions will be given.

The variables

(E) Emotions. This is a bidimensional variable representing dysphoric emotions (e.g., anxiety, grief, shame, guilt, and anger) at the upper end of the dimension (positive values of E) and positive emotional experiences (e.g., joy, self-esteem, happiness) at the lower end (negative values of E). This definition of polarity is based upon the results of a factor analysis of the Therapy Process Questionnaire (TPQ, Haken and Schiepek 2010), which is used to generate the empirical data for model testing.

(P) Problem and stress intensity, symptom severity, experienced conflicts or incongruence

(M) Motivation to change, readiness for the engagement in therapy-related activities and experiences

(I) Insight; getting new perspectives on personal problems, motivation, cognition, or behavior (clarification perspective in terms of Grawe 2004); confrontation with

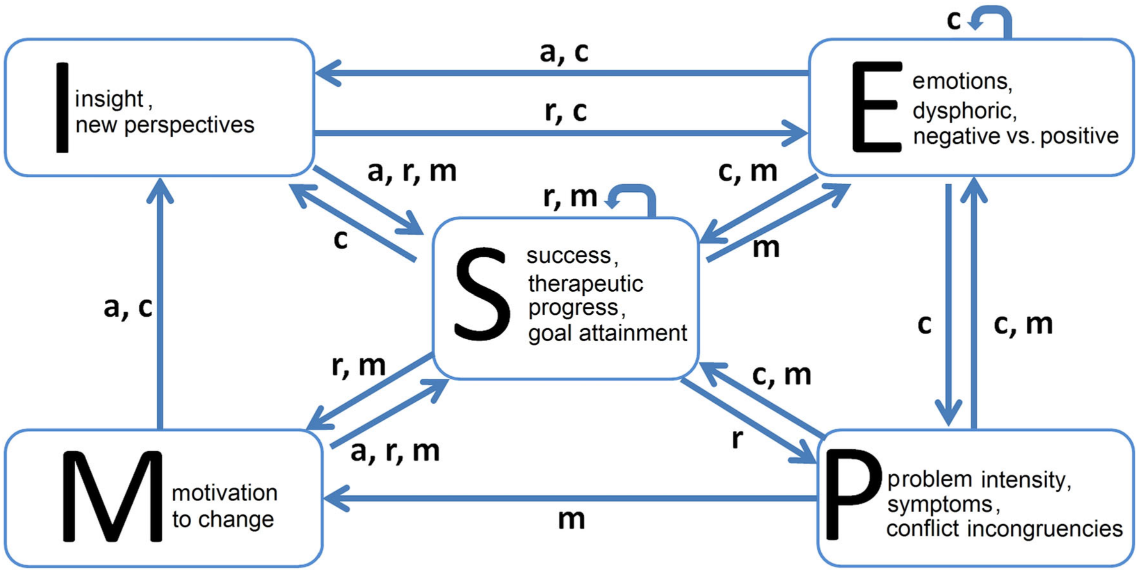


Fig. 1 The structure of the model illustrates the dependencies between the variables and the parameters of the system

conflicts, avoided behaviors and cognitions, or with repressed traumatic experiences

(S) Success, therapeutic progress, goal attainment, confidence in a successful therapy course.

The parameters

The model includes four parameters which mediate the interactions between variables. Depending on their values, the effect of one variable on another is intensified or reduced, activated or inhibited. Formally they modify the functions which define the relationship of the variables to each other.

(*a*) Working alliance, capability to enter a trustful cooperation with the therapist, quality of the therapeutic relationship, interpersonal trust. This parameter signifies the disposition to engage in a trustful relationship (attachment disposition) and also resembles the realized quality of the therapeutic alliance

(*c*) Cognitive competencies, capacities for mentalization and emotion regulation, mental skills in self-reflection, and the level of the personality structure (in the sense of the Operationalized Psychodynamic Diagnostics, www.opd-online.net)

(*r*) Behavioral resources or skills that are available for problem solving

(*m*) Motivation to change as a trait, self-efficacy, hopefulness, reward expectation, and "health plan" as suggested by the control mastery theory (Silberschatz 2009).

The graphs in the coordinate planes of Fig. 2 illustrate how the shape of each function depends on the parameter values. The full range of the variables is covered by the functions defining the influence of other variables, that is, no arbitrary segmentations or thresholds have been introduced from the beginning. Thresholds and discontinuous jumps of the dynamics are emerging from the dynamics and not forced by some specific preliminary assumptions.

It should be noted that the variables and parameters are partially overlapping with the Research Domain Criteria (RDoC; Insel et al. 2010), promoted by the National Institute of Mental Health, which address similar psychological constructs, e.g., "negative valence" (variable E) or "attachment" (parameter *a*). Yet our model goes beyond the RDoC list by connecting the constructs into a large-scale model. Nonlinear dynamical models like the one proposed here are well suited to obtain this goal, not only by linking the elements but rather by formulating mechanisms of their interaction producing the emerging dynamics.

An empirical validation of the model is in preparation and will be based on 941 cases which were assessed (daily self-ratings) by the process questionnaire TPQ during the last years.

The functions

The shape of each function represents theoretical as well as empirical findings from psychotherapy research (e.g., common factors research) and other psychological topics like emotion regulation, motivation, problem-solving and self-related cognition. The psychological interrelations between the variables were modelled by mathematical functions. Some connections are represented by functions of sigmoid shape and varying scales. The function $E_t(S_{t-1}) = \frac{1.25}{1+e^{5S_{t-1}-0.5}} - 0.5 - 0.5m$ for example describes how negative

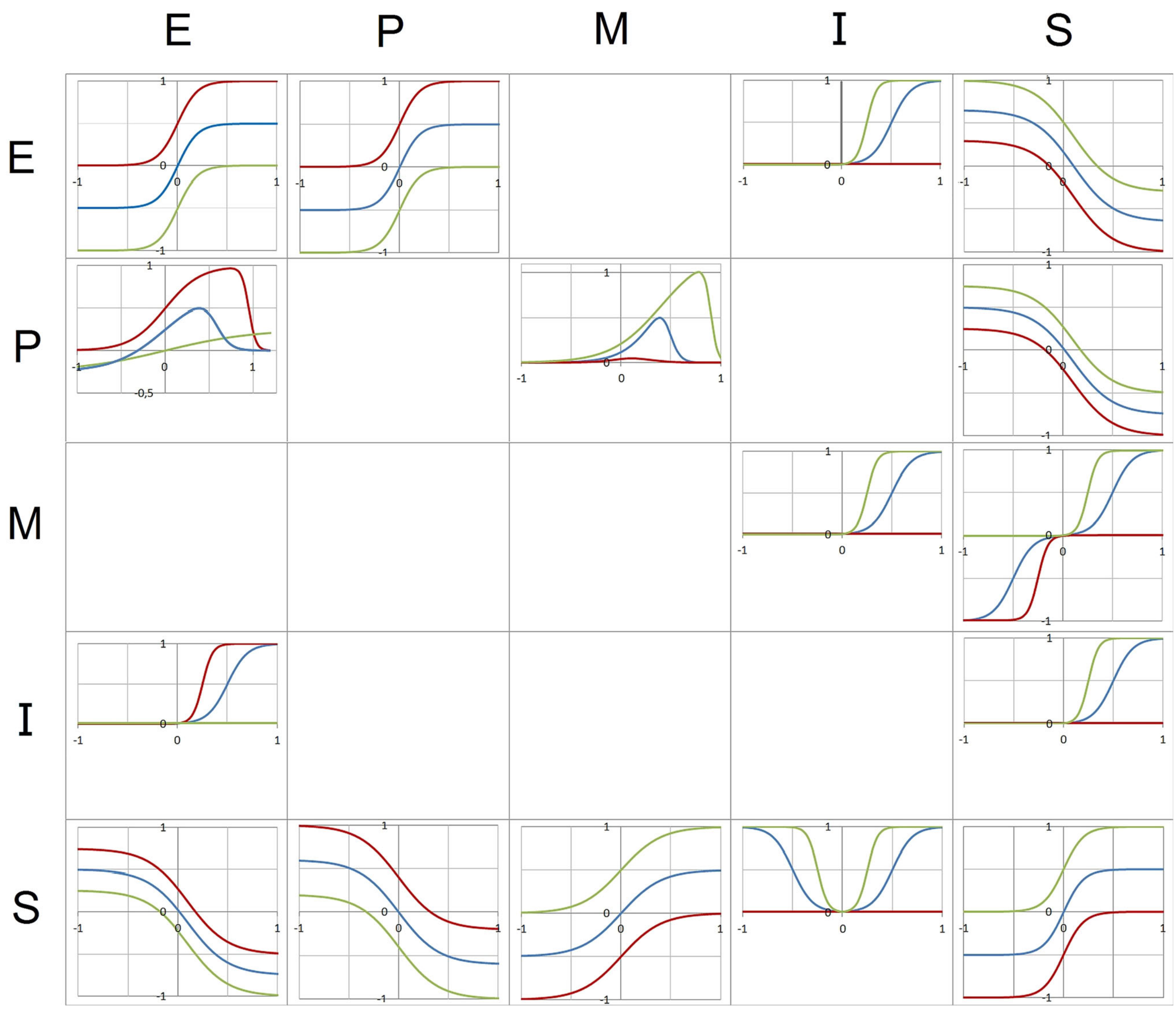


Fig. 2 The figure represents the 16 functions of the model (for a detailed description see Schiepek et al. 2017). The variables noted on the left of the matrix (lines) represent the input, the variables noted at the top (columns) represent the output. Each function is represented by a graph in a coordinate system (x-axis: input, y-axis: output). Green function graphs correspond to the maximum of the respective control parameter(s) (= 1), red graphs to the minimum of the parameter(s) (= 0). Blue graphs represent an in-between state (0 < parameter value < 1)

emotions E depend on therapeutic success S (Fig. 2, bottom left), i.e., the experience of negative emotions like fear, grief, shame, or anger are reduced or are inversely related to feelings of progress and being successful in solving personal problems, with a saturation effect for extreme values of S. The strength of the effect is mediated by parameter *m*, that is, by feelings of self-efficacy and a general positive expectation in problem-solving efforts. The higher *m*, the better S will reduce worrying emotions.

Other relations, e.g., E(P) and M(P), required more refined mathematical functions to capture the psychological mechanisms. The dependence of negative emotions E on the problem intensity P, for example, describes a complex relationship and represents the state of knowledge on emotion regulation and the psychopathology of borderline personality disorder (Fig. 2, left column, second from bottom). Increasing problems activate worrying and distressing emotions. The more severe or stressing the problem, the more such emotions will be triggered (exponential increase). This emotion triggering effect is more pronounced if the person has only minor competencies (red line) in emotion-regulation, self-reflection, and mentalization (parameter *c*) and/or reduced expectations in his/her capacity to solve problems or to manage difficult or stressful situations (self-efficacy expectation, parameter *m*). With higher values of in *c* and/or *m* (green line), coping strategies for the down-regulation of negative emotions at distinct problem intensities will be available and can be applied. The higher c and/or m, the lower the maximum of E and the earlier coping mechanisms and emotion regulation skills will reduce negative emotions. At low levels of c and m (red line), even lower levels of affect intensities cannot be managed or reduced until completely distressing and disturbing emotions (high levels of E) are interrupted, repressed, or disconnected from conscious experience by consuming drugs or alcohol, by self-harm, or by mechanisms of dissociation (switch of ego-states).

Finally, the functions are added to five coupled nonlinear equations, one for each variable, determining the dynamical system:

$$E(E,I,P,S,c,r,m) = \frac{1}{1+e^{-10E}} - c + \frac{1}{1+e^{-20I\cdot\left(1-\frac{c+r}{2}\right)+5}} + \frac{\frac{-1}{1+e^{\left(2+3\cdot\left(1-\frac{c+m}{2}\right)\right)\cdot P}} + 0.5 + 0.5\cdot\left(1-\frac{c+m}{2}\right)}{1+e^{25\cdot\left(1-\frac{c+m}{2}\right)\cdot\left(P-0.2-0.75\cdot\left(1-\frac{c+m}{2}\right)\right)}} + \frac{1.25}{1+e^{5S-0.5}} - 0.5 - 0.5m$$

$$\mathrm{I}(\mathrm{E},\mathrm{M},\mathrm{S},\mathrm{a},\mathrm{c}) = \frac{1}{1+\mathrm{e}^{-20\mathrm{E}\cdot\left(\frac{a+c}{2}\right)+5}} + \frac{1}{1+\mathrm{e}^{-20\mathrm{M}\cdot\left(\frac{a+c}{2}\right)+5}} + \frac{1}{1+\mathrm{e}^{-20\cdot|\mathrm{S}|\cdot c+5}}$$

$$\mathrm{M}(\mathrm{P},\mathrm{S},\mathrm{r},\mathrm{m}) = \frac{1.261}{1+\mathrm{e}^{(\mathrm{P}-0.05-0.85\mathrm{m})\cdot(10.1+19.9\mathrm{m})}} \cdot \frac{1}{1+\mathrm{e}^{-(\mathrm{P}-0.43+0.03\mathrm{m})\cdot(7-3m)}} - \frac{1}{1+\mathrm{e}^{5\mathrm{S}}} + \frac{\mathrm{r}+\mathrm{m}}{2}$$

$$P(E,S,c,r) = \frac{1}{1+\mathrm{e}^{-10\mathrm{E}}} - c + \frac{1.2}{1+e^{5S-0.5}} - 0.2 - 0.8r$$

$$S(E,I,M,P,S,a,c,m,r) = \frac{1.3}{1+e^{5E-0.5}} - 0.65 + 0.35\cdot(c+m-1) + \frac{1}{1+\mathrm{e}^{-20\mathrm{I}\cdot\frac{(a+m+r)}{3}+5}} + \frac{1}{1+\mathrm{e}^{-20\mathrm{M}\cdot\frac{(a+m+r)}{3}+5}} - \frac{1}{1+\mathrm{e}^{20\mathrm{M}\cdot\left(1-\frac{a+m+r}{3}\right)+5}} + \frac{1.25}{1+e^{5P-0.5}} - 0.5 - 0.5\cdot\left(1-\frac{c+m}{2}\right) + \frac{1}{1+\mathrm{e}^{-10\mathrm{S}}} + \frac{m+r}{2} - 1$$

Neural correlates of the phenomenological model

The variables and the parameters of this phenomenological model are defined at a psychological level, which of course is based on neuronal activity. Dating back to 1895, Freud made first attempts to link psychological processes to underlying neuronal mechanisms. It is worth noticing that he addressed the aim to link psychiatric disorders to the underlying neurobiological laws. More than a 100 years later, Kandel (1998) asked for a program on integration of cognition and behavior (especially related to psychiatric phenomena) with biological findings on brain processes. Since his seminal paper, the field developed rapidly and studies using different brain imaging methods (e.g., fMRI, EEG) revealed effects of psychotherapy on the activity of functional neuroanatomic structures and on neuronal networks (for reviews see Barsaglini et al. 2014; Schiepek et al. 2011). Research also focused on the brain mechanisms involved in therapeutic change processes (Cozolino 2010, 2015; Schiepek 2011).

Mathematical models were developed to explain the neuronal mechanisms of specific disorders. For example, a mechanistic framework of brain network dynamics underlying Major Depressive Disorder (Ramirez-Mahaluf et al. 2015) described how abnormal glutamate and serotonin metabolisms mediate the interaction of ventral anterior cingulate cortex (vACC) and dorsolateral prefrontal cortex (dlPFC) to explain cognitive and affective symptoms and its medical treatment by Selective Serotonin Reuptake Inhibitors (SSRI). Other approaches like The Virtual Brain (TVB; Leon et al. 2013; Ritter et al. 2013) integrate data from subjects (fMRI, MEG, or EEG) with full brain network simulations across different brain scales. TVB is a neuroinformatics platform for network simulations using biologically realistic connectivity which allows for the reproduction of a broad range of dynamic features, e.g., focal or distributed changes in the network dynamics of brain disorders and approaches to counteract those pathological processes.

Conceptually, simulations and measures at different brain scales focus on physico-chemical mechanisms which relate to mental or psychological phenomena (cognitions, emotions) like statistical mechanics of gas dynamics relate to phenomenological gas theory. In terms of Synergetics, we deal with a relative micro level of a multi-level and multi-scale system which may create order parameters at an emergent macro level (Haken 2002). Both levels are related to each other, but given our actual knowledge, there exist emergent qualities at the macro level (e.g., phenomenological consciousness) which cannot be fully reduced to the micro level. Anyway, the dynamics at two or more levels may be correlated (see the K model of Freeman 2000, 2004; Kozma 2016). In one of our own studies we were able to show that order transitions in the dynamics of cognitions and emotions during psychotherapy (assessed by daily self-ratings) were timely related to pattern transitions of brain activity (assessed by repeated fMRI scans; Schiepek et al. 2013).

A huge amount of neurophysiological studies investigated the neural underpinnings of the variables, parameters, and also the mechanisms behind the functions of our model. Any attempt to delineate these findings would be beyond the scope of this article. Especially the neurobiology of emotions (variable E) has created a neuro-psychological subdiscipline of its own: affective neuroscience. Also problem intensity (P) is related to the experience of stress and all neural and neuroendocrine mechanisms of stress regulation (Subhani et al. 2018).

Given the enormous amount of literature on the topic, only some findings should illustrate that the parameters of the model can be related to neuronal underpinnings. For example, the neuronal mechanisms of emotion regulation, which is an important part of the parameter *c*, concern the top–down regulation of the dorsal and ventromedial prefrontal cortex and of the ACC on limbic structures, including the insular cortex and the amygdalae as prominent regions (e.g., Etkin et al. 2015). Similar areas (e.g., the dorsal and medial prefrontal cortex) seem to be involved in mentalization (for a review see Mahy et al. 2014), justifying the combination of the two constructs in one parameter (c). The neuronal correlates of the parameter *m* have been investigated by Hashimoto et al. (2015). Based on the analysis of gray and white matter volumes, the authors suggest an internal locus of control, associated with self-regulation and reward expectation, encompassing the anterior cingulate cortex, striatum, and anterior insula. Dopaminergic structures such as the ventral striatum (nucleus accumbens), the putamen or the nucleus caudatus, are involved in reward expectation and motivation for goal directed actions (Knutson et al. 2001; Hurano and Kawato 2006). Krueger et al. (2007) found the paracingulate cortex and the septal area involved in partnership building and maintenance of reciprocal trust, comparable to the client's engagement in the therapeutic alliance (parameter *a*). The modulation of neuronal activity by oxytocin and its receptor dynamics (Costa et al. 2009) relate to attachment styles as well as all neural networks recruited for empathy and theory of mind processes (Mahy et al. 2014) in interpersonal communication. These competencies together with behavior skills for social interaction and problem solving are concerned by the parameter *r* of our model.

A synergetic interpretation of states and traits

The variables of the model can be understood as psychological states with varying intensities with a sampling rate of once per day, so that each iteration of a simulation run can be interpreted as a daily measurement of the variables. This corresponds to the way the TPQ is applied in practice. In terms of Synergetics, the variables represent the order parameters of the system. Order parameters are variables which describe the global bottom-up dynamics of a complex system. They are constituted by many sub-systems or subprocesses (e.g., the amplitude and frequency of convection cells in fluid dynamics, which are constituted by the molecules of the fluid), and also realize a top-down synchronization, which regulates (orders) the dynamic behavior of the sub-systems or system components (*enslaving principle*) (Haken 2004). Order parameters capture the most important information of a multi-component system on a few dimensions (*information compression*).

While states correspond to the order parameters of the model, traits correspond to its control parameters. Psychologically, the control parameters can be interpreted as traits or dispositions changing at a slower time scale than the variables or states (separation of the time scales). In terms of Synergetics, the change of control parameters drives the phase transitions of the system (Haken 2004) (or in a more general and psychological sense the *order transitions*). Indeed, a linear and continuous change of one or more parameters may have sustainable effects on the dynamic patterns of a system, constituting a *phase transition* (Haken 2004). The effect of a parameter shift in *c* is demonstrated in Fig. 3. A continuous shift (continuous stepwise increase) in the sensitive range of the parameter produces a discontinuous jump of the system dynamics (order to order transition, Haken and Schiepek 2010).

However, there is a big difference between control parameters in physical or physiological experiments, which are susceptible to direct external control (this is why they are called *control parameters*), and psychological parameters in the sense of traits. Traits are merely indirectly open to external input (Haken and Schiepek 2010). Traits in the sense of skills or competencies can be developed, but not directly influenced. They are dependent on concrete behavior, emotions, and cognitions, that is, on the experiences a person has in numerous consecutive specific situations. Any training program for skills or competencies uses such an indirect way of actualization of behaviors, feelings, and thoughts, that is, by the way of states (e.g., experiencing new behavior). *Learning* or *personality development* can in that view be expressed as the modification of the dynamics of a system by the modulation of the nonlinear functions that connect the order parameters with each other (states), while these states in themselves can modulate the traits or dispositions. There is a circular causality from traits to states and from states to traits, from control parameters to the order parameter dynamics, and from the dynamics of order parameters to control parameters (Fig. 4).

Allowing for a short historical side note, the fit of this conceptualization of personality development not only to

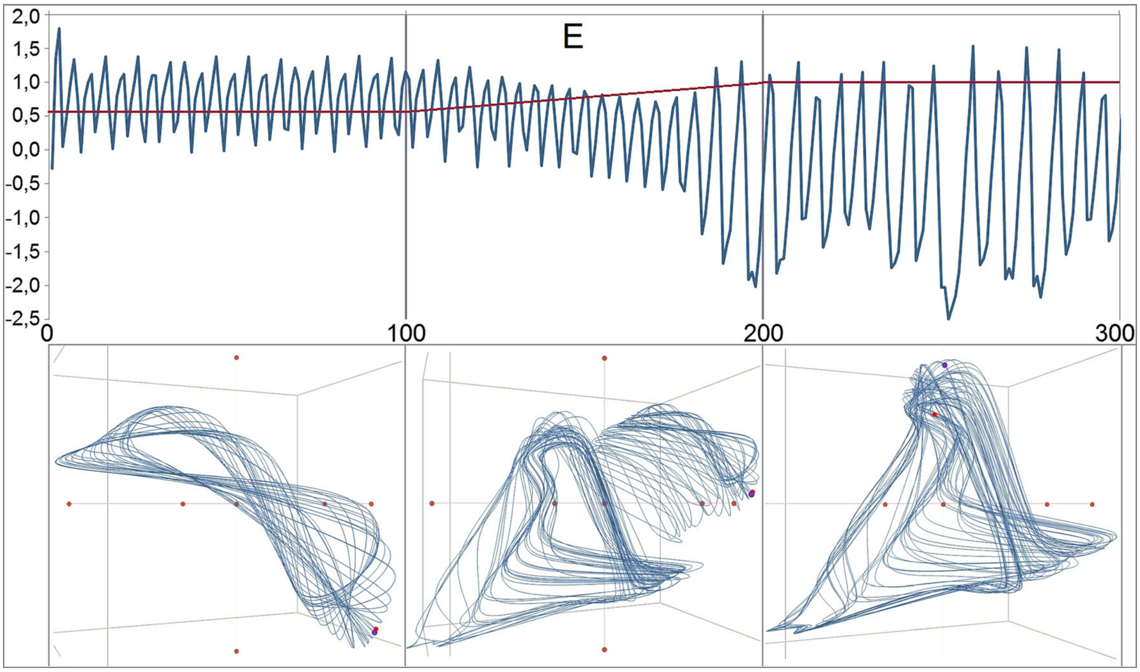


Fig. 3 Order transition in the dynamics of the variable E. The numbers at the y-axis refer to the values of the parameter c ($0 < c < 1$, red line) and to the z-transformed values of E (blue line). The transition of the pattern depends on a stepwise linear increase of the parameter c from 0.60 to 1.00 between iteration 100 and 200. From iteration 0 to 100, the parameter is kept constant at 0.60, creating a certain dynamic pattern (attractor). After the 200th iteration, c is constant at 1.00, producing another pattern at a lower mean level of E, at a lower frequency, and with higher amplitudes of the chaotic oscillations. The attractors are shown below the time series. For the generation of the attractors, the discrete iterations were splined by the Excel standard spline function. During the linear stepwise increase of the control parameter, the transient attractor combines features of the pre- and the post-attractor and by this is more complex than each of both

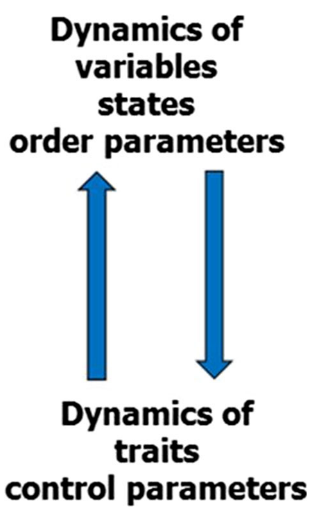


Fig. 4 Circular causality between state (order parameter) and trait (control parameter) dynamics. The feedback-loop includes different time-scales

Synergetics but also to other concepts of self-organization in psychology should be remarked. Especially the Gestalt psychology tradition goes back to the early twentieth century, when Gestalt psychologists Koehler (1920, 1940, 1947), Metzger (1940) and others described the emergence of patterns in perception, cognition, emotions, and behavior. In this paradigmatic frame, pattern formation is driven by basic psychological laws of "Gestalt". These ideas were expanded by Lewin (1936a, 1936b, 1951), who included the impact of human needs, social contexts, and the personality on behavior. His topological view on personality integrated the environment as it is perceived by a motivated subject. The environment as a gradient field is given by the famous formula B = f (P, E): Behavior B is a function of the person P and his environment E. In this Lewinian tradition, the model proposed here is not aimed to describe averaged behavior for which statistics would be a suitable method, but focuses on the single case, that is, on the developmental trajectories of individual clients. Like in Lewin's work, our model intends to explain psychological processes by mathematical means, nowadays called computational systems psychology.

Model extension on parameter dynamics

The circular causality between states and traits demands an extension of the state or order parameter model described so far, which is realized as coupled nonlinear difference equations (discrete model with one equation for each variable, see Schiepek et al. 2017). The basic idea about the evolution of traits is its dependency on the increases or decreases of the states, i.e., concrete experiences in emotions (E), problem intensity (P), motivation to change (M), insight (I), and success (S).

Therefore, the functions describing the dynamics of the parameters a, c, m and r depend on the values of these variables. a_t depends on increases of success and on the experience of positive emotions. c_t depends on increased insight and on therapeutic success. Social and behavioral resources (r_t) may also contribute to the evolution of c_t, since these competencies may offer a broader range of personal experiences contributing to a better understanding of oneself and of one's social environment. In the opposite direction, the evolution of r_t depends on cognitive competencies and on skills in emotion regulation (c_t), which allow for a more effective development of social and other behavioral skills, together with success in problem solving and therapeutic progress in other fields. The evolution of self-efficacy, positive reward expectation and a generalized hopeful attitude to oneself (m_t) depends on successful problem reduction, the experience of positive emotions, increased state motivation to change, and therapeutic success.

The influence of the state variables on the progression of the control parameters has to consider different time-scales for the variables' evolution on the one and the trait dynamics' evolution on the other hand (see the filter functions f in the parameter equations). Additionally, one has to prevent for favoring designated time-points, e.g., distinct starting values. Therefore, the most important effect on the parameters is exerted by the increase or decrease of the state variables in relation to a decay-affected mean value, and the actual values a_t, c_t, r_t, m_t of the parameters at time t are calculated by functions which increase or reduce the parameter values of the last iteration a_{t-1}, c_{t-1}, r_{t-1}, m_{t-1} to a certain amount—dependent on the long term impact of variable dynamics:

$$a_t = a_{t-1} + s_a \cdot w_a \cdot a_{t-1} \cdot \frac{1}{2}\left(f_{S,t,n} - f_{E,t,n}\right) \quad (1)$$

$$c_t = c_{t-1} + s_c \cdot w_c \cdot c_{t-1} \cdot \frac{1}{3}\left(f_{I,t,n} + f_{S,t,n} + r_{t-1}\right) \quad (2)$$

$$r_t = r_{t-1} + s_r \cdot w_r \cdot r_{t-1} \cdot \frac{1}{2}\left(f_{S,t,n} + c_{t-1}\right) \quad (3)$$

$$m_t = m_{t-1} + s_m \cdot w_m \cdot m_{t-1} \cdot \frac{1}{4}\left(-f_{E,t,n} - f_{P,t,n} + f_{M,t,n} + f_{S,t,n}\right) \quad (4)$$

Each equation consists of several elements that will now be explained in detail:

- $f_{E,t,n}$, $f_{P,t,n}$, $f_{M,t,n}$, $f_{I,t,n}$, $f_{S,t,n}$ are filter functions which represent the effect of each variable on the respective parameter considering the differing time-scales by a combination of averaging and weighting recent changes stronger than prior ones. Within a running window of time length n (for the simulation runs of this paper, n = 14) the impact at t_i of the value depends on the sum of all differences from the arithmetic mean of the variable within the window, e.g., $\sum_{i=1}^{n}\left(E_i - \overline{E}\right)$. Using this procedure, not the absolute level of the variable has an effect, but its relative increases or decreases. In addition, we assume a memory effect which accentuates recent emotions or cognitions more than older ones. This is modeled by an exponential decay function with a characteristic steepness λ from the latest value within the running window (at t) to the oldest value at t–n. The exponential decay of the impact of each variable on the parameter change is given by $e^{-\lambda(t-n+i)}$.

  The filter functions for the variables are given by expressions like this (here illustrated by E):

$$f_{E,t,n} = d_E \cdot \sum_{i=1}^{n}\left(E_{t-n+i} - \overline{E}_{t,n}\right) \cdot e^{-\lambda(t-n+i)} \quad (5)$$

  In order to correct for the mean shift, which results from using decay-affected difference-values within the running window, correction factors (d_E, d_I, d_M, d_P, d_S) are introduced. Their values are $d_E = d_P = d_M = d_I = d_S = 0.535$, for the decay-constants λ they are calculated from half-life constants $\tau_E = \tau_P = \tau_M = \tau_I = \tau_S = 7d$, using the relation $\lambda = \frac{ln2}{\tau}$, resulting in $\lambda_E = \lambda_P = \lambda_M = \lambda_I = \lambda_S = 0.099$.
- w_a, w_c, w_r, w_m are weights which are introduced in order to dampen the effect of the variables on the parameters, i.e., scaling them to an appropriate range respective to the variables. They model the sensitivity and the impact of the state dynamics on the evolution of the traits. For the simulation runs presented in this paper, $w_a = w_c = w_r = w_m = 0.004167$.
- The constants 1/2, 1/3 and 1/4 normalize the sum of contributors of the filter functions (may it be variables or parameters) to 1.
- The functions $s_a^*, s_c^*, s_m^*, s_r^*$ are saturation functions, which limit the growth or the reduction of the parameters onto the predefined range from 0 to 1. For example, the saturation of the parameter c is realized by

$$s_{c_t}^* = k \cdot \Delta c \left(\frac{1 + sgn(\Delta c)}{2}\left(c_{max} - c_{t-1}\right) + \frac{1 - sgn(\Delta c)}{2}\left(c_{t-1} - c_{min}\right)\right) \quad (6)$$

- k is a gain factor for a windowing procedure, which restricts the possible range of the parameters [0,1] to the range of complex or chaotic dynamics, as it was defined by inspection of the bifurcation diagrams of the system (see Fig. 6 in Schiepek et al. 2017). For example, restricting c to the interval $0.1 \leq c \leq 0.8$ yields $k = c_{max} - c_{min} = 0.7$.
- Δc is the difference between c_{t-1} and c_t.
- The first term within the bracket is activated only if there was an increase in c: if $\Delta c > 0 \rightarrow \text{sgn}(\Delta c) = +1 \rightarrow \frac{1+sgn(\Delta c)}{2} = 1$. For a decrease $\Delta c < 0 \rightarrow \text{sgn}(\Delta c) = -1 \rightarrow \frac{1+sgn(\Delta c)}{2} = 0$. With the same logic, the second term is activated (unequal to zero) if there was a decrease in the parameter.
- Furthermore, the saturation functions are activated only if the parameter values are beyond a certain threshold, > 0.8 or < 0.2 for all parameters. Taken c as an example:

$$s_c = \begin{cases} (1-c)s_c^*|(c > 0.8) \cap (\Delta c > 0) \\ s_c^*|0.2 \leq c \leq 0.8 \\ (c-1)s_c^*|(c < 0.2) \cap (\Delta c < 0) \end{cases} \quad (7)$$

- Concerning the evolution of the parameter a_t, the two aspects of parameter a can be taken into consideration. As we noted above, this parameter signifies the disposition to engage in a trustful relationship (attachment disposition). In the psychotherapy process, it also refers to the empirically realized quality of the therapeutic relationship between patient and therapist. In many studies, the therapeutic alliance has been proven as an important contributor to the therapeutic success (e.g., Flückiger et al. 2012; Wampold and Imel 2015). The alliance as perceived by the client can be measured by the items of the therapeutic alliance subscale of the TPQ. Hereby, the time series of the experienced quality of the therapeutic alliance of the psychotherapeutic process is hereby available. The concrete value of the empirically given quality of the alliance at time t is denoted b_t. The two aspects are combined by calculating their mean,

$$a'_t = \frac{1}{2}(a_{t-1} + b_t). \quad (8)$$

Here, a_{t-1} is substituted by a', the mean of a_{t-1} and b_t. If no information is available about the values of b_t, they are set to $b_t = a_{t-1}$ and therewith $a' = a_{t-1}$ in Eq. (8).

The interactive simulation system, performing simulation with the described framework and settings, can be used on www.psysim.at.

Results: model dynamics

In the following, some specific results of the simulated system behavior are presented. The simulation dynamics which are shown in Figs. 5, 6, 7 and 8 represent some characteristic features of the system and of psychotherapeutic processes. The dynamic patterns are based on specific parameter values and initial conditions, but can also be generated by other simulation runs within a range of parameter values and seed keys. Even without any specific interventions, unspecific dynamic noise applied to the variables can lead to a positive trend of the parameters (Fig. 5): a spontaneous transient period is realized at the beginning, from high levels of E and P and low levels of S and M to a balanced dynamics of all variables. Evidently, without intensive or continuous stressors or bad experiences, the model is capable of realizing a trend, which in psychological terms might be interpreted as a personal growth or self-actualization. On the long term, this could lead to spontaneous remission.

Interventions, which were implemented between $t = 50$ and $t = 60$ on all variables, have a time-limited impact on the state dynamics and by this, also on the traits. However, an order transition is not triggered by these multiple interventions.

Punctual interventions are less likely to change attractors than continuous evolution. In the example of Fig. 6a, the interventions on S (+ 38%) at $t = 17$, 30, and 50 have no impact on the dynamic pattern, and the parameters do not change neither except for small fluctuations around a stable state. However, longer periods of continuous intervention—in Fig. 6b an intervention of + 38% on S from $t = 17$ to 25 is applied—have a higher probability to change patterns. The existence of bi- or multistability in the dynamics of a system opens the option of order transitions with parameter drifts following the state dynamics, not only, as classical Synergetics predicts, from parameter drifts to order transitions.

Interestingly, sometimes unspecific daily hassles or spontaneous happiness, represented in the simulation as dynamic noise, can trigger order transitions. In Fig. 7a, a noise level of 10% on E and P and 5% on M, I and S has no long-term effect and qualitative impact on the dynamics (although from $t = 35$ to 45 a successful period occurs by chance). The same amount of noise, but with different random values, can trigger an order transition with long-term consequences on the trait levels (Fig. 7b). Here—like in Fig. 6b—the parameter drift seems to follow the state dynamics and to be a consequence, not a cause of the order transition. A closer look on the dynamics reveals a circular causality during the transition period: small changes in the levels of the variables (here due to noise) increase the level

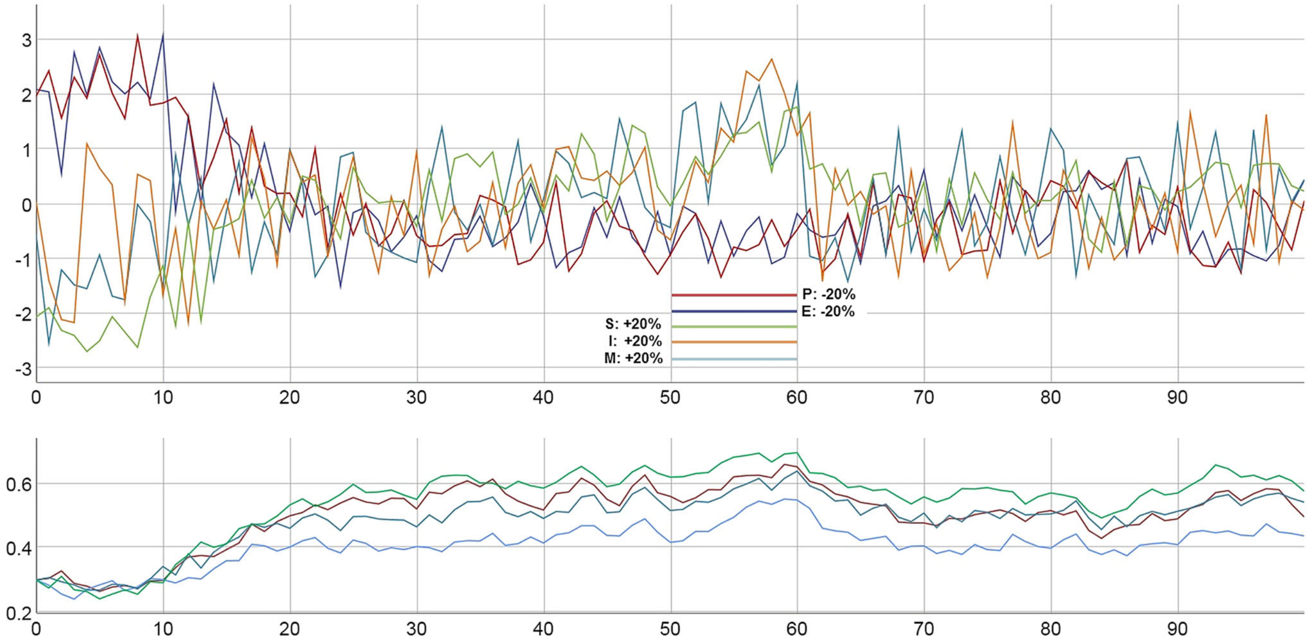


Fig. 5 Noise-driven order transition between the 10th and the 20th iteration, accompanied by an increase of all parameters. Between the 50th and the 60th iteration, a multiple intervention is introduced (+ 20% on M, I, and S, − 20% on E and P). After this period, a spontaneous deterioration occurs since the effects of the interventions do not sustain. Parameters: *a*: red, *m*: green, *c*: bright blue, *r*: dark blue. Initial values: E: 97.6, P: 61.5, M: 7.5, I: 100, S: -40.7; all parameters: 0.30. Dynamic noise 30%, continuously. Variables: z-transformed. For this and the following figures, the respective simulations and simulation data are available for both download and direct application with our online simulation tool PSYSIM (www.psysim.at). We provide two types of links: with links named SIM-xx, you can open our online simulation tool PSYSIM and load the input and output of the simulation applied to the actual figures for direct inspection and further processing. Result data can be downloaded in CSV formal by the links named CSV-xx. SIM-5, CSV-5

of the parameters, i.e., the client integrates new qualities of his/her experience and continues with higher competencies. This in turn affects his/her experience, represented by "better" values of the variables, until a new stable state is reached. From there, small perturbations (noise) cannot shift the system any further; the variables and parameters fluctuate around a certain fix point.

In many cases, a rebound effect occurs after a longer period of interventions. Correspondingly, many patients in real therapies indeed experience the release from inpatient treatment or from a day treatment center as a difficult time. Figure 8 illustrates this rebound effect: all interventions on P, M, I and S are stopped at $t = 100$. Only a reducing effect on stressful emotions of −10% continues, what might correspond to a continued intake of antidepressant or anxiolytic drugs. The continued (e.g., pharmacological) effect on E does not prevent the rebound effect to elevate the system to the same level and the same pattern as in the beginning, before any intervention had been started. Moreover, it seems to prevent a self-organizing process which on the long term relaxes the dynamics on a different "healthy" attractor. But continuously and especially after the intervention on E was stopped, a positive development in success and on problem reduction takes place, corresponding to an increase in competencies of *m* and *c*. In the example of this simulation run, but also in many others (not shown here), the model realizes a rebound effect to levels lower than at start. In the long run, both—state- and trait-dynamics—evolve to patterns that entail improvement (recovery).

Specific dynamics are shown when the b_t-vector, which represents the empirically given dynamics of the therapeutic alliance, is introduced. Figure 9 shows the effect of interventions and of the alliance dynamics. The interventions start at $t = 35$, which realistically correspond to the treatment onset in the day treatment setting of this specific client (diagnosis: obsessive–compulsive disorder). Until that time, the client had not been involved in treatment programs because of holidays of the responsible therapist and of organizational problems at the ward. The client was disappointed, but from the moment the therapy started, she developed a good therapeutic alliance with her therapists. She was engaged in all treatments available to her, especially in a cognitive-behavioral therapy program.

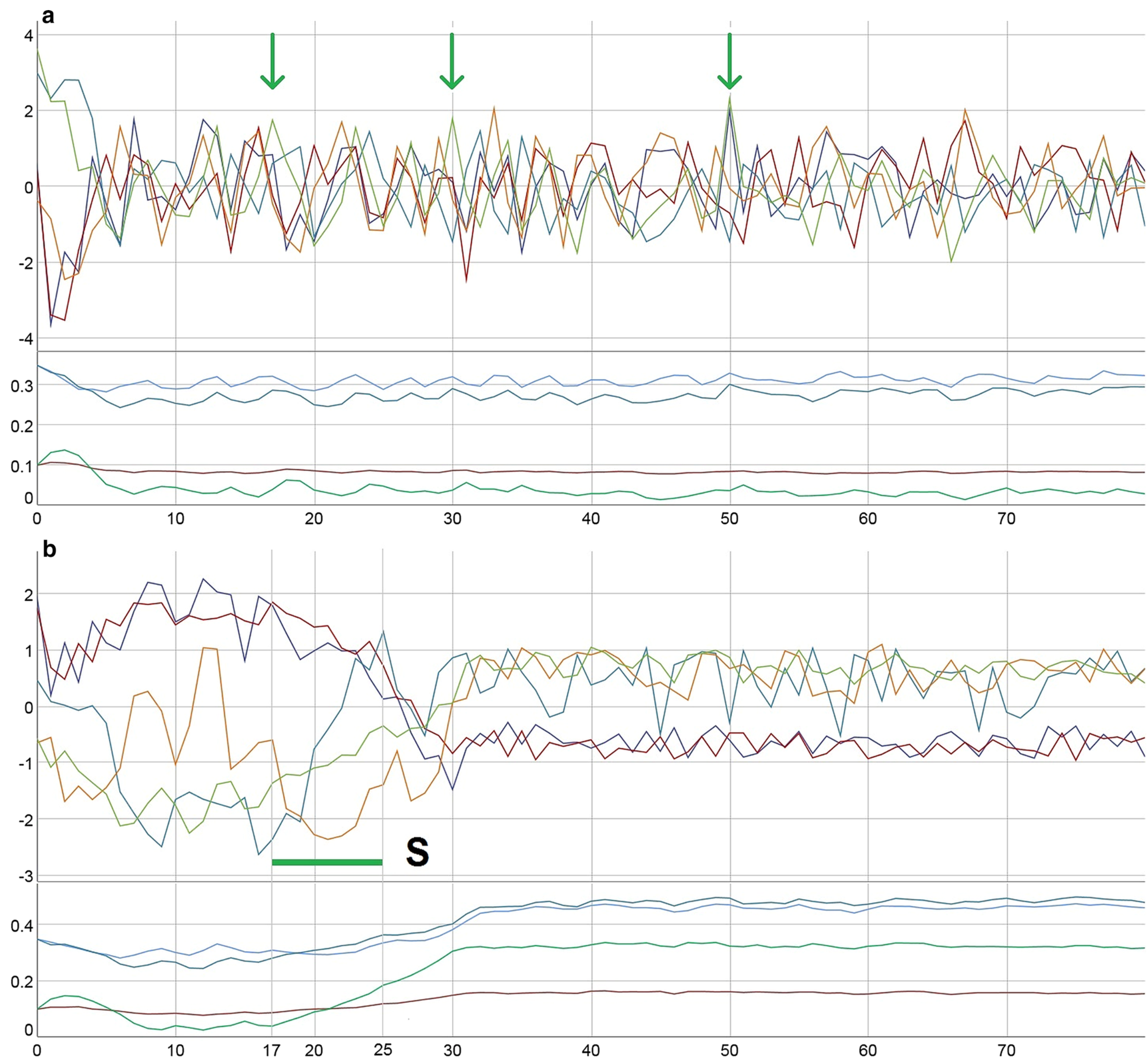


Fig. 6 **a** Punctual interventions on S (+38%) at t = 17, 30, 50. Data: SIM-6a, CSV-6a. **b** Continuous interventions on S (+ 38%) from t = 27 to 25. Parameters: a: red, m: green, c: bright blue, r: dark blue. Initial values of variables and parameters: E: 100, P: 79, M: 32.5, I: 50, S: 33.5; a: 0.10, c: 0.35, r: 0.35, m: 0.10. Dynamic noise 10%, continuously. Variables: z-transformed. Data: SIM-6b, CSV-6b

Discussion

In the described personality dynamics model of psychotherapy, a circular causality between traits and states was established. The dynamics of states—behavior, cognitions, and emotions of a client—can trigger order transitions and modify the traits. This closed circle extends the classical model of Synergetics, which focuses on the role of control parameters for the energy-driven destabilization of patterns (non-equilibrium phase transitions) onto a model of interconnected order parameters (corresponding to states) and control parameters (corresponding to traits). In psychotherapy, this circular causality conceptualizes a model of personality development and exhibits important features of psychotherapy dynamics.

Limitations

There are some limitations in the current model and its mathematical realization. The model still contains a number of parameters shaping the various influence functions, such that they conform to a wide range of empirical knowledge about psychotherapy (see Schiepek et al. 2017). In the long run, a more minimal model should be

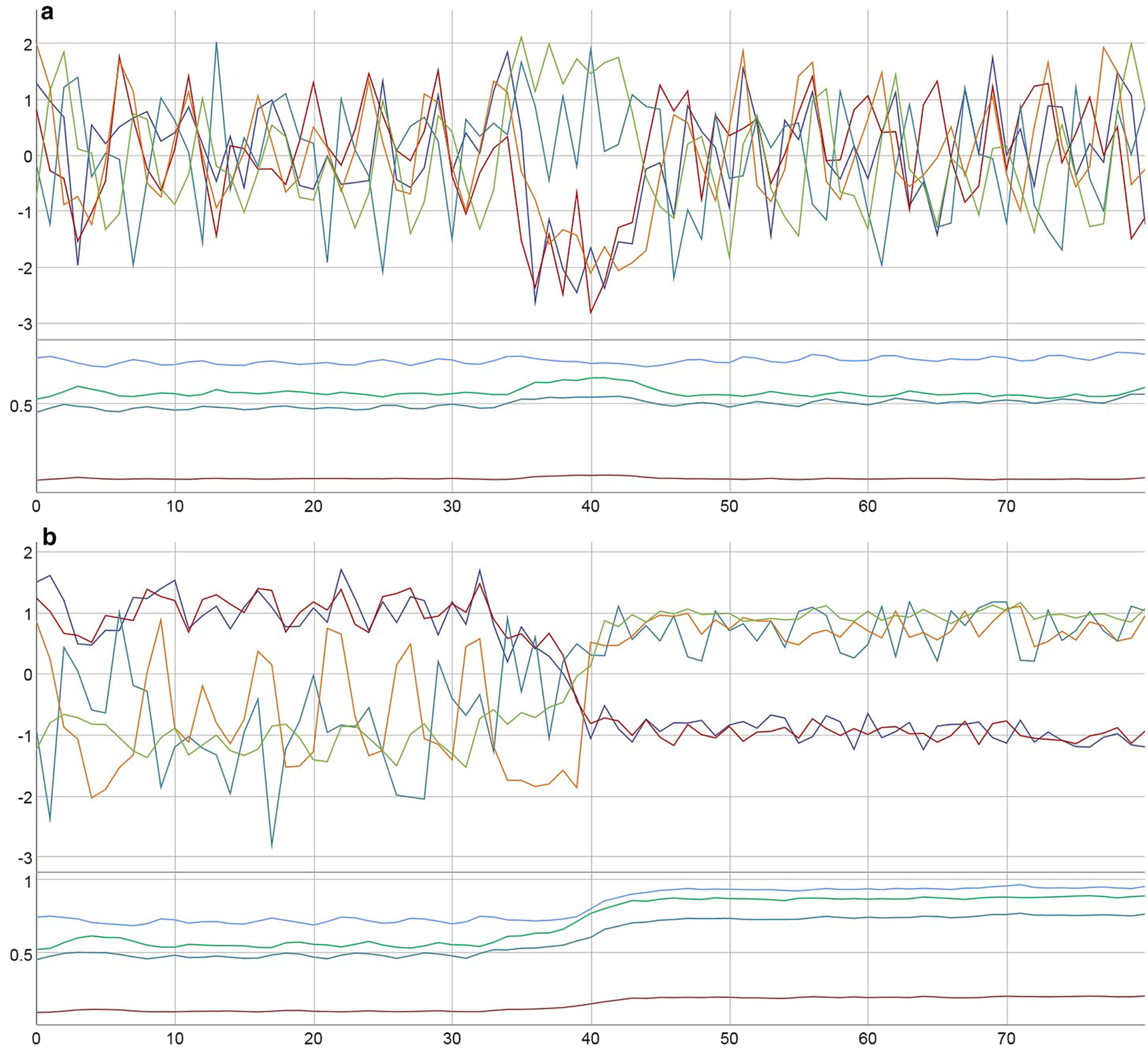


Fig. 7 Two realizations (random numbers) of the same levels of dynamic noise (**a**, **b**). Parameters: *a*: red, *m*: green, *c*: bright blue, *r*: dark blue. In both cases, the initial values of variables and parameters are: E: 97.6, P: 61.5, M: 7.5, I: 100, S: − 40.7. *a*: 0.10, *c*: 0.75, *r*: 0.46, *m*: 0.53. Dynamic noise 10% on E and P, 5% on M, I, and S, continuously. Variables: z-transformed. Data: SIM-7a, CSV-7a, b: SIM-7b, CSV-7b

constructed by understanding more deeply which model elements are necessary and sufficient for a particular dynamical behavior.

Another limitation concerns the question whether a model with continuous time (differential equations instead of difference equations) will also have a chaotic regime. It should be noted that the dimension of the model (D = 5) would in principle allow for chaoticity also in continuous time. For the present investigation, we decided to explore the discrete-time version of the model. Our argument here is that the dynamical variables indeed only exist at discrete time points. The process of filling out the Therapy Process Questionnaire on a daily basis goes along with a process of internal inspection, where—formally speaking—the client maps his/her complex emotional pattern to certain values of the variables. In this sense, the measurement process, induced by the TPQ, forms these variables at discrete times and the psychotherapy dynamics as a system is periodically driven by the TPQ. It is well-known that such periodic driving can trigger a complex dynamical response (Glass 2001; Hütt 2001; Hütt et al. 2002).

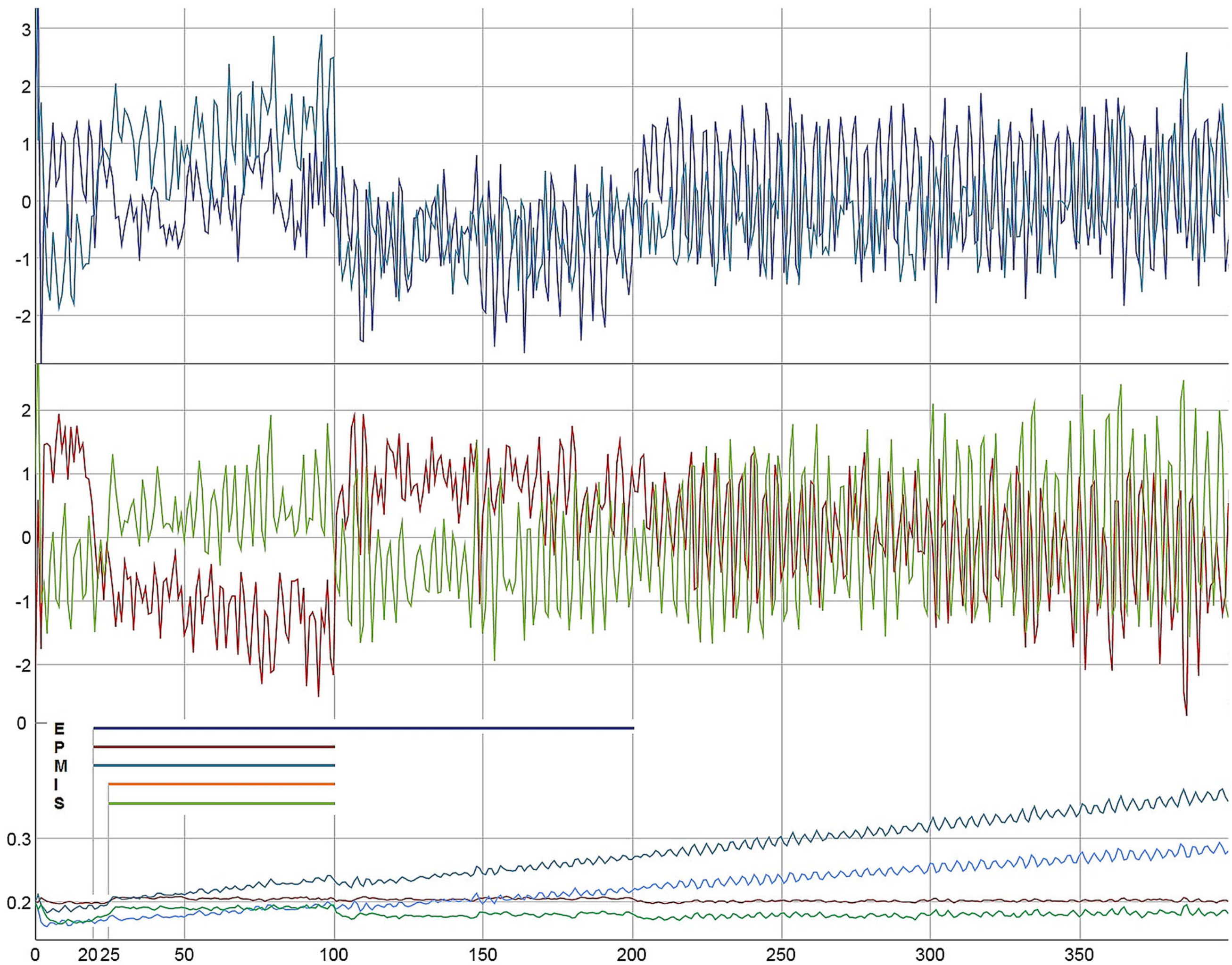
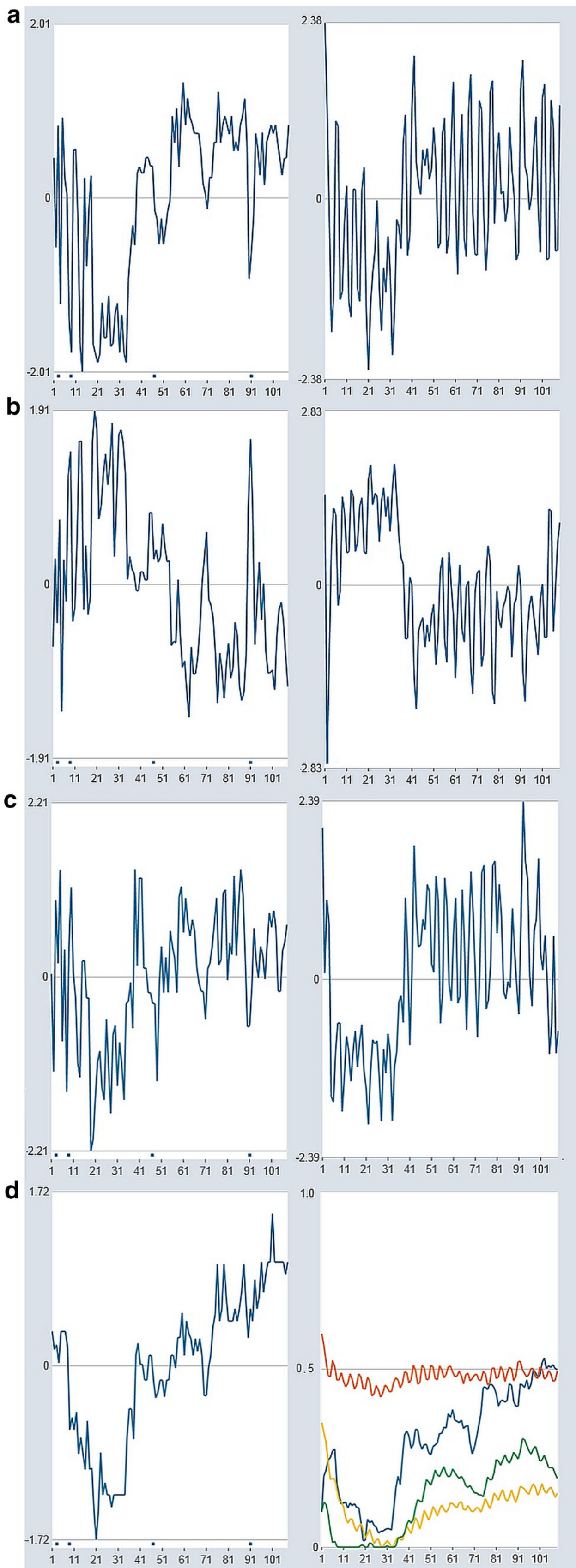


Fig. 8 Interventions on E, P, and M start at t = 20, interventions on I and S at t = 25 (+ 5% on M, + 10% on S and I, − 10% on E and P). Except for E, all interventions end at t = 100, the intervention on E continues to t = 200. The interventions have an effect on all variables, but also a distinct rebound effect in S and M (decreases) and P (increase) can be observed. The continued intervention on E (− 10%) until t = 200 reduces stressful emotions, but also the motivation to change (M) (upper part of the figure). After this period, M and S increase slowly, and P decreases. It seems that a long-term recovery and self-healing process can only start if negative emotions are not suppressed, that is, the self-organizing effect onto another stable attractor can only take place if the system can follow its own unrestricted dynamics. Initial values of variables and parameters: E: 97.6, P: 61.5, M: 7.5, I: 100, S: − 40.7; *a, c, r, m*: 0.20. Dynamic noise: 2%, continuously. Variables: z-transformed. Data: SIM-8, CSV-8

Other models of psychotherapy dynamics

There are only few other attempts to mathematically model psychotherapy. Peluso et al. (2012) and Liebovitch et al. (2011) focused on the co-evolution of emotional valences expressed by a therapist and his client. The differential equations defined by the Liebovitch–Peluso–Gottman et al. group consist of segments of linear functions, each defining the gradient of emotional changes, which the client exerts on the therapist and vice versa. This leads to the prediction of stable fix-point attractors of the therapeutic relationship at the intercept of the valence functions, or to drop-outs, depending on the initial conditions in the two-dimensional phase portrait. Chaos is not possible within the scope of this model. One distinctive feature of the approach presented in this paper compared to that of the Liebovitch–Peluso–Gottman et al. group is that the current approach focuses on the psychological processes of clients in relation to their own experiences—not primarily on the client–therapist-interaction—and that we regard chaos and chaoto-chaotic phase transitions as important features of psychotherapeutic processes (Schiepek et al. 2017).

In another mathematical analysis of psychotherapeutic interventions (Haken and Tschacher 2017) the emergence of a pattern results from a competition of modes, each having a parameter value attached. The model uses a specific connectionist system (the synergetic computer), which was designed as a mathematical tool for visual



◀**Fig. 9** **a** Dynamics of the factor "Therapeutic Progress and Self-Confidence" of the TPQ as it was assessed by daily self-ratings (corresponding to S) in the real client (t = 108 days) (left) and the simulated dynamics of S when interventions were added on P, M, and S from t = 35 to 100 (P: − 10%, M: + 10%, S: + 10%), and on E and I from t = 35 to 50 (E: − 10%, I: + 10%) (right). **b** Factor "Symptom Severity and Problem Intensity"(P) of the TPQ, as empirically assessed in the real client (left) and simulated dynamics of P with the interventions as described in **a** (right). **c** Factor "Motivation to Change" (M) of the TPQ, as empirically assessed in the real client (left) and simulated dynamics of M with the interventions as described in **a** (right). **d** The dynamics of the factor "Therapeutic Alliance and Quality of the Therapeutic Relationship" of the TPQ as it was assessed in the real client (corresponding to the b_t vector) (left) and the evolution of the parameters a, c, r, m triggered by the dynamics of the variables and the interventions as described in **a** (right). Initial values of the variables and the parameters: E: 100; P: 79, M: 32.5, I: 50, S: 1; a = 0.10 (red), c = 0.60 (light blue), r = 0.35 (dark blue), m = 0.10 (green). Dynamic noise: 2% on E and P, 5% on M, I, S. Variables: z-transformed. Data: SIM-9, CSV-9, Patient Data: CSV-9P

pattern recognition, assuming that the scenarios of psychopathology and therapeutic interventions are analogous to that of visual pattern recognition. This approach focuses on the question under which conditions a previously established psychopathological pattern will not be restituted. One result of the simulation study is that successful corrective interventions should focus on one alternative pattern only. This alternative (healthy) pattern must be provided with higher valence (i.e., affective and motivational intensity) than the pathological pattern. The authors interpret this finding as a support of an "holistic" rather than a symptom-focused treatment approach. It is preferable to intensively support a single alternative instead of many less and only partially supported alternative patterns with less motivational intensity than the disorder. Corrective intervention must be "valent", hence work with a focus on affective experiencing, emotion regulation, and motivation.

Model testing

In order to test the model proposed in this paper, the time series of 941 cases (< 3% missing data in each case) are available from different psychotherapy centers, where therapy monitoring and therapy feedback by the TPQ has been implemented in routine practice for many years. A more specific empirical test on the state-trait-dynamics of the model is currently realized in the inpatient psychotherapy department of the Christian Doppler University Hospital, Salzburg, Austria. The prospective study intends to contribute to a better understanding of inter-individual variability of dynamic patterns corresponding to individual dispositions and competencies. The concrete dynamics of the variables, their initial values at the beginning of the therapeutic process, the daily input on E, I, M, P, and S as experienced by the client (interventions), and the parameter levels of *a*, *c*, *m*, and *r* (pre and post treatment) of the clients, will be assessed.

As mentioned above, the variables of the model correspond to five factors of the Therapy Process Questionnaire (Schiepek et al. 2016c), which is administered once per day in routine practice. The administration of the questionnaires is realized by an internet-based device, the Synergetic Navigation System (Schiepek et al. 2015, 2016a, c). The parameters *a*, *c*, *m*, and *r* are widely used psychological constructs, which can be assessed by known questionnaires: The parameter *a* is assessed by the "Adult Attachment Scale" (AAS, Schmidt et al. 2004) and the dynamics of the therapeutic relationship (the b_t vector of our model) by the Therapeutic Alliance Subscale of the TPQ. The parameter *c* is assessed by the "Hannover Self-Regulation Inventory" (a questionnaire on ego-functions and competencies in self–regulation; Jäger et al. 2012) and by the "Emotionale–Kompetenz–Fragebogen" (Questionnaire on Emotional Skills; Rindermann 2009). The parameter *r* is assessed by the "Essen Inventory of Resources" (Tagay et al. 2014). The parameter *m* is assessed by the "Beck Hopelessness Scale" (BHS; Beck et al. 1974; Krampen 1994) with high scores in the BHS corresponding to low levels of *m*, and by the "Questionnaire on Optimistic Expectancies on one's Competencies" (Schwarzer 1994).

Figure 10 illustrates how the model can be fitted to the specific conditions of a client, if the empirical initial conditions, the interventions as assessed by the client, and finally the quality of the relationship to her fellow clients at the ward[1] is taken into consideration for the simulation run. The empirical data and the simulation run refer to one of our study clients, diagnosed with posttraumatic stress disorder combined with anorectic eating disorder. As can be seen, the simulation run (b) with specific information on the client taken into consideration is more similar to the empirical process (c) than the simulation run without these additional information (e): there is a slow rhythm, but no phase transition, and P and E are synchronized, whereas S is antisynchronized.

[1] Here, instead of the subfactor "Quality of the therapeutic relationship" of the TPQ, the subfactor "Ward atmosphere and relationship to the fellow patients" was used as vector b_t in Eq. 8, since the latter has been proven to be even more important than the relationship to the professionals. This is also an example of how flexible the model is in terms of testing alternative hypotheses.

Specific features and conclusions of our model

By summarizing the results and consequences of our mathematical model, some specific features—compared to other models (see above)—become evident:

- The option to create chaotic dynamics and chaoto-chaotic phase transitions (Kowalik et al. 1997) is an important feature of change dynamics and corresponds to empirical findings (Schiepek et al. 2016a, 2017). The model is designed in such a way that—depending on the parameters—a spectrum of dynamic patterns (e.g., chaotic patterns) occur.
- The model includes the quality of the therapeutic relationship. Findings show that the therapeutic alliance, as it is perceived by the client, correlates with and predicts the therapeutic outcome better than the alliance as perceived by the therapist or an external observer (Horvath and Symonds 1991; Orlinsky et al. 2004). The model integrates the concrete empirical dynamics of the client-therapist-relationship of a specific case and takes into consideration the evolution of the quality of cooperation as perceived by the client.
- The model does not presume the existence of alternative attractors or patterns in a potential landscape, but explains how new attractors will emerge by modulating the parameters, which are shaping the landscape. In principle, there are two complementary kinds of interventions: First, interventions can be understood as experimental inputs to explore the switching points or to identify the triggers which may switch on a different attractor within the range of unique dynamic patterns of the system. In the metaphor of potential landscapes, the ball (the realized system behavior) is driven beyond the separatrix into another valley of the landscape—if it exists. Secondly, the interventions influence the parameters via the state dynamics, and the parameters then reshape the landscape, creating new potential valleys (attractors).
- There are many ways how to create change: All variables (order parameters) of the model are open for interventions. Perhaps a converging effect of more than one component—corresponding to more than one treatment approach—is preferred. This corresponds to the well-known Dodo-Bird effect, which implies that there are no substantial differences in the effectivity of treatments (e.g., Wampold and Imel 2015).
- There might be a complementarity and synergistic effect of interventions, but without motivation to change (M) and without a positively experienced therapeutic bond, no dynamics of change will emerge. Also, our model opens the way for an evolution of M

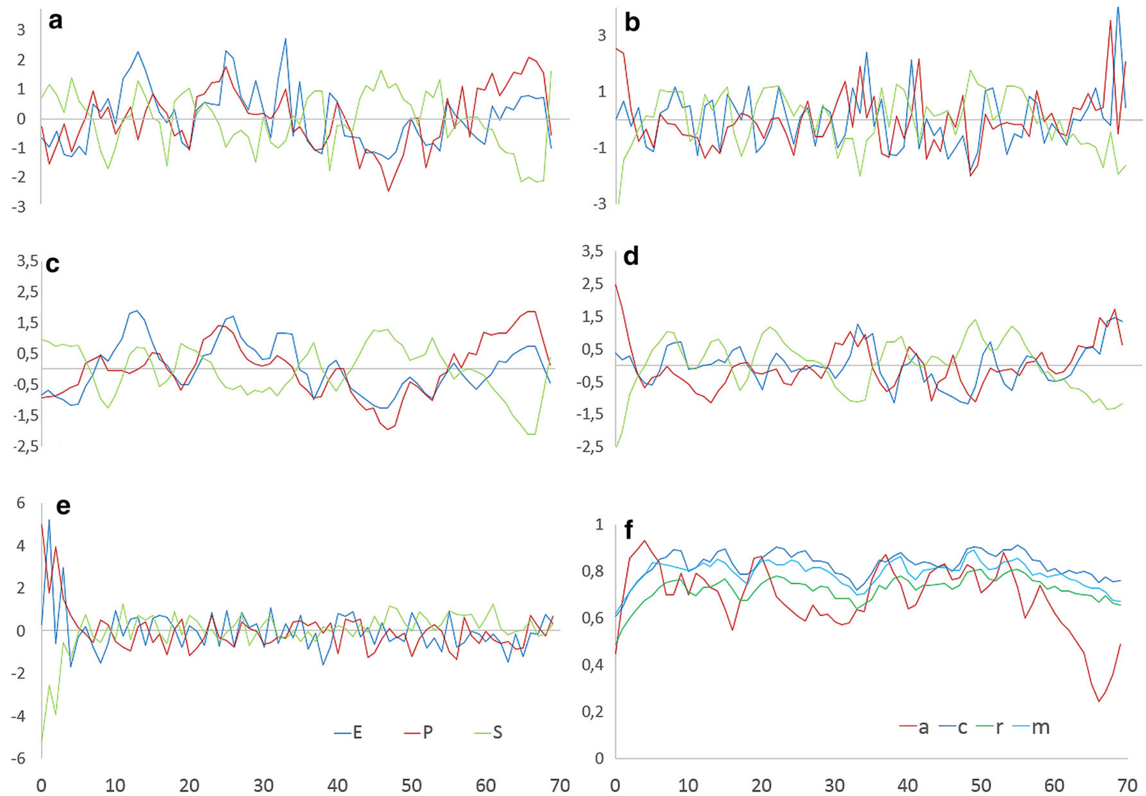


Fig. 10 Model test by using empirical data from a real client. **a** The empirical time series of the variables E, P, and S as assessed by the TPQ. **b** Simulation of the dynamics of E, P, and S with the empirically assessed initial conditions, the b_t vector and the therapeutic interventions. The interventions for all variables were assessed by the client's daily ratings of the experienced input on these variables from his environment. Below, **c**, **d** show the above time series, but smoothed by an overlapping gliding window (window width = 3, calculation of the arithmetic mean). In comparison to **b**, **e** shows the simulation run without specification of input and the b_t vector. **f** Evolution of the parameters using the b_t vector. Variables: z-transformed

and *a* (and of other states and traits) even when a client starts from bad initial conditions.

- A long-term stabilization of treatment effects requires a change in the levels of traits (control parameters), that is, new or enhanced competencies and skills.
- There are long-term effects of psychotherapy, even after crises or rebound effects, which occur when treatments end or clients are released from inpatient or other treatment settings. Psychological long-term effects correspond to processes of neuronal reorganization which also take time and have to be stabilized even in stressful environments.
- Crises in the sense of critical instabilities are conceptualizable as important transients on the way to self-organized pattern transitions.
- The model predicts inter- and intra-individual differences in context-specific behavior depending on traits and attractors. States fluctuate depending on situational contexts (e.g., triggered by interventions) and on other states. The interconnectedness of states and traits implies that people react to situations or contexts by personal patterns of cognitions, emotions, behavior, motivation, or activation of symptoms (compare the findings of Geukes et al. 2017; Wilson et al. 2016). These patterns characterize the personality and evolve in time by self-organizing processes.

Further developments on mathematical modeling and data-related simulation of human change processes could open new ways of testing therapeutic interventions before administering them on human beings. We do not expect any options for long term predictions in chaotic systems like this, but for short term predictions and early warning signs. Conceptually, the traits of the model could be related to the ego-functions and the levels of the personality structure of clients as outlined by the Operationalized Psychodynamic Diagnostics (OPD, Doering et al. 2013). The assessment of the traits (control parameters) of the model could be cross-validated by the semi-structured interview procedures and the personality questionnaire provided by the OPD. Finally, the phenomenological (psychological) model could be more closely linked to the neural mechanisms of human change processes. Emergent psychological mechanisms could be related to more basic (meso- and micro-level) neural network dynamics (Bonzon

2017; Freeman 2000; Haken 2004; Haken and Schiepek 2010; Kozma 2016) and by this, the promising approaches of computational systems neuroscience and computational systems psychology could be integrated.

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A Nonlinear Dynamic Systems Model of Psychotherapy: First Steps Toward Validation and the Role of External Input

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Abstract:

Problem: Psychotherapy works, but despite decades of process research, the mechanisms and dynamics of change are not well understood until now. Mathematical modeling and computer simulations are important means to create an understanding of these mechanisms. The challenge is to design mathematical models which not only predict outcome, but simulate the trajectories of change which – according to current knowledge – are characterized by nonlinearity and nonstationarity. Another challenge is to test and to validate the models with empirical data.

Theory: We proposed a model on change dynamics of psychotherapy, which integrates five variables (states or order parameters) and four control parameters (traits) by a set of nine coupled nonlinear difference equations.

Method: Here we outline how the model can be tested and validated by empirical time series data of the variables, by parameters measured at the beginning and at the end of the psychotherapeutic process, by time series of the therapeutic alliance, and by assessing the input onto the system ("interventions") as it is perceived by the client. The methodological steps are illustrated by the data of a client who used an internet-based tool for high-frequency therapy monitoring.

Results: Especially after applying the input vector, the similarity between the empirical and the model dynamics becomes evident. The discussion opens perspectives on the combination of mathematical modeling with internet-based real-time monitoring in order to realize data-driven simulations for short-term predictions and to estimate the effects of interventions in a virtual system before real interventions are applied to real clients.

Keywords: Psychotherapeutic processes, nonlinear dynamics, computer simulation, mathematical modeling, model validation, interventions

INTRODUCTION

For the purpose of understanding complexity and nonlinear dynamics in human change processes, empirical studies and theoretical modeling have to be combined. Within the paradigm of nonlinear dynamic systems, theories have to be developed in order to understand nonlinear patterns of change (e.g., order transitions, critical instabilities, nonlinear trajectories) and in a second corresponding step time series data have to be analyzed for testing hypotheses derived from theoretical models. Theories have to be formalized by mathematical tools in order to explain the observed dynamics. Any explanation of system dynamics implicates the reproduction of the processes by computer simulations which are performed after a well-defined theoretical model has been transformed into a mathematical algorithm. This procedure may contribute to methodological requests stated by Kazdin (2005, 2009) who asks for evaluating timelines (dynamic patterns) and for a clarification of the relations between factors and their causal involvement contributing to psychotherapeutic effects. Especially computer simulations can substantially promote our understanding of how and why psychotherapy works.

Although mathematical modeling and computer simulations have some tradition in clinical psychology (e.g., Schiepek et al., 1992), simulation studies still are uncommon (for exceptions see Liebovitch et al., 2011; Haken & Tschacher, 2017; Malkina-Pykh, 2018). Compared to our focus on the process, the few existing other models focus on different topics, e.g., the co-evolution of emotional valences expressed by client and therapist (Liebovitch et al., 2011) or relationship ruptures with repair-oriented interventions (crisis-repair sequences) (Strawinska-Zanko et al., 2018). Haken & Tschacher (2017) use the connectionist algorithm of the synergetic computer to test the stability of psychopathological patterns. Malkina-Pykh (2018) presents a generalized multiplicative model as a nonlinear regression method to predict the outcome of rhythmic movement therapy (Malkina-Pykh, 2013). The model differentiates the impact of a set of psychological variables by implementing partial response functions (Malkina-Pykh & Pykh, 2013) to each of the variables. Compared to linear approaches, the nonlinear regression model includes interaction effects among predictors for subjective well-being as the main outcome criterion and provides higher explanatory power than linear approaches. One challenge of the nonlinear multiplicative approach which is similar to other approaches is the estimation of multiple parameters.

Here we refer to a mathematical model which was developed to reproduce essential features of psychotherapeutic change dynamics (Schiepek et al., 2016a, 2017; Schöller et al., 2018). The "explanandum" of the model is the process. We report on first steps toward a data-driven validation of the model, which is based on daily self-assessments of a client.

Before any model can be tested by comparing simulation runs with empirical data, the validation of mathematical models has to pass some preceding steps:

1. The model has to be built on the empirical and theoretical knowledge of the system under consideration. In this case, it is the cognitive-emotional functioning of clients during psychotherapeutic change. The model focuses on psychological mechanisms which have repeatedly been shown to be important within the „client system" (Grawe, 2004; Orlinsky et al., 2004), e.g., common factors of psychotherapy, emotion regulation, mentalization, self-esteem, motivation for change, reward expectation, problem-solving, psychopathology, and other topics. This is the criterion of qualitative model justification.
2. The formalization of the model has to be logically and mathematically sound. The formal approach should fit the type of dynamics which has to be reproduced. In this case, it is a set of coupled nonlinear difference equations, which is able to create chaotic and self-organizing patterns.
3. The simulation should reproduce the most important dynamic features of the empirical system under consideration. Concerning psychotherapeutic change dynamics, this is chaoticity (e.g., positive Lyapunov exponents and fractal dimensionality; Haken & Schiepek, 2010; Kowalik et al., 1997; Strunk et al., 2015), sensitive dependence of the dynamics on initial conditions, nonstationarity and order transitions of the dynamics (e.g., sudden gains or sudden losses), the emergence of critical fluctuations and other precursors of order transitions, co-evolution of state and trait dynamics, time-dependency of interventions, and others (Gelo & Salvatore, 2016; Haken & Schiepek, 2010; Hayes et al., 2007; Heinzel et al., 2014; Pincus, 2009; Schiepek et al., 2014, 2017, 2018; Strunk & Schiepek, 2006). The psychotherapy model under consideration is able to reproduce these features (Schiepek et al., 2016a, 2017; Schöller et al., 2018).
4. Computer simulations can be tested by applying specific virtual interventions (inputs) onto the system and by observing the behavior of the model under specific conditions (experimentum in silico, Mainzer, 2007). The features of a particular simulation run can be defined by the parameter values, the boundary conditions, and the initial values of the variables. In the psychotherapy model discussed in this article, we see the time-dependency of interventions, the dependence of intervention effects on the stability or instability of the dynamics, and phase transitions produced by a linear increase of one or more control parameters (Schiepek et al., 2017; Schöller et al., 2018).

In general, an important aim of formal modeling and of computer simulations is to get a deeper understanding of the mechanisms behind the phenomena to be explained and to specify the nonlinear interactions between the included variables in an explicit way. Formal modeling requires a degree of transparency of concepts, functions, and network connectivity which usually cannot be reached by verbal or metaphorical delineations. Compared to any metaphorical use of concepts, criticism is easier, more concrete, and hopefully also more constructive. Any further steps beyond this basic aim, e.g., in reproducing the specific dynamics of particular cases or technical applications of computer models on human systems are important, but given our current level of understanding, we are at the very beginning on this way. Let's go some steps in order to fathom the options.

THE MODEL

The model we refer to in this article is based on the assumption that it is the client who contributes most or at least significantly to the course and outcome of psychotherapy (Bohart & Tallman, 2010; Duncan et al., 2004; Orlinsky et al., 2004; Sparks & Duncan, 2010; Wampold & Imel, 2015). In consequence, the model focuses on psychological mechanisms which have been shown to be important within the client, both empirically and theoretically (e.g., Grawe, 2004; Orlinsky et al., 2004). The model includes five variables, which are connected by 16 functions, mediated by four parameters (Figure 1). Beside the reference on results from common factors research and change-related psychological topics another reason for focusing on the selected set of variables is their correspondence to the factors (subscales) of the Therapy Process Questionnaire (TPQ, Haken and Schiepek, 2010), which is used in routine practice of psychotherapy feedback (Schiepek et al., 2016c).

In the following, a short outline of the variables, parameters and functions will be given. A detailed description of the constructs and of the psychological mechanisms is presented in Schiepek et al. (2017) and Schöller et al. (2018). Both articles describe a development of the first step model (Schiepek et al., 2016a), which underwent some optimization in terms of mathematical formalization and psychological underpinnings.

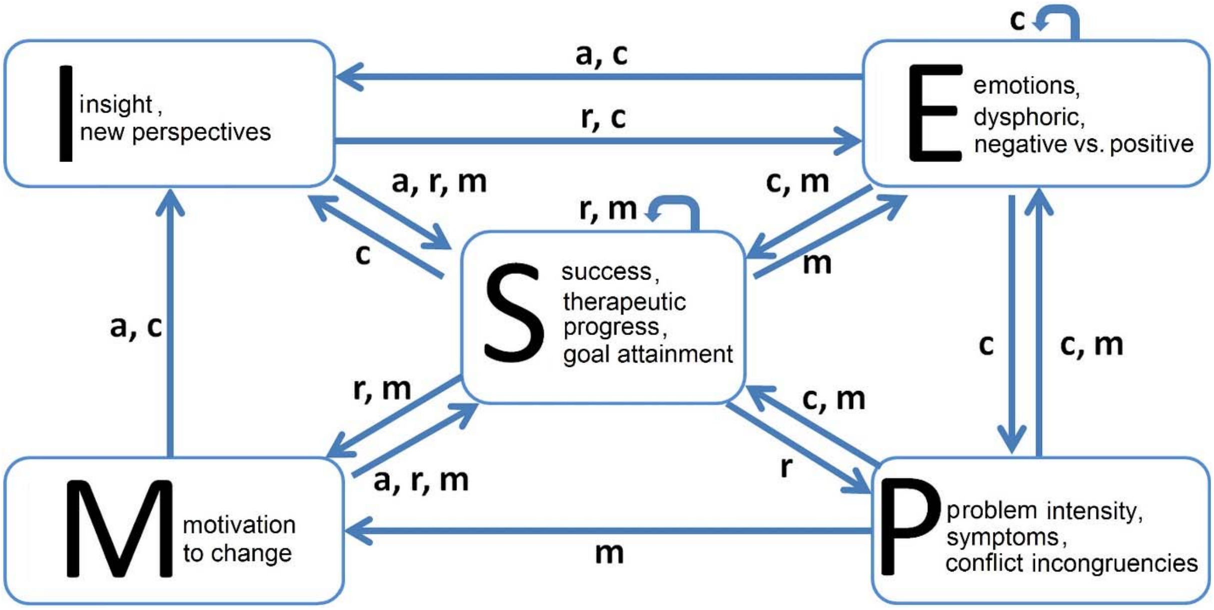

Figure 1: The structure of the model illustrates the dependencies between the variables and the parameters of the system.

The variables

The variable E ("emotions") is conceptualized as a bipolar construct representing dysphoric emotions (e.g., anxiety, grief, shame, guilt, and anger) at the upper end of the dimension. (positive values of E), and positive emotional experiences (e.g., joy, self-esteem, happiness) at the lower end (negative values of E). This definition of polarity is based upon the results of a factor analysis of the Therapy Process Questionnaire (TPQ, Haken and Schiepek, 2010; Schiepek et al., 2016b), which is used for psychotherapy feedback and generated the empirical data for model testing.

I ("insight") refers to the creation of new perspectives, to understanding oneself, and to becoming aware of relationships between symptoms or problems, behavior, cognitions, emotions, and personal motives which were not seen so far (clarification perspective in terms of Grawe, 2004). Insight might also result from confrontation with conflicts, avoided behaviors and cognitions, or with suppressed traumatic experiences.

M ("motivation for change") denotes the readiness for any engagement in therapy-related activities and experiences.

P ("problem and stress intensity") refers to symptom severity, the intensity of experienced conflicts or stress, and to the experience of incongruence in terms of Grawe (2004).

S ("success") represents therapeutic progress, steps toward goal attainment, and confidence in a successful therapeutic course

The parameters

The model includes four parameters, which mediate the interactions between variables. Depending on their values, the effect of one variable onto another is intensified or reduced,activated or inhibited. Formally they modify the functions, which define the relationship of the variables onto each other.

Parameter *a* represents the "working alliance", comprising both the capability to enter a trustful cooperation with the therapist, and the quality of the realized therapeutic relationship. This parameter signifies the disposition to engage in a trustful relationship (attachment disposition) and also resembles the quality of the therapeutic alliance in the therapeutic process (vector b_t, compare equation 6) as it is experienced by the client. Parameter *c* refers to "cognitive competencies", i.e., capacities for mentalization and emotion regulation as well as mental skills in self-reflection and self-relatedness.

Parameter *r* represents the "behavioral resources" or skills (e.g., social skills) of a client which are available for problem-solving and for transforming insight into action. *r* should allow for the realization of any real-world impact of creating goals, intentions, and understanding of oneself and others.

Parameter *m* represents "motivation for change" as a trait, which includes self-efficacy, hopefulness, and reward expectation resulting from accumulated life experiences during the biography. *m* is different from M, because of the different time scales which are addressed by *m* and M (*m* as a trait evolves at a slower time scale). Further on, *m* is a basic and in many situations unconscious attitude toward the relationship between oneself and the world. Finally, *m* is a disposition which may be activated in concrete situations. M is a short scale "net effect" of the approach and avoidance gradients of a concrete situation.

In terms of psychodynamic concepts and of Operationalized Psychodynamic Diagnostics (OPD, www.opd-online.net), *a*,

c, r, and m represent what is called the "structure of personality".

The functions

The shape of each function represents theoretical and empirical findings from psychotherapy research and from other psychological topics like emotion regulation, motivation, problem-solving, or self-related cognition. Based on the literature on common factors creating the outcome of psychotherapy and on psychological findings in emotion- and stress-regulation, motivation, regulation of self-esteem, self-efficacy, learned helplessness and other fields, the model was designed. The functions contain all knowledge which was available to the authors, with one author (G.S.) having decades of experience in psychotherapy research. The model interrelates the variables in a qualitative way, and in a next step the interrelations between the variables are modeled by mathematical functions. Here we can present only two examples of such functions, all others would go beyond the scope of this article. The function $E_t(S_{t-1}) = \frac{1.25}{1+e^{5S_{t-1}-0.5}} - 0.5 - 0.5m$ for example describes how emotions (E) depend on therapeutic success (S) (Figure 2), i.e., the experience of emotions like fear, grief, shame, or anger are reduced by or inversely related to feelings of progress and being successful in solving personal problems, with a saturation effect for extreme values of S. The strength of the effect is mediated by parameter m, that is, by self-efficacy and a general positive expectation in problem-solving efforts. The higher m, the more S will reduce worrying emotions.

Other relations, e.g., E(P) and M(P), require more refined mathematical functions to capture the psychological mechanisms. The dependence of negative emotions E on the problem intensity P, for example, describes a complex relationship and represents the state of knowledge on emotion regulation and on the psychopathology of borderline personality disorder (Fig 2, left column, second from bottom). Increasing problems activate worrying and distressing emotions. The more severe or stressing the problem, the more such emotions will be triggered (exponential increase). This emotion triggering effect is more pronounced if the person has only minor competencies in emotion-regulation, self-reflection, and mentalization (parameter c) and/or reduced expectations in his capacity to solve problems or to manage difficult or stressful situations (self-efficacy expectation, parameter m). With higher values of c and/or m, coping strategies for the down-regulation of negative emotions at distinct problem intensities will be available and can be applied. The higher c and/or m, the lower the maximum of E and the earlier coping mechanisms and emotion regulation skills will reduce negative emotions. At low levels of c and m, even low levels of affect intensities cannot be managed or reduced until completely distressing and disturbing emotions (high levels of E) are interrupted, repressed, or disconnected from conscious by consuming drugs or alcohol, by self-harm, or by mechanisms of dissociation (switch of ego-states).

All functions of the model are integrated as terms into five coupled nonlinear equations, one for each variable:

$$E(E,I,P,S,c,r,m) = \frac{1}{1+e^{-10E}} - c + \frac{1}{1+e^{-20I\cdot\left(1-\frac{c+r}{2}\right)+5}} + + \frac{\frac{-1}{1+e^{\left(2+3\cdot\left(1-\frac{c+m}{2}\right)\right)\cdot P}}+0.5+0.5\cdot\left(1-\frac{c+m}{2}\right)}{1+e^{25\cdot\left(1-\frac{c+m}{2}\right)\cdot\left(P-0.2-0.75\cdot\left(1-\frac{c+m}{2}\right)\right)}} + \frac{1.25}{1+e^{5S-0.5}} - 0.5 - 0.5\,m \quad (1)$$

$$I(E,M,S,a,c) = \frac{1}{1+e^{-20E\cdot\left(\frac{a+c}{2}\right)+5}} + \frac{1}{1+e^{-20M\cdot\left(\frac{a+c}{2}\right)+5}} + \frac{1}{1+e^{-20\cdot|S|\cdot c+5}} \quad (2)$$

$$M(P,S,r,m) = \frac{1.261}{1+e^{(P-0.05-0.85m)\cdot(10.1+19.9m)}} \cdot \frac{1}{1+e^{-(P-0.43+0.03m)\cdot(7-3m)}} - \frac{1}{1+e^{5S}} + \frac{r+m}{2} \quad (3)$$

$$P(E,S,c,r) = \frac{1}{1+e^{-10E}} - c + \frac{1.2}{1+e^{5S-0.5}} - 0.2 - 0.8\,r \quad (4)$$

$$S(E,I,M,P,S,a,c,m,r) = \frac{1.3}{1+e^{5E-0.5}} - 0.65 + 0.35\cdot(c+m-1) + \frac{1}{1+e^{-20I\cdot\frac{(a+m+r)}{3}+5}} + \frac{1}{1+e^{-20M\cdot\frac{(a+m+r)}{3}+5}} - \frac{1}{1+e^{20M\cdot\left(1-\frac{a+m+r}{3}\right)+5}} + \frac{1.25}{1+e^{5P-0.5}} - 0.5 - 0.5\cdot\left(1-\frac{c+m}{2}\right) + \frac{1}{1+e^{-10S}} + \frac{m+r}{2} - 1 \quad (5)$$

The graphs in the coordinate planes of Figure 2 illustrate how the shape of each function depends on the parameter values. The variables as noted on the left side of the matrix (lines) define the input, the variables as noted on the top (columns) define the output. Each function is represented by a graph in a coordinate system (x-axis: input, y-axis: output). Grey function graphs correspond to the maximum values of the respective control parameter(s) (= 1), dashed graphs (short dashes) to the minimum of the parameter(s) (= 0). Dashed graphs (long dashes) represent an in-between state (0 < parameter values < 1). The full range of the variables is covered by the functions defining the influence of other variables, that is, no arbitrary segmentations or thresholds have been introduced from the beginning. Thresholds and discontinuous jumps of the dynamics are emerging from the dynamics and are not forced by some specific preliminary assumptions.

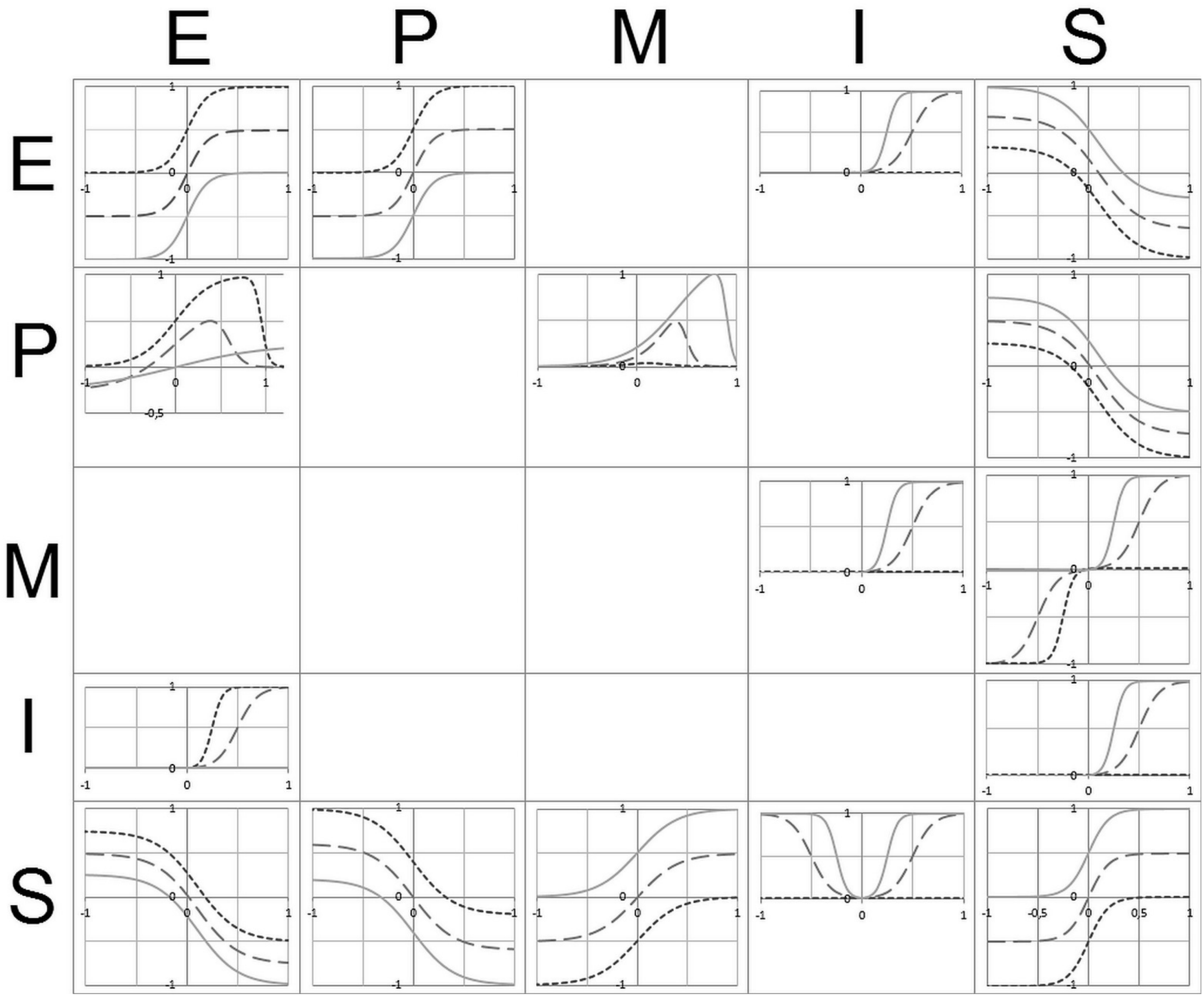

Figure 2: The 16 functions of the model. The specific shape of the functions depends on the parametrization: highest value of parameters *a, c, r, m*, — — — — — in between value, - - - - - lowest value.

In terms of Synergetics, the variables or states correspond to the order parameters of the model, traits correspond to its control parameters. Psychologically, the control parameters can be interpreted as traits or dispositions changing at slower time scales than the variables or states (separation of time scales). The change of control parameters drives the phase transitions of the system (Haken, 2004). Usually, a continuous shift in the sensitive range of the parameters produces a discontinuous jump of the system dynamics (Haken & Schiepek, 2010).

The effect of a parameter shift in *c* is demonstrated in Figure 3. The transition of the pattern (nonstationarity) depends on a stepwise linear increase of the parameter *c* from 0.60 to 1.00 between iteration 100 and 200. From iteration 0 to 100 the parameter is kept constant at 0.60 creating a certain dynamic pattern (attractor). After the 200^{th} iteration, *c* is constant at 1.00, producing another pattern at a lower mean level, at a lower frequency, and with higher amplitudes of the chaotic oscillations. The attractors are shown below the time series. For the generation of the attractors, the discrete iterations were splined by the Excel standard spline function. During the linear stepwise increase of the control parameter, the transient attractor combines features of the pre- and the post-attractor and by this is more complex than each of both.

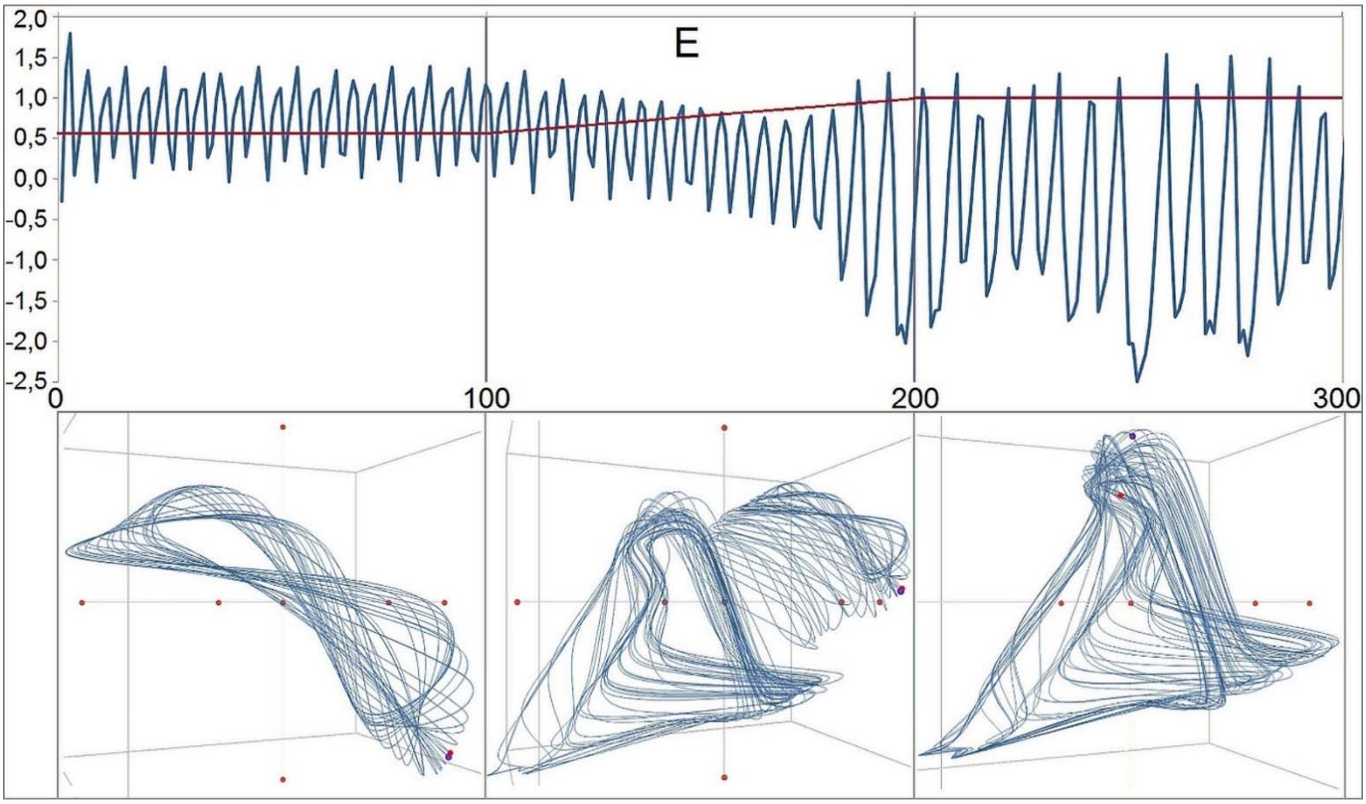

Figure 3: Order transition in the dynamics of E (emotions). The y-axis refers to the values of the parameter c ($0 < c < 1$) and to the z-transformed values of E.

The circular causality between states and traits is realized by coupled nonlinear difference equations of variables (states) and control parameters (traits). State dynamics are dependent on traits, and the evolution of traits is dependent on states, i.e., concrete experiences in emotions (E), problem intensity (P), motivation to change (M), insight (I), and success (S). For a detailed development of this state-trait model which connects state and trait equations see Schöller et al. (2018)

$$a_t = \frac{1}{2}(a_{t-1} + b_t) + s_a \cdot w_a \cdot a_{t-1} \cdot \frac{1}{2}(f_{S,t,n} - f_{E,t,n}) \quad (6)$$

$$c_t = c_{t-1} + s_c \cdot w_c \cdot c_{t-1} \cdot \frac{1}{3}(f_{I,t,n} + f_{S,t,n} + r_{t-1}) \quad (7)$$

$$r_t = r_{t-1} + s_r \cdot w_r \cdot r_{t-1} \cdot \frac{1}{2}(f_{S,t,n} + c_{t-1}) \quad (8)$$

$$m_t = m_{t-1} + s_m \cdot w_m \cdot m_{t-1} \cdot \frac{1}{4}(-f_{E,t,n} - f_{P,t,n} + f_{M,t,n} + f_{S,t,n}) \quad (9)$$

The functions s_a, s_c, s_r, s_m are saturation functions which limit the growth and reduce the control parameters onto the predefined range from 0 to 1. $f_{E,t,n}$, $f_{P,t,n}$, $f_{M,t,n}$, $f_{I,t,n}$, $f_{S,t,n}$ are filter functions which represent the effect of each variable onto the respective parameter considering the different time-scales by a combination of averaging and weighting recent changes stronger than prior ones. w_a, w_c, w_r, w_m are weights which are introduced in order to dampen the effects of the variables onto the control parameters, i.e. the weights scale them to an appropriate range with respect to the variables. They model the sensitivity and the impact of the state dynamics on the evolution of traits. For the simulation runs presented in this paper, $w_a = w_c = w_r = w_m = 0.004167$.

Concerning the evolution of the control parameter a_t, an internally added factor b_t is implemented, which takes account of the twofold meaning of the parameter a. As we noted above, this parameter signifies the disposition to engage in a trustful relationship (attachment disposition), but it also refers to the empirically realized quality of the therapeutic alliance in a concrete therapeutic cooperation. The alliance as perceived by the client can be measured by the therapeutic alliance subscale of the TPQ-R. The concrete value of the empirically given quality of the alliance at time t is represented by b_t (see equation 6).

METHODOLOGICAL STEPS TO VALIDATION

The data for the validation of the model were taken from a client (female, 26 years old) who was treated at an inpatient psychotherapy center (11 weeks of hospital stay). The client was diagnosed with Posttraumatic Stress Disorder (ICD 10: F43.1), eating disorder (atypical anorexia nervosa; ICD 10: F50.1), and Major Depressive Disorder, recurrent (ICD 10: F33.2). At admission to the hospital, she was in a state of severe depression, but without the psychotic symptoms she showed in previous times. The treatment followed an integrative approach with different components, such as individualized psychotherapy with an experienced therapist, psychoeducation, mentalization-focused groups, skills training following Dialectic Behavioral Therapy, music and art therapy, climbing and walking. She was treated with anti-depressive medication without changing dose throughout the hospital stay. The treatment outcome was small or even deteriorating, that is, the client has to be classified as a "non-responder." However, a detailed evaluation of the hospital stay by the therapeutic staff appraised that the treatment prevented her from further deterioration, because of some severe life events during this period (e.g., loss of employment, separation from her companion in life). The subscale values of the ICD 10-based Symptom Rating Scale (Tritt et al., 2008) comparing pre-treatment vs. post-treatment were: depression 1.25 vs. 1.25, anxiety 1.00 vs. 1.75, obsessive-compulsive disorder 0.67 vs. 1.67, somatoform disorder 0.00 vs. 0.00, eating disorder 0.00 vs. 0.00, additional scale 1.25 vs. 0.92, total score 0.77 vs. 1.00. The outcome (pre vs. post) in the subscales of the Depression Anxiety Stress Scales (DASS 21, Lovibond & Lovibond, 1995) were: depression 2 vs. 10, anxiety 4 vs. 4, stress 8 vs. 14. In all scales, higher values indicate higher levels of symptom severity.

The variables E, I, M, P, and S correspond to the factors of the TPQ-R and were assessed once per day (Schiepek et al., 2016b). The length of the time series is 71 measurement points (= days) (Fig. 4b). An important contribution to the evolution of the system is its input from outside. This input may be interventions as intended by professionals, but also other events in the social environment of the client. We know that not only intended therapeutic interventions from the professionals may be "significant therapeutic events" as perceived by the client (Timulak, 2010), but also other experiences and events in their personal "field" ("Lebenswelt", Lewin, 1951). It is an open research question to what extent personal growth or personal change really depends on intended treatments, even in a highly structured inpatient setting, or on common or extra-therapeutic factors (e.g., Wampold, 2015). The input or "interventions" on the state variables E, I, M, P, and S were rated once per day by five items (7 step Likert scales) (Fig. 4a) (E: "Today's experiences affected my feelings and emotions [to the worse – to the better]", I: "Today's experiences affected my understanding of mental and behavioral patterns, of how feelings, cognitions, and behavior relate to each other, or created new perspectives on solutions [to the worse / to the contrary – to the better / very much]", M: "Today's experiences affected my motivation for change and my engagement for the treatment [to the worse – to the better]", P: "Today's experiences affected my problems and symptoms [to the worse – to the better]", S: Today's experiences affected my progress in therapy [to the worse – to the better]".

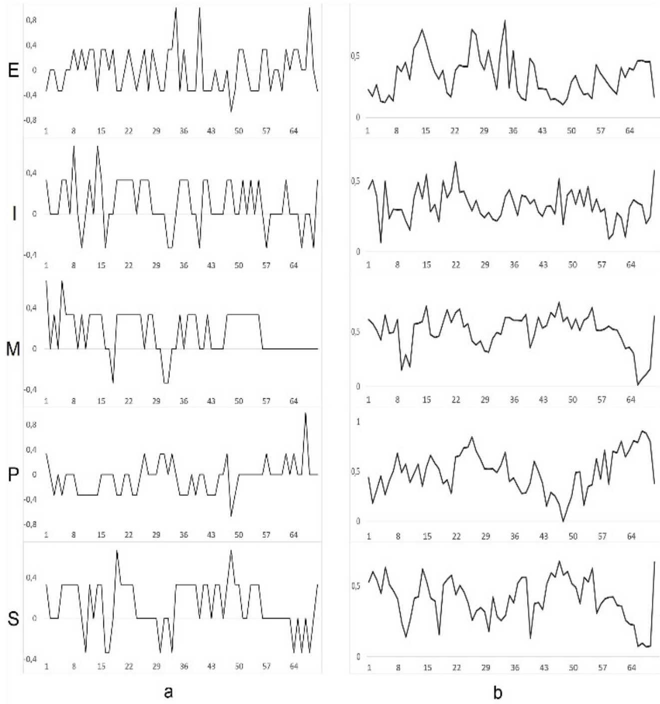

Figure 4: (a) The perceived input or "interventions" on the state variables E, I, M, P, S. (b) The empirical dynamics of E, I, M, P, S as assessed by the client (see text) using the TPQ-R (daily ratings, 71 measurement points).

The parameters *a*, *c*, *m*, and *r* are psychological constructs which can be assessed by known questionnaires. The parameter *a* combines two components, and in consequence, is assessed by two questionnaires: the Adult Attachment Scale (AAS, Schmidt et al., 2004) represents the disposition to engage in a trustful relationship (e.g., in the working alliance with a therapist), whereas the dynamics of the therapeutic relationship is assessed by the Therapeutic Alliance Subscale of the TPQ-R (this is the b_t vector in equation 6 of the model). The parameter *c* is assessed by the Hannover Self-Regulation Inventory (a questionnaire on ego-functions and competencies in self–regulation; Jaeger et al., 2012) and by the Questionnaire on Emotional Skills (Emotionale-Kompetenz-Fragebogen; Rindermann, 2009). The parameter *r* is assessed by the Essen Inventory of Resources (Tagay et al., 2014). The parameter *m* is assessed by the Beck Hopelessness Scale (BHS, Beck et al., 1974; Krampen, 1994) with high scores in the BHS corresponding to low levels of *m*, and by the Questionnaire on Optimistic Expectancies in one's Competencies (Schwarzer, 1994).

In a first step, the values of the questionnaires are transformed into parameter values between 0 and 1 with the range of the questionnaire ratings defining a range between 0 and 1 (for *c* and *m* the arithmetic mean of two questionnaires is calculated, for the calculation of *m* the BHS values have to be inverted). In a next step we checked at which parameter values the intensity and the configuration of the variable dynamics was closest to the empirical pattern of the autonomous dynamics, and used the resulting parameter values as the best estimation of the real parameters. This may seem to be arbitrary, but it is a necessary step onto a calibration or adjustment algorithm that adapts the measured parameters to a model-related rescaling of the parameters. The parameters as they are measured by the questionnaires and as they are rescaled are shown in Table 1. The parameter values of *a* remain unchanged and the others respect the direction (increase or decrease) as well as the magnitude of change. Further cases will be used for defining a valid and robust model-related parameter rescaling algorithm.

	measured		adjusted for simulation	
	pre	post	pre	post
a	0.45	0.50	0.45	0.50
c	0.61	0.64	0.30	0.32
r	0.49	0.38	0.24	0.19
m	0.62	0.46	0.31	0.23

Table 1: Empirical values of the parameters *a, c, r, m* as measured by questionnaires (see text) at the beginning (pre) and at the end (post) of psychotherapy. The parameters were adjusted to values which create a fitting pattern of empirical and simulated dynamics.

With the adjusted parameters the simulation produces a qualitative pattern similar to the empirical pattern of the client. Figure 5(a) shows the simulated pattern of E, I, M, P, and S by using the rescaled parameters (pre-treatment and post-treatment), and a linear continuous parameter drift. We decided for the linear drift in order to follow the empirical parameter effect as close as possible, which in this case is a very small effect (as in *a* and *c*) or even a deterioration (as in *r* and *m*). The simulation shown in (a) is deterministic (no noise added). Adding Gaussian noise of 10% standard deviation on each variable reveals the bi-stability of the dynamics. Based on 300 simulation runs, patterns as shown in (b) (high intensities of E, P, and I, low intensities of M and S) emerged in 78% of all realizations, patterns as shown in (c) (high intensities of S and I, medium levels of M, low intensities of P and E) emerged in 22% of all realizations (identical parametrization). Pattern (b) qualitatively corresponds to the empirical pattern of the client much more than pattern (c).

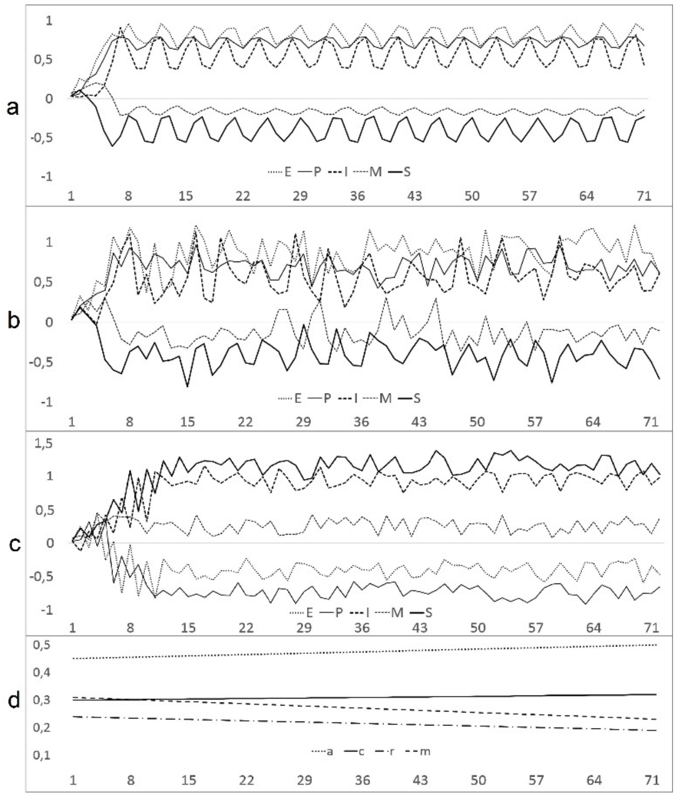

Figure 5: (a) Simulated pattern of E, I, M, P, S by using the adjusted parameters, and linear continuous parameter drift (*a*: .45 - .50, *c*: .30 - .32, *r*: .24 - .19, *m*: .31 - .23). Simulation without noise (deterministic dynamics). (b) and (c): Simulations with Gaussian noise.

For an unambiguous distinction between patterns of type (b) or (c) the following criteria are applied:

1. A transition to either type has to occur before the 50th iteration;
2. The values of E and P have both to be either higher (leading to classification b) or lower (leading to classification c) as the variables M and S after the 50th iteration (I realizes high levels in both types)
3. Simulation runs with unclear patterns after the 50th iteration were discarded and not considered for statistics.

The criterion of a stabilization of the patterns (b) or (c) after the 50th iteration is taken because of cases with longer transients than those shown in Figure 5(b) and (c) (here the patterns are stable after 8 to 15 iterations). Interestingly, in all simulation runs the patterns (b) or (c) emerged with no fuzzy in-between patterns. Given the selected parametrization the potential landscape seems to realize exactly two valleys.

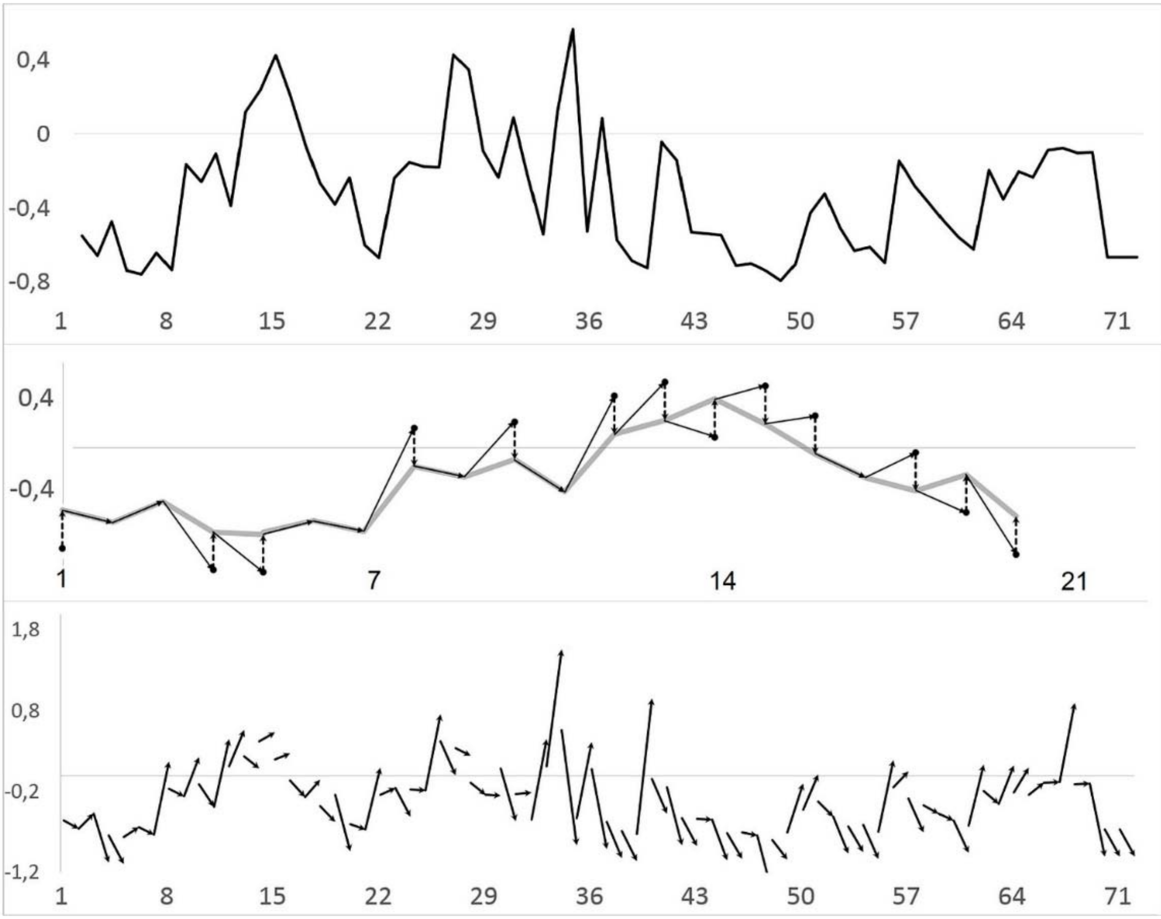

Figure 6: Autonomous dynamics (variable E), which is a hypothetical course without input (interventions) onto the system.

In a next step, the role of external input (interventions) is included. We assume that the empirical dynamics of a client results from his autonomous dynamics and the perceived input ("real" dynamics = autonomous dynamics + input). As a first approximation, we suppose that input or interventions create a linear deviation from the trajectory which is processed by the nonlinear functioning of the system ("dynamic input"). The empirical (clinical) dynamics of variable E as measured by the TPQ-R is shown in Figure 6(a) (comp. Fig. 4b). Without interventions, the "autonomous" dynamics of the client would be a hypothetical course which is realized by the deterministic dynamics of the model. This course is modified by the input as rated by the "intervention"-items in the Therapy Process Questionnaire Revised (TPQ-R). By this "correction" the empirical trajectory (grey line) is realized (illustrated by the first 20 values of the time series, Fig. 6b). The interventions play the role of a "dynamic input", this means that any value resulting from autonomous dynamics *and* input is transformed by the system to the next "autonomous" value. In Figure 6(c), the sequence of vectors shows where the system would have been gone iteration by iteration if the correcting effects of the input would not modulate the dynamics (stepwise autonomous dynamics). The hypothetical time series shows how the system would have been developed without input. Figure 6(d) is the stepwise development of the dynamics without the correcting effects of the input. The graph (Figure 5c) follows a line from arrowhead to arrowhead. This stepwise "input-reduced" ynamics was taken for a comparison with the deterministic dynamics of the model in order to adjust the parameters (Table 1). The criterion was to minimize the squared difference between the time series. Given many cases, we could define a transform function from the measured to the adjusted parameters based on the best fit between simulated and empirical dynamics.

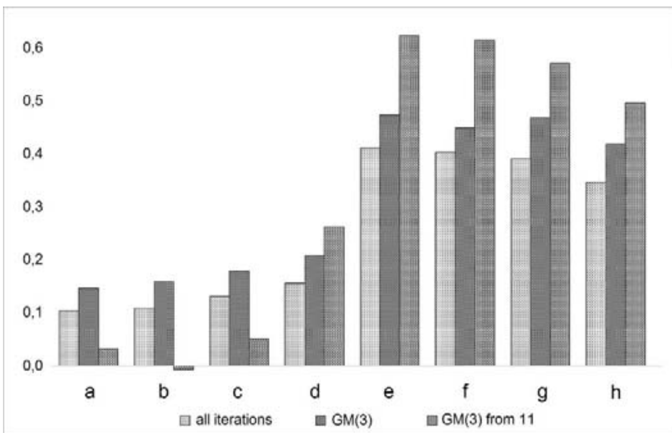

Figure 7: Correlations of the simulated dynamics with the empirical time series.

Figure 7 presents the correlation of the simulated with the empirical time series. It differentiates between correlations which incorporate all measurement points or iterations (left columns in Figure 7), correlations which are calculated by using time series which were smoothed by a short gliding window (window width = 3) (GM3, middle columns in Figure 7), and correlations which are calculated by using the same short gliding window and also respect the fact that system dynamics need some transient dynamics in order to relax on its attractor. For the calculation of the correlations which are represented by the right columns in Figure 7, the first 10 iterations of the time series were omitted (GM3 from 11). There are different steps of respecting information about the parameter dynamics and the external input onto the dynamics: Figure 7(a) represents the correlation of the empirical dynamics with noiseless simulations. It respects the initial values of the variables and the initial values of the empirical, but adjusted parameters of the client. The adjusted parameters as assessed at the beginning of the therapy (pre) were kept constant during the simulations. In a next step (Figure 7b), again noiseless (deterministic) simulations were correlated with the empirical dynamics, but in addition to the initial values of the variables and the initial values (pre) of the adjusted parameters, the parameters (pre) were linearly changed to the parameter values post (compare Table 1). In Figure 7(c), correlations were based on noiseless simulations. Other than in (a) and (b), the parameter dynamics was simulated by the model (equations 6 to 9) without using the therapeutic alliance vector b_t in equation 6. In 7(d), the parameter dynamics was simulated by the model (equations 6 to 9) *with* using the vector b_t in equation 6. In a next step (7e) noiseless simulations like in (d) were compared to the empirical dynamics, and the empirically assessed input (experienced interventions, see Figure 4a) were added. Figures 7(f-h) show correlations of simulated to empirical dynamics with added Gaussian noise of increasing standard deviations on all variables (7f: Gaussian noise of 5% standard deviation; 7g: 10%; h: 20%). The correlations as shown in Figure 7(a-e) are based on deterministic, noiseless simulations. Hence, the results will be always the same for many realizations. Without varying initial conditions or parameter values, there is no difference or any "butterfly effect" to be observed between different realizations. The correlations as shown in Figure 7(f-h) are based on simulations with added noise. They were calculated by averaging several realizations.

The results show a significant increase of the correlations if the dynamics of the therapeutic alliance (vector b_t) is used for the dynamic simulation of parameter a_t (Figure 7d compared with a-c), and especially if the input onto the system is respected (Figure7e-h compared with a-d). The highest correlations are realized for comparisons which apply the small gliding window onto the time series and omit the transients (first 10 iterations of the time series). Adding Gaussian noise of 5% or 10% standard deviation level onto the simulated deterministic dynamics does not significantly change the correlations. If the level of noise is further increased, the correlation is slightly reduced, this is, the real and the simulated dynamics loose similarity.

Figure 8 shows the superimposed time series of a simulated and the real psychotherapy process with an applied gliding window of window width 3 to all variables E, I, M, P, and S. The noiseless deterministic simulation incorporates the initial values of the variables, the initial values of the adjusted parameters, and the input onto all variables The parameter dynamics is simulated by using the therapeutic alliance vector b_t. The values of the correlations are shown in Table 2; the mean correlation of all variables is .473 (see Figure 7e, column GM3). Given this procedure, it should be noted that the simulated dynamics is not based on arbitrary parameters and initial conditions but on the parameters and conditions which are given by the concrete empirical case. In chaotic systems like this, dynamics may be unpredictable, but chaoticity implicates that the trajectories are sensitive to the continuous input and to the empirical part b_t of the dynamics of parameter a. Both can be assessed and by this, global similarity of simulated and real dynamics as well as short-term predictability is possible. In spite of – or rather: because of – the "butterfly effect" the simulated dynamics can be reproduced.

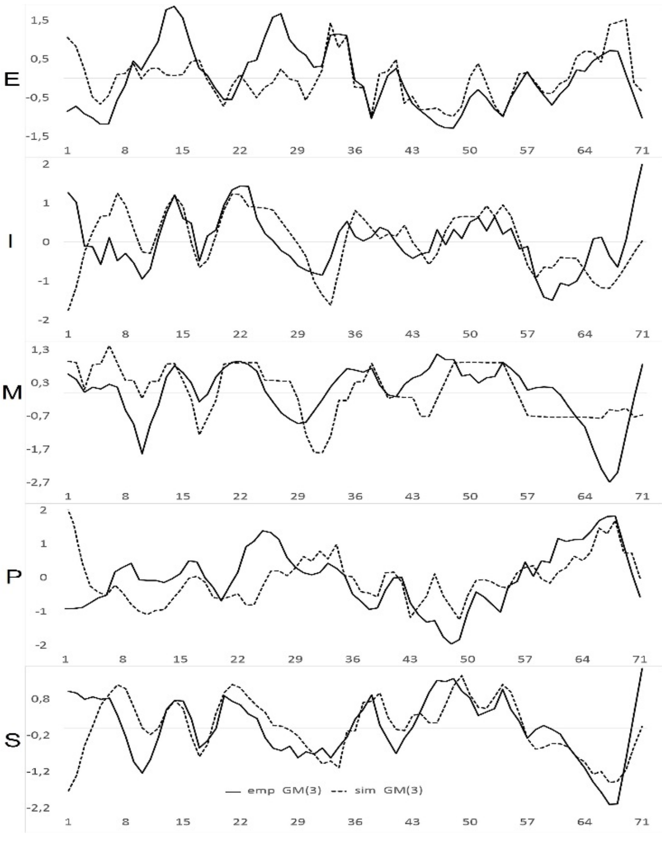

Figure 8: Dynamics of the simulated and the empirical psychotherapy processes with an applied gliding window (window width = 3) on both. Noiseless deterministic simulation using the initial values of variables and parameters from the empirical case. Also b_t and the input vector are applied to the simulation.

Table 2 presents the correlations between simulated and empirical dynamics of all variables E, I, M, P, S, differentiated for three types of comparisons: correlations based on all iterations, correlations based on time series after a gliding mean (window width = 3) was applied (GM(3)), and correlations based on time series after the gliding mean was applied and the first 10 iterations were omitted (GM(3) without the first 10 iterations) (compare Figure 7). The correlations were calculated for condition (e) in Figure 7 (deterministic noiseless simulation, input added, b_t vector was used for the simulation of parameter dynamics). Almost all correlations are significant at a level of $p \leq .01$.

	E	I	M	P	S
all iterations	0.469** [0.243;0.666]	0.377** [0.146;0.599]	0.449** [0.323;0.581]	0.228 [0.024;0.419]	0.535** [0.334;0.716]
GM(3)	0.520** [0.338;0.672]	0.420** [0.128;0.662]	0.431** [0.319;0.558]	0.401** [0.144;0.635]	0.604** [0.384;0.780]
GM(3) without first 10 iterations	0.596** [0.432;0.741]	0.631** [0.426;0.774]	0.466** [0.337;0.587]	0.626** [0.465;0.758]	0.807** [0.694;0.887]

Table 2: Correlations between simulated and empirical dynamics of the state variables E, I, M, P, S, differentiated for three types of comparisons. ** significance level of the correlations at $p \leq 0.01$. Brackets: range of the 95% -confidence intervals of the correlations.

DISCUSSION

The results presented in this article reveal that a validation of the mathematical model of psychotherapeutic change dynamics (Schiepek et al., 2017) may be possible. The data were taken from an internet-based monitoring device (Synergetic Navigation System [SNS], Schiepek et al., 2016b) which was used by a client during her hospital stay (about 11 weeks of inpatient treatment). The state variables (E, I, M, P, S) of the model were assessed once per day (71 measurement points, no missing data) by the corresponding subscales of the Therapy Process Questionnaire – Revised (Schiepek et al., 2016b). The parameters *a*, *c*, *m*, and *r* of the model were measured by appropriate questionnaires which were applied at the beginning and at the end of the hospital stay. The input or "interventions" on the variables were rated by five items added to the TPQ-R. Finally, the dynamics of the therapeutic alliance (b_t) was assessed by a subscale of the TPQ-R and was used as an empirical input vector to the dynamics of parameter *a* as modeled and simulated by the parameter equations.

The steps of validation we report on in this article can be used as guidelines for further steps in data-based validation and model testing. The empirical boundary and initial conditions as given by the data produce an increasing similarity between the real psychotherapeutic course and the simulated dynamics. Especially if interventions as perceived by the client and the empirical dynamics of the therapeutic alliance are taken into consideration, the correlations between real and simulated dynamics effectuate ranges from 0.40 to 0.65. It can be concluded that data-driven simulations based on a theoretically grounded mathematical model like this can achieve a significant similarity to the empirical dynamics.

A limitation of this preliminary study is that the data used for validation are taken from a single case. The modest aim of this study was to illustrate a problem-solving procedure how to use empirical data from routine monitoring procedures in a clinical routine setting to fit simulation runs to the dynamics of a real client. This may be seen as a first step to the validation of this mathematically formalized model of psychotherapy. Especially the adjustment (calibration) of measured parameter values may feel arbitrary, but the adapted values are as close to the empirical ones as possible and further cases will provide the database for defining a strict model-related adjustment algorithm. A current validation study will provide the data of a larger sample of clients for the development of this algorithm.

The perspectives of data-driven modeling of psychotherapeutic change processes are manifold:

1. It is a contribution to the development of an empirically well-founded nonlinear dynamic systems theory of psychotherapy and to the growing field of computational systems psychology (Schiepek et al., 2016a, 2017; Schoeller et al., 2018).
2. As it could be demonstrated by the single case we used for model validation, the appraisal of therapy outcome and effects may be optimized. In this case, the interventions and the dynamics of the therapeutic alliance as perceived by the client did not enable a successful outcome of the therapy, but prevented the client from deterioration due to severe life-events which occurred in her private life during the hospital stay. Data-driven simulations may contribute to outcome assessments which may estimate the effects of interventions, settings, and therapeutic relationship compared to the autonomous dynamics without those. Contrasting an autonomous with an input-driven process makes it comprehensible that even unchanged dynamics may be a valuable result

compared to a potential deterioration without treatment.

3. Even with the aid of computer simulations, long-term predictions will not be possible in chaotic systems – and psychotherapy is a chaotic system (Schiepek et al., 2017). But there are options for short-term predictions, which can be optimized by using current data on the relevant variables, parameters, and the input onto the system. Data-driven computer simulations may establish new options for testing interventions onto the system before they are applied by real therapists onto real clients. This way, unintended and negative effects may be avoided and helpful short-term effects may be increased for a better long-term outcome. One example is the estimation of the intensity or duration of interventions in order to pass self-organized thresholds created by the interaction of state variables (order parameters) and traits (control parameters) and to produce therapeutic phase transitions.
4. Computer simulations can be integrated into internet-based monitoring and feedback systems like the SNS (Schiepek et al., 2016b). The estimation of appropriate next therapeutic steps and interventions using current data and simulations may be seen as an artificial intelligence (AI) tool for optimizing psychotherapy. This new technology is a contribution to e-MentalHealth and digitalization in psychotherapy, may it be called psychotherapy 4.0. Other than usual approaches in AI, this is not primarily a bottom-up, but a top-down approach that can process current data from a single case and can be optimized by big data from many cases. This may be a step into new technologies for psychotherapy 4.0 based on the nonlinear dynamic systems approach.

The model and the simulation runs based on it allow for some considerations about the mechanisms of change and on how to optimize clinical practice.

This model implements the hypothesis that getting in touch with negative emotional states – i.e., the activation of negative emotional schemata – is necessary for creating emotion-related insight and, vice versa, insight might activate negative affect. Another assumption is that motivation is necessary for creating insight, but insight might not directly increase motivation. This “view into the abyss“ model corresponds to concepts from psychodynamics and to Grawe’s conjecture that “hot” insight is based on activated affective schemata. Quite another mechanism of change easily could be tested by minor modifications of the model, e.g., the “heureca” hypothesis. This hypothesis follows the idea that no negative affectivity is needed to create insight and that insight directly is linked to positive motivation by bi-directional circular causality.

A hypothesis about momentum effects would be that interventions have a stronger (multiplicative) effect when a client is already improving. In other words, if a client is next to critical instability, encouraging interventions easier should help to realize an order transition than interventions could do during stable periods. Real-time monitoring systems like the SNS have to be implemented in order to get aware of upcoming instabilities in time. Psychotherapy needs what is called stability diagnostics and short-term prediction of “kairos” moments.

Given specific initial values of the state variables and of the control parameters (traits) of a particular client the probability of successful or poor dynamic patterns can be estimated by repeating many simulation runs with varying degrees of noise. Given the values of our case, we found a higher probability of poor dynamics (78%) than of successful dynamics (22%), as shown in Figure 5. However, we should note that these patterns are created by using the control parameter values pre and post. Of course, post-values only can be measured at the end of a therapy. An option to solve the problem could be to estimate post-values by taking the pre-values as predictors in a big sample. If a certain probability of poor dynamics will be given, specific supportive interventions could be developed to improve prognosis.

Our model implicates that control parameters play a crucial role in the evolution of successful patterns (non-stationarity) and the stabilization of newly emerging attractors. In consequence, clinicians should optimize ways of intervening on variables with a direct impact onto the control parameters, i.e., the competencies addressed by *a, c, r,* and *m.* As we showed (Schoeller et al., 2018), continuous and more frequent interventions have a higher impact on the order parameter to control parameter circularity than punctual interventions. This asks for app-based high-frequency input and for other experiences based on every-day life (ecosystemic therapy).

Finally, the model motivates for an extended understanding of outcome assessment: point-measures (pre- vs. post-treatment) should be complemented by process measures (changed patterns or quasi-attractors). Given the importance of the control parameters for the emergence and stability of new dynamic patterns, exactly these parameters should be assessed, e.g., by the questionnaires which were applied to the case reported in this article.

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Psychotherapy Is Chaotic— (Not Only) in a Computational World

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Objective: The aim of this article is to outline the role of chaotic dynamics in psychotherapy. Besides some empirical findings of chaos at different time scales, the focus is on theoretical modeling of change processes explaining and simulating chaotic dynamics. It will be illustrated how some common factors of psychotherapeutic change and psychological hypotheses on motivation, emotion regulation, and information processing of the client's functioning can be integrated into a comprehensive nonlinear model of human change processes.

Methods: The model combines 5 variables (intensity of emotions, problem intensity, motivation to change, insight and new perspectives, therapeutic success) and 4 parameters into a set of 5 coupled nonlinear difference equations. The results of these simulations are presented as time series, as phase space embedding of these time series (i.e., attractors), and as bifurcation diagrams.

Results: The model creates chaotic dynamics, phase transition-like phenomena, bi- or multi-stability, and sensibility of the dynamic patterns on parameter drift. These features are predicted by chaos theory and by Synergetics and correspond to empirical findings. The spectrum of these behaviors illustrates the complexity of psychotherapeutic processes.

Conclusion: The model contributes to the development of an integrative conceptualization of psychotherapy. It is consistent with the state of scientific knowledge of common factors, as well as other psychological topics, such as: motivation, emotion regulation, and cognitive processing. The role of chaos theory is underpinned, not only in the world of computer simulations, but also in practice. In practice, chaos demands technologies capable of real-time monitoring and reporting on the nonlinear features of the ongoing process (e.g., its stability or instability). Based on this monitoring, a client-centered, continuous, and cooperative process of feedback and control becomes possible. By contrast, restricted predictability and spontaneous changes challenge the usefulness of prescriptive treatment manuals or other predefined programs of psychotherapy.

Keywords: psychotherapy processes, mathematical modeling, deterministic chaos, common factors, complexity science, psychotherapy integration

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INTRODUCTION: EVIDENCE FOR DETERMINISTIC CHAOS IN PSYCHOTHERAPEUTIC PROCESSES

During the past few decades, the conceptualization of psychotherapy as a nonlinear, dynamic, and complex process has been outlined in many publications and by different research groups (Schiepek et al., 1992a, 2014a,b; Orsucci, 2006, 2015; Hayes et al., 2007; Guastello et al., 2009; Pincus, 2009, 2015, 2016; Haken and Schiepek, 2010; Salvatore and Tschacher, 2012; Gelo and Salvatore, 2016). The interest in this approach is increasing, since it is capable of explaining important features of human change processes, including: discontinuous progress (sudden gains or sudden losses, Lutz et al., 2013; Stiles et al., 2003), missing proportionality and nonlinear relations between interventions and outcome (Muran et al., 1995; Hayes et al., 2007; Haken and Schiepek, 2010), unpredictability of long-term courses (Strunk et al., 2015), the dependency of human functioning on specific contexts and situative requirements (Kashdan and Rottenberg, 2010), the eigendynamics and individuality of evolutionary patterns (Barkham et al., 1993; Tschacher et al., 2000; Molenaar, 2004; Fisher, 2015; Fisher and Boswell, 2016), and the important role of client's contributions (e.g., motivation, ressources) to psychotherapeutic gains (Orlinsky et al., 2004; Bohart and Tallman, 2010).

Some authors discuss the nonlinear dynamics approach as a new paradigm or a meta-theoretical framework in psychology (Lichtwarck-Aschoff et al., 2008; Haken and Schiepek, 2010; Orsucci, 2015; Gelo and Salvatore, 2016). We are currently seeing an era where the life sciences, including psychology, become ever more sophisticated and computational in their modeling practices—with high-throughput technologies providing access to different layers of data, from biological to organizational scales, and with simulations becoming an integral part of the discovery process. Driven by the rich data on psychotherapy dynamics obtained with high-frequency feedback (e.g., from the Synergetic Navigation System using standardized questionnaires like the Therapy Process Questionnaire (TPQ), Schiepek et al., 2016a) a quantitative complexity science of psychotherapy processes is now possible. Synergetics, nonlinear dynamics, and the theory of complex systems provide an appropriate theoretical foundation for this endeavor.

Beyond guiding the interpretation of otherwise puzzling empirical and practical matters in psychotherapy, specific conjectures can be deduced from these complexity-based theories. One is the emergence of critical fluctuations which are uniquely predicted by Synergetics. In empirical studies based on daily self-ratings by psychotherapy clients, critical instabilities, or increased fluctuations, could be found just before pattern transitions occurred (Heinzel et al., 2014; Schiepek et al., 2014b), and the intensity of these critical fluctuations was correlated with therapy outcome (Haken and Schiepek, 2010). Furthermore, using critical fluctuations as a marker of order transitions, neuronal activity patterns also changed significantly across these therapeutic transitions (Schiepek et al., 2013).

Perhaps the most crucial, and likewise the most difficult conjecture of the nonlinear dynamics approach, is the emergence of deterministic chaos. Chaos as an umbrella term covers a broad spectrum of irregular and complex system behaviors, which is different from white noise at the one side and from regular oscillations at the other[1]. The phenomenon of chaos is crucial because just the basic assumption of ubiquitous nonlinearly interacting variables implies the possibility of chaotic dynamics. In the case of continuous flow, only three interacting variables are necessary to produce chaotic behavior (Schuster, 1989; Ott, 1993; Strunk and Schiepek, 2006).

Indeed, most biological and mental systems are typically concieved to involve nonlinear relations between multiple components. However, attempts to find empirical proof of chaotic dynamics are ambitious at best, because of the difficulties in finding time series data of sufficient length, scale resolution, and accuracy of measurement. Another major challenge is the ubiquitous transitions that occur within chaotic patterns in adaptive and self-regulatory systems. Psychological and physiological flexibility are fundamental aspects of health (Kashdan and Rottenberg, 2010). With respect to dynamics, this means that healthy systems remain poised to switch attractors depending upon stimulation and demands. These types of chaotic nonstationarities have been observed in default modes in brain functioning (Deco et al., 2013), in chaotic shifts in living systems (Kowalik and Elbert, 1994), and most relevantly within the chaotic phase transitions of learning and psychological development (Haken and Schiepek, 2010). Considering the high likelihood that psychotherapy involves chaotic processes along with the difficulties of identifying it, the empirical validation of the chaos hypothesis in psychotherapy is as important as challenging. The solution to this challenge lies in the use of methods which are sensitive in detecting deterministic chaos, while also able to withstand the presence of nonstationarities in the form of phase transitions.

One early line of research into chaos and dynamic transitions in psychotherapy targeted the dynamics of the therapeutic relationship (Kowalik et al., 1997; Schiepek et al., 1997; Strunk and Schiepek, 2006). The method of these studies was *Sequential Plan Analysis*, which was derived from the *hierarchical plan analysis* approach of Grawe and Caspar (c.f., Caspar, 1996). In this context, "plans" are more or less conscious and verbally or nonverbally communicated intentions and/or self-presentations in a social situation. Using this notion of plans, client and therapist's interactional behavior was analyzed from video recordings of two complete therapies, encoded with a sampling rate of 10 s. At this measurement frequency, a psychotherapy process of 13 sessions was represented by multiple time series of about 3,800 measurement points, and a therapy of 9 sessions by time series of about 2,900 points.

[1]In a short side note, it should be said that chaos is different from critical instability. Chaos is a complex dynamic pattern (unpredictable yet ordered, not disordered *per se*), which is represented by its (*strange* or *chaotic*) *attractor*. To be identified as chaotic, a certain stability of this pattern is required, but of course, it can change to another chaotic attractor (i.e., *chaoto-chaotic* phase transition). In contrast to this, *critical instability* is typically considered to be a transient phenomen, which endures only for a relatively short period of time. As a precursor of dynamic transitions it is, at least in some aspects, a marker of disorder or noise.

Nonlinearity was proven by surrogate data tests (Rapp et al., 1994) using random surrogates and FFT-based phase-randomized surrogates. The time series were analyzed by methods which are sensitive to the nonlinearity (chaoticity) as well as the nonstationarity of the processes. The estimation of the time-varying change of fractal dimensionality by the method of pointwise correlation dimension D2 (PD2, Skinner et al., 1994) and of the "butterfly effect" of the dynamics by the Local Largest Lyapunov Exponent (LLLE, Rosenstein et al., 1993) was used to identify phase-transition like discontinuities. Following the evolution of the fractal dimensionality by PD2, both therapies displayed nonstationarities, and both therapies showed periods of strongly synchronized and anti-synchronized PD2-processes between client and therapist. Similar, yet even more pronounced dynamical jumps were identified when applying the LLLE, which represents changes in the chaoticity of a time signal (Kowalik et al., 1997). Most of the discontinuities of the LLLE were exactly synchronized between client and therapist. This makes sense in terms of dynamical systems, in that both persons are involved within a self-organizing communication system or relationship, which enables and triggers the individual change process of the client (corresponding to the *generic model* of psychotherapy; Orlinsky, 2009).

These conclusions were supported as well from nonlinear coupling measures between the time series of the interaction partners. Specifically, Pointwise Transinformation and Pointwise Coupling Conditional Divergence (Vandenhouten, 1998) were carried out on the same data, each indicating shifting, time-dependent coupling strengths between the time series of the client and therapist. Interestingly, there was no priority of the therapist's influence on the client, or vice versa. From a systems viewpoint, this circular causality underlying psychotherapeutic self-organization contradicts the classical view that unidirectional input from the therapist determines the client's output.

In sum, these results corroborate the hypothesis of: (i) nonlinearity and deterministic chaos realized in therapeutic change dynamics and interaction, (ii) spontaneous order transitions within these chaotic processes, and (iii) synchronization and synchronized order transitions between client and therapist. Subsequent studies focused on self-organized synchronization between client and therapist at different time scales using an even wider variety of methods (Rockstroh et al., 1997; Ramseyer and Tschacher, 2008; Walter et al., 2010; Gumz et al., 2012).

In another study on ordered dynamics in psychotherapeutic change processes we used the data from daily self-assessments of 149 patients during inpatient psychotherapy (Strunk et al., 2015). The self-ratings were collected by an Internet-based device (the Synergetic Navigation System [SNS], Schiepek et al., 2015, 2016a). Every day, patients completed the Therapy Process Questionnaire (TPQ, inpatient version with 23 items, grouped into 5 subscales) (Schiepek et al., 2012). Most of the patients were categorized into one of three ICD-10 diagnostic groups: F30 (affective disorders), F40 (neurotic stress-related and somatoform disorders), and F60 (specific disorders of personality, esp. F60.3, emotionally unstable personality disorder, referred to as borderline type in other classification systems). On average, the TPQ was completed by patients during 97 days (SD: 50.3). The measurement series of all 149 patients were joined together, resulting in 5 artificial time series (one for each subscale) with a length of $n = 14{,}425$ points (one time series for each subscale of the TPQ).

The time series of the factors of the TPQ were analyzed by the PD2 algorithm. While D2 provides a complexity estimation (fractal dimensionality) of the attractor of the whole process, PD2 portrays the possible changes of dimensional complexity over time (nonstationarity). D2-estimates are taken from vector point to vector point and can be portrayed in a PD2 $\times$ time diagram (Skinner, 1992; Skinner et al., 1994). We adopted Skinner's criterion (Skinner, 1992) of at least 75% valid measurement points for the calculation and interpretation of the PD2. This implies that the majority of the process is suitable for interpretation as ordered dynamics instead of a stochastic process. The arithmetic means of the PD2 measures of the 5 time series ranged from 0.947 to 5.187, indicating a low-dimensional chaotic processes (6 or less independent dimensions). Large standard deviations in the PD2 dynamics were also found, which make sense considering the different levels of fractal dimensionality among different clients, and also to the nonstationarities of the dynamics: order transitions during the course of each treatment.

A crucial aspect of the PD2 analysis is the validation by Fast Fourier Transformed (FFT) surrogate time series. This approach is particularly rigorous and discriminating because it not only contains means and variances of the surrogate time series used for comparison, but also their frequency spectra. Only nonlinear characteristics are removed, providing the basis for determining that there is a statistically significant difference in D2 complexity between empirical and surrogate time series. When nonlinear dynamic structures are destroyed by producing FFT surrogates, one would expect significantly increased fractal complexity of the surrogates. This hypothesis was confirmed: all *t*-tests were highly significant. The hypothesis of chaoticity and nonlinearity of psychotherapeutic processes was corroborated once again.

The identification of chaos in psychotherapeutic change processes may to some seem to be only of academic interest; however the consequences are actually far reaching. First, chaotic processes are sensitively dependent on initial conditions and on small fluctuations, which means that psychotherapy process would be considered to be inherently unpredictable, beyond the bounds of linear control. A second consequence of the chaoticity of change processes is the distinctive individuality of each person's psychotherapy. Any notion of superposition of dynamics within or between individuals (systems) is untenable, meaning that concepts like "standard tracks" or "normative processes" are entirely inappropriate in describing psychotherapeutic change. Since chaotic behavior does not result from irregular input from an *outside* source, but is instead produced by self-organizing processes *within* the system itself, a proof of chaoticity at the same time is a proof of the concept of self-organization. Inherent to this concept of self-organization, there are fundamental doubts about classical notions of input-output mechanisms, such as the role of intervention as a primary force of change, and on strategies aimed at process control by adherence to therapy manuals. By contrast, chaos in psychotherapy processes requires that the therapist remain flexible and attentive to the actual state of the process, particularly concerning its stability or instability over time. Rather than developing more manuals, or selecting this or that technique, psychotherapy may be better supported through the use of real-time process monitoring technologies combined with a continuous collaborative process between therapist and client (Schiepek et al., 2016a).

Beyond the consequences for practical work and empirical research strategies, chaos also brings consequences for the theoretical modeling of change mechanisms. After decades of focusing on the question, *if* psychotherapy works, motivating outcome research, efforts have intensified to understand *how* psychotherapy works (Kazdin, 2005, 2009), taking seriously that the "explanandum" is the change process and that the answer lies within the change process itself, rather than within this or that approach. Theoretical models should be able to simulate the nonlinear dynamics of change processes including all features of deterministic chaos: irregularity of the dynamics, sensitive dependency of the process on initial conditions and on small but well-timed interventions, global stability of the system's behavior within its (more or less stable or transient) attractors, and the dependency of the actually realized attractor on the control parameters of the system, resulting in attractor shifts during the change process. The aim of this paper is to do just that, to demonstrate how a client-cantered, common factors model of psychotherapy can produce each of these features.

THE MODEL

One of the most robust findings in common factors research is the importance of the client contributing to the course and outcome of psychotherapy (Duncan et al., 2004; Orlinsky et al., 2004; Orlinsky, 2009; Bohart and Tallman, 2010; Sparks and Duncan, 2010). For this reason we focus on the variables and the psychological mechanisms which have repeatedly been shown to be important within the "client system" both empirically and theoretically (e.g., Grawe, 2004; Orlinsky et al., 2004). Another reason for choosing these variables is their correspondence to the factors (subscales) of the Therapy Process Questionnaire (TPQ, Haken and Schiepek, 2010), which is used in the routine practice of psychotherapy monitoring. The variables of the model can be seen as psychological states with varying intensities on a given time scale. In terms of Synergetics they represent the order parameters of the system. Here we suppose a sampling rate of once per day, i.e., each iteration of the simulation can be interpreted as a daily measurement of the variables, as assessed by the TPQ. The model is a further development of the model we described in Schiepek et al. (2016b). The differences from the prior model are noted below (paragraph "Functions"). The structure of the model and the interrelations of the variables are shown in **Figures 1**, **2**.

The model focuses on the psychological mechanisms of the client for a couple of key reasons. First, it is well established that any intervention only has an impact if the client reacts on it, what is referred to as "self-relatedness" in the "generic model" of psychotherapy (Orlinsky et al., 2004; Orlinsky, 2009). Another reason—as just mentioned—is the importance of client-related factors to therapeutic effects (Duncan et al., 2004; Bohart and Tallman, 2010). Nevertheless, the model does include other contributions as well, such as: more or less intended interventions; the therapeutic alliance as experienced by the client; daily hassles, or other personal experiences within the client's environment which are represented by punctual or repeated input onto the variables. As a result, the model is not exclusively client-centered. Of course, there are many other contextual impacts on the therapeutic process, such as other patients in an inpatient setting, or impacts from the client's social network(s) in outpatient treatments (see the extended "generic model," Orlinsky, 2009). But these contextual impacts are not easy to operationalize and their dynamics are not known in detail, and so are difficult to incorporate. Further developments of the model will, however, ideally integrate other systems which are coupled with the client system, such as the therapist's mental functioning as a network of perceptions, emotions, and cognitions with an impact on professional judgment and behavior.

Variables

The following variables constitute the model:

(E) Emotions. This is a bidimensional variable representing dysphoric emotions at one end of the dimension (e.g., anxiety, grief, shame, guilt, and anger) and positive emotional experiences at the other end (e.g., joy, self-esteem, and flow). This definition of polarity is based upon to the factor analytic results of the TPQ (Haken and Schiepek, 2010).

(P) Problem intensity, symptom severity, experienced conflicts or incongruencies.

(M) Motivation to change, readiness for the engagement in therapy-related activities and experiences.

(I) Insight, getting new perspectives on personal problems, motivations, cognitions, or behaviors (clarification perspective in the sense of Grawe, 2004), confrontation with conflicts, avoided behaviors and cognitions, or with repressed traumatic experiences.

(S) Success, therapeutic progress, goal attainment, confidence in a successful therapy course.

Parameters

Parameters mediate the interactions between variables. Depending on their values the effect of one variable on another is intensified or reduced, activated or inhibited. Formally they modify the function defining the relationship of two (or more) variables to each other. Psychologically, parameters can be interpreted as traits or dispositions changing at a slower time scale than the variables or states of a system. In terms of Synergetics, the change of control parameters drives the phase transitions of the dynamics (Haken, 2004). The range of the parameters is from 0 to 1. The model includes 4 parameters:

(*a*) Working alliance, capability to enter a trustful cooperation with the therapist, quality of the therapeutic relationship,

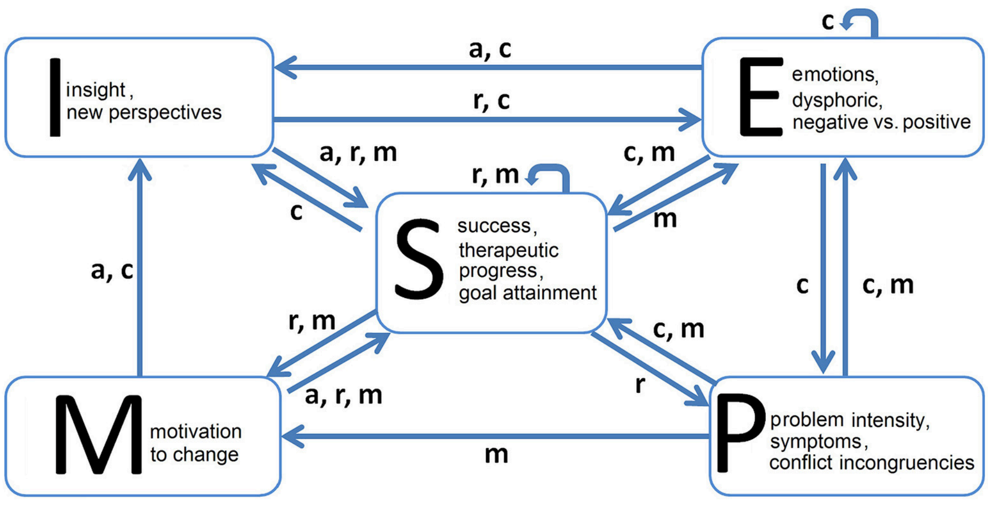

FIGURE 1 | The structure of the model illustrates the dependencies between the variables and the parameters of the system.

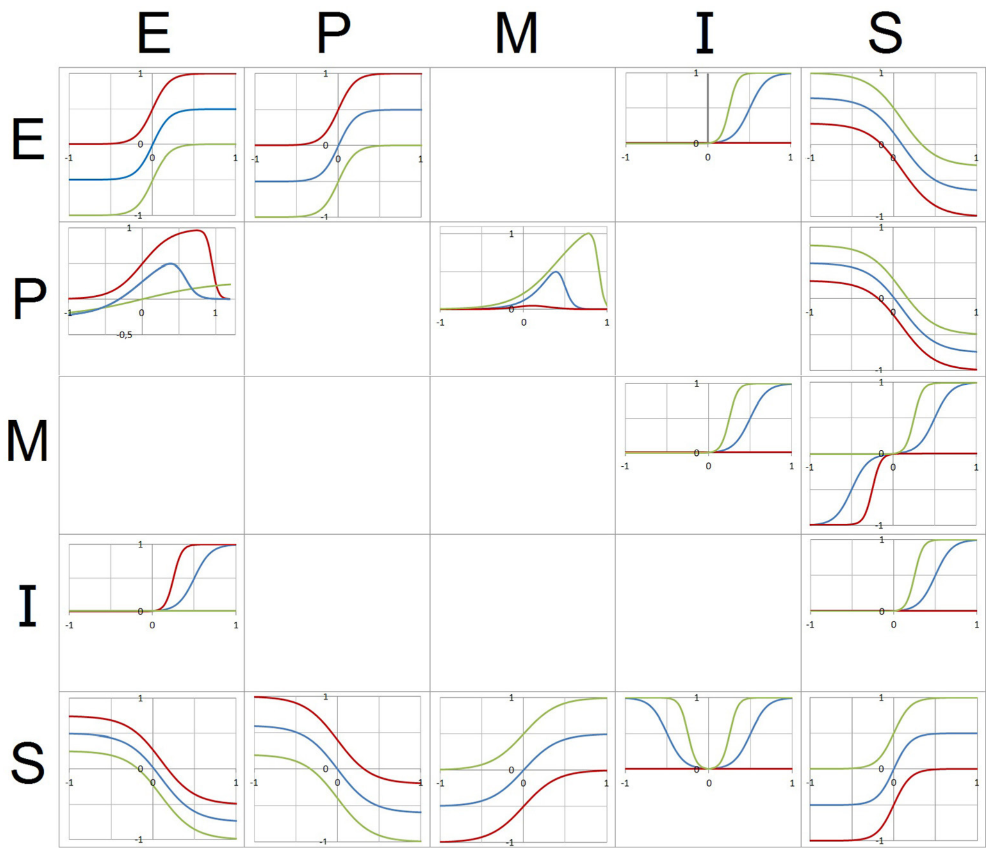

FIGURE 2 | The figure represents the 16 functions of the model (see text). The variables noted at the left side of the matrix (lines) represent the input, the variables noted at the top (columns) represent the output. Each function is represented by a graph in a coordinate system (x-axis: input, y-axis: output). Green function graphs correspond to the maximum of the respective control parameter(s) (= 1), red graphs to the minimum of the parameter(s) (= 0). Blue graphs represent an in-between state (0 < parameter value < 1).

interpersonal trust. At the one hand, this parameter signifies the disposition to engage in a trustful relationship (attachment disposition) and at the other hand it refers to the realized quality of the therapeutic bond.

(*c*) Cognitive competencies, capacities for mentalization and emotion regulation, mental skills in self-reflection, and the level of structure based upon the Operationalized Psychodynamic Diagnostics (OPD, www.opd-online.net).

(*r*) Behavioral resources or skills which can be applied to problem solving.

(*m*) Motivation to change as a trait, self-efficacy, positive expectations in one's development, reward expectation, and "health plan" as understood through control mastery theory (Weiss, 1993; Silberschatz, 2009).

Functions

The model covers 16 functions connecting 5 variables (**Figure 2**). The functions are represented in mathematical terms which are integrated into 5 coupled nonlinear equations (one for each variable, see **Appendix**). The graphs in the coordinate planes (x-axis: input variable, y-axis: output variable) illustrate the dependency of the shape of each function on the parameter values. The development of the model compared to its previous formulation concerns the functions E → E, E → P, I → E, M → S, P → E, S → I, S → M, and S → S.

Beyond the empirical foundation as it is cited in the description of the functions, the model's functions and parameters were supported following an in-progress systematic review of the empirical evidence on common factors (Sungler, 2017). In this review the author compiled the studies underpinning the model and the empirical findings from psychotherapy research and cognitive psychology, motivation psychology, and emotion regulation explaining the psychological mechanisms behind the functions. Where empirical evidence was not available, choices were made following the cited theoretical conceptualizations (e.g., Horowitz, 1987; Mergentaler, 1996; Greenberg, 2002; Grawe, 2004; Silberschatz, 2009). One of the authors (G.S.) is an expert in psychotherapy research and decided on the plausibility of the model assumptions where the available data and findings were not conclusive.

E → E

Depending on competencies in emotion regulation and mentalization (*c*), emotions can be up- or down-regulated. At low levels of *c* negative emotions like fear, grief, anger, or shame cannot effectively be down-regulated. Stressful emotions are intensified and even moderate positive emotions are transformed into negative qualities. At higher levels of *c* the downregulation of negative emotions can be effectively realized and even moderate negative emotions are transformed into positive ones. *c* plays the role of a bifurcation parameter in the autocatalytic effect of E on itself.

In the previous formulation of the model, the autocatalytic effect only concerned negative emotions, whereas in this actualized function, positive emotions may also be self-activated by positive feedback. The arbitrary threshold at $c = 0.05$ separating the up- or down-regulation of E was eliminated, and the linear function was replaced by a sigmoid growth which implicates a damped effect of E on E at very intensive emotions (instead of unlimited linear growth). Additionally, we introduced an option of transforming moderate positive emotions into negative ones and vice versa, depending on *c*.

E → I

As outlined also in the I → E function, insight refers to an emotionally "hot" understanding of personally important topics, psychological mechanisms, conflicts, or biographically relevant events, and their impacts on the client's life. In this sense, emotionally important experiences or emotion-associated "states of mind" (Horowitz, 1987) are a condition for such "hot" insights. In terms of Grawe's general psychotherapy model, only activated negative cognitive-affective schemata can produce new qualities of understanding (Grawe, 2004) or an integration of cognitions and emotions with emerging new qualities ("connecting" in the Therapeutic Cycle Model of Mergentaler, 1996). As Greenberg outlined in his emotion-focused approach, the interaction of emotion and self-related cognition (E ⇄ I) is crucial for psychotherapeutic change (Greenberg, 2002). The function E → I is a logistic growth function with an inert onset (small intensities of stressful feelings do not yet activate negative schemata) followed by an exponential increase and finally a damped effect of E on I. It is assumed that mid-size intensities of emotions will be optimal to create emotionally important insight. Overwhelming affects do not fulfill this effect, because they intensify self-protecting defense mechanisms and inhibit learning and self-reflection by neuronal processes (top-down regulation and transmitter dynamics). Mediating parameters are personal competencies in self-reflection and mentalization (*c*) and the quality of the therapeutic alliance (*a*) (only in a safe and appreciative interpersonal relationship may one risk engagement within intensive, self-referential processes, see the "control mastery theory," Weiss, 1993; Silberschatz, 2009).

Research supports the importance of emotional experiences for cognitive change and for creating problem-related insight by connecting emotions to cognitions (Mergentaler, 1996; Greenberg, 2002; Grawe, 2004). The confrontation with emotional situations and experiences may be one of the core mechanisms in the treatment of affective disorders, whereas avoiding emotions seem to result in negative therapeutic effects (Greenberg and Pascual-Leone, 2006). Conflicts expressed within the therapeutic relationship, such as crisis-repair sequences, or within other social relationships, may facilitate interpersonal learning (Stiles et al., 2014). While emotions seem to be important for self-related processing, arousal and affective intensities beyond a certain level make things out of control and impede learning (Carey et al., 2006). One of the supporting conditions in this process is the therapeutic relationship (parameter *a*) (Weiss, 1993; Silberschatz, 2009; Flückiger et al., 2012), the other is emotion regulation, self-reflection, and competencies in mentalization and self-regulation (parameter *c*) (Bateman and Fonagy, 2013). If clients cannot activate these competencies, interventions are unlikely to be successful (Orlinsky et al., 2004; Dimaggio et al., 2013; Wirtz et al., 2014; Bateman and Fonagy, 2015). There even may be an interaction between *a* and *c*, since the quality of the interpersonal alliance contributes to feelings of control and to reduced fear of overwhelming emotions, and the other way round, this supports emotion-related coping strategies (Sugiura and Sugiura, 2015).

E → P

The intensity of worrying emotions (E > 0) like fear, anger, grief, or feelings of guilt contributes directly to the experience of problem intensity. In the case of affective or anxiety disorders, such emotions are by definition part of the problem or of the symptoms. The contribution of E to P has the shape of a logistic growth function, with the steepness of the effect depending inversely on *c*: the smaller the capacity in emotion regulation, self-reflection, and mentalization, the more intense the contribution of E to P. If *c* is small, even moderate positive emotions may intensify the experience of problems or strain, and given high levels of *c*, even moderate negative emotions may be converted into reduced problem or symptom intensity. In general, positive feelings like joy and experiences of self-esteem (E < 0) reduce the intensity of problems or conflicts, with the E → P effect depending on the value of the parameter *c*.

Different from the previous model, the linear effect of E on P was replaced by a sigmoid growth function which implicates a sensitive effect of emotions on experienced problem or stress intensity next to the turning point of positive to negative emotions. Like in other modalities of perception, extreme inputs have less impact on perceptual sensitivity than smaller inputs. The unlimited linear growth of the former function was replaced by a more realistic one. Additionally, the function was extended by the possible effect of positive emotions on experienced problem or stress reduction. Depending on *c*, the vertical position of the growth function introduces the option of transforming moderate or—compared with the expectations—insufficient positive emotions into an experience of problems or distress, and conversely transforming moderate negative emotions into successes or stress relievers (i.e., negative values of P).

E → S

The experience of "negative" emotions like fear, grief, shame, or anger reduces (or is inversely related to) feelings of progress and being successful in solving personal problems. Within a certain range of intensity, the reducing effect on the confidence in a successful therapy course depends on the intensity of worrying emotions. This reducing effect is given by an inverse logistic function with the steepest gradient in a range of mean emotional intensity. Despite this general effect, small to middle degrees of distressing emotions can contribute to an experience of therapeutic progress, since it can be expected that confrontation with personal conflicts, exposure to anxiety-provoking situations or imaginations, and other kinds of focusing on stressful experiences are painful but necessary as a transitional phase in personal development. "Positive" emotions (E < 0) intensify the feeling of being successful and of progressing in therapy. These effects are mediated by parameters *c* and *m*, that is, by competencies in mentalization and emotion regulation, by self-efficacy, and by positive expectations in progress. The less *c* and *m* are available to a client, the more worrying emotions will reduce S.

I → E

In this conceptualization of psychotherapy dynamics, insight is based on an emotionally "hot" understanding of personally important (in-)congruencies, of conflicts, or of the impact of biographically relevant events (traumata or life events) on the client's mental functioning. Insight is not understood to be abstract or emotionally "cold" knowledge, such as disease-related information as it is communicated within psychoeducation. This holds for true as well if insight refers to new perspectives on possible scenarios of the client's life. Insight (e.g., narrative confrontation and background stories on emotionally important or even traumatic experiences) can activate intense emotions. The activation of emotions doesn't linearly correspond to the personal importance of the insight, but firstly is exponentially increasing with the "intensity" or importance of the insight, followed by a damped effect at higher levels of I. The sigmoid growth function is inversely mediated by *c* and *r*: the less competencies in self-regulation or emotion regulation (*c*) and behavioral skills (*r*) are available, the more insight will trigger powerful or even uncontrollable emotions. In the previous model this function was exponential which in psychological (e.g., perceptual) and biological systems does not correspond to reality.

I → S

Insights into the background and the psychological mechanisms of a client's problems and the development of perspectives on his/her life will create a feeling of progress in therapy. In other words, understanding is a precondition for progress in problem solving, behavior change, and new qualities of interpersonal relations. The effect of I on S is mediated by a logistic growth function, with the steepness of the gradient depending on *a*, *m*, and *r*. This effect requires a certain degree of emotional support and safety, given by the therapeutic relationship (*a*), as well as hopeful expectations and trust in personal development (*m*) in order to transform insight into concrete steps of behavior change (S). Of course, skills and behavioral competencies (*r*) are also necessary to transform I to S.

M → I

In order to create or construct emotionally important new insights, the client has to be sufficiently motivated. The attempt to establish personally meaningful relations between aspects of information may be energy consuming, as does facing of conflicts or emotionally charged memories. Different states of motivation facilitate processes of self-reflection or insight by a logistic growth function, with the steepness of the gradient depending on *a* (quality of the therapeutic alliance supporting the emotionally charged process of self-reflection) and *c* (personal competencies in self-reflection and mentalization).

M → S

Motivation supports success. With increasing motivation to engage in the therapeutic work, progress becomes more probable. Engagement is an important condition for goal attainment and accomplished steps in problem solving. Additionally, a motivation-related focus on self-efficacy and reward expectation is a prerequisite for any progress to be perceived and valued. The function is a logistic growth function with an inert onset followed by an exponential increase and finally a damped effect of motivation on experienced success. The mediating parameters are *a* (quality of the therapeutic alliance), *m* (reward expectation, self-efficacy), and *r* (personal resources and skills), with the assumption that these conditions help to transform motivational states into therapeutic progress. From the opposite direction, there is an inverted logistic growth function which transforms "negative motivation" into reduced experience of success, failure, or therapeutic loss. "Negative" motivation corresponds to avoidance goals (Grawe, 2004), resistance against change, self-handicapping, self-harm, and failure-oriented motives (Baumeister, 1991, 1993).

Compared to the previous model, this function is symmetrical by combining the growth function of M on S with an inverted sigmoid growth function. This allows the model to take into account the impact of positive *and* negative motivations ("negative" in the sense of resistance, avoidance goals, or failure-oriented motives) with both playing an important role in human change processes. At high levels of *a*, *r*, and *m* there is no or only a minor effect of "negative" motivation on S, whereas at very low levels of these parameters, "negative" motivation has a more or less negative impact on the experience of S, but no or only a minor positive impact.

P → E

This function describes a complex relationship between P and E. Increasing problems or conflict intensity activates worrying and distressing emotions. The more severe or stressing the problem, the more such emotions will be triggered (exponential increase). This emotion triggering effect is more pronounced if the person has only minor competencies in emotion-regulation, self-reflection, and mentalization (which are structure functions of the personality in the sense of OPD) (*c*), and reduced expectations in the capacity to solve problems or to manage difficult or stressful situations (self-efficacy expectation, *m*). With higher dispositions or competencies in *c* and *m,* coping strategies for the down-regulation of negative emotions at distinct problem intensities will be available and can be applied. The higher *c* and/or *m*, the lower is the maximum of E and the earlier coping mechanisms and emotion regulation skills will reduce negative emotions. At low levels of *c* and *m*, different degrees of affect intensities cannot be managed or reduced until completely distressing and disturbing emotions (high levels of E) are interrupted, repressed, or disconnected from conscious experience by consuming drugs or alcohol, by self-harm, or by mechanisms of personality dissociation (Nijenhuis and van der Hart, 2011).

This function differs completely from the previous model which simply proposed an inverted U-shaped relation between P and E. The psychological mechanisms behind the function in the present model correspond more closely to findings in emotion regulation (Koole, 2009; Gross, 2015). The prototypic example of this model of emotional dysregulation rests within the psychopathology of Borderline Personality Disorder (BPD), characterized by heightened emotional sensitivity, reactivity, impulsivity, and deficient impulse control, manifesting in behaviors including impulsive aggression and self-harm, triggered by even the most minor of stressors (Lieb et al., 2004; Crowell et al., 2009). The vulnerability to BPD is represented by low levels of *c* and *m*. Hypersensitivity applies to different kinds of stressors, particularly social rejection and interpersonal conflicts (Schmahl et al., 2014). However, research indicates that affective dysregulation is not specific to BPD, but constitutes a transdiagnostic mechanism that manifests in similar ways in different mental disorders (Santangelo et al., 2016). In consequence, the psychology of emotional (dys-)regulation may be a general mediator in the psychological treatment of affective, as well as other classes of disorders.

P → M

This function describes the dependency of the actual motivation to change on the intensity of problems, conflicts, or symptom severity. It is the suffering or psychological strain component of the broader urge to change something (i.e., avoidance goals in the sense of Grawe, 2004). If there is no problem and no suffering, there is no need to engage in problem solving. With increasing subjective problem intensity, the motivation to change increases exponentially until a maximum level. Beyond this the problem seems too big to be mastered. With the problem intensity exceeding this threshold, feelings of helplessness and expectations of failure will dominate and motivation decreases (compare the findings on "learned helplessness," Abramson et al., 1978). The degree of the parameter *m* (learned self-efficacy, positive expectations in one's development, reward expectation) defines where in the range of the problem intensity this point of return is reached. The value of *m* defines the way in which problems and strain encourage the actual state of motivation to change (maximum of the function). At high levels of *m* even severe problems encourage activities in problem solving, whereas at low levels of *m* the person feels helpless, discouraged, or paralyzed (depressed mode) even when confronted with minor problems. In this sense small levels of *m* correspond to the construct of "hopelessness" (Beck et al., 1993).

There is a wide range of empirical evidence on the different aspects of the P → M function, especially concerning the moderating effect of *m*. Some studies show that problem and symptom intensity increase the motivation to change and activate the search for and the utilization of health care providers (Ryan et al., 1995; Rapp et al., 2003; van Beek and Verheul, 2008). Motivation to change is given at higher levels of self-efficay (*m*) even in patients with severe problems like substance abuse and various comorbidities (Schmidt et al., 2009). At low levels of self-efficacy and low self-regulation competence, activities seem to be blocked and persons are more dependent on external motivation (Derryberry and Reed, 1994), with a gap between intention/motivation and action (e.g., procrastination; Steel, 2007) along with low motivation for health-related activities (Sirois, 2004). High levels of intrinsic motivation and self-efficacy contribute to the application of coping strategies during psychotherapy (Caviness et al., 2013) as well as to health-related behavior (Conner and Norman, 1995).

P → S

Problem intensity has a negative impact on experienced success. If problems, symptoms, or conflicts increase (P > 0), the perceived success and progress is reduced. From the opposite direction: a decrease in problems or symptoms (P < 0) will be perceived as success. The function is an inverse logistic function with the steepest effect gradient of P on S in the vicinity of P = 0. Problems and symptoms have a higher negative impact on S if the parameters *c* (cognitive competencies, e.g., in self-regulation and emotion control) and *m* (reward and self-efficacy expectations) are low, and they have less reducing impact on S if *c* and *m* are high. Persons with more distinguished cognitive competencies and learned self-efficacy are more resilient and robust against problem exacerbations, relapses, or personal crises. In the other direction, problem solving (P < 0) is experienced as personal success.

S → E

Experiences of success and therapeutic progress reduce the intensity of negative emotions and intensify positive emotions and self-esteem. This reducing effect is given by an inverse logistic function with the steepest gradient in a middle range of success. Conversely, failures or reduced therapeutic progress (S < 0) intensify bad feelings. This effect is mediated by *m*, that is by self-efficacy, positive expectations in the therapeutic progress, or "trait" motivation. The more pronounced the parameter *m*, the better success and therapeutic progress will activate positive emotions and self-esteem, and the less failures or setbacks will activate worrying emotions.

S → I

Increases in therapeutic success or progress produce information on how problems can be solved. One aspect is the motivating effect of success (S → M) with motivation facilitating the examination of and the involvement in personal topics (M → I). Another aspect is information created by therapeutic progress. This is based on some kind of quasi-experimental relation between changed behavior (independent variable) and its effect on mental functioning, behavior, or social experiences (dependent variable). Success produces insight in the sense of information. The same is true for failure. Just as in a scientific experiment, the rejection of an hypothesis also creates information. In consequence S → I is a symmetric logistic growth function with an inert onset followed by an exponential increase and finally a damped effect of S on I. The symmetry of this function is different than its previous formulation, which only considered the positive branch of S (S > 0). As far as cognitive processes (information processing, mentalization, observation and reflection of one's behavior in relation to the effects on the behavior of others or oneself) are important, the parameter *c* plays a crucial role in shaping this function. Its steepness depends on the value of *c*.

S → M

Success motivates. With therapeutic progress and growing confidence in a successful therapy, the motivation to engage in the therapeutic work increases. The effect of therapeutic success and reward experiences on motivation follows a logistic growth function with an inert onset (small successful steps at first do not yet trigger big jumps in motivation), followed by an exponential increase, and finally to a damped effect of success on motivation. The parameters *r* and *m* determine the magnitude and steepness of the motivation gradient in the growth function. The more the client can trust his/her behavioral skills or resources, self-efficacy, and reward expectations, the more motivation will play a beneficial role. Low resources and low self-regard together with the expectation of failure reduce motivation. This is not only true in the case of experienced failure and therapeutic losses (i.e., negative success), but also for small degrees of success which in a depressed attitude frame are not sufficient to be experienced as positive. The point symmetry of this function is different from its previous formulation, which only considered the motivating effect of success, and did not include the disencouraging effect of failure or of unsufficient success below the threshold of expectation. Each may either support or impede the therapeutic progress.

S → P

Problem intensity is reduced by increasing therapeutic success and experienced progress. Positive experiences during psychotherapy (e.g., positive intra-session outcome) and steps onto a desired goal have a reducing impact on demoralization or emotional problems, and thereby reduce the self-perceived problems of a client. The effect is represented by an inverse logistic growth function with the steepest effect gradient of S on P in the vicinity of S = 0. S > 0 reduces P, S < 0 increases P. The effect is mediated by *r*, that is, by the behavioral resources and skills a person can apply to the transformation of new and positive experiences made in therapeutic situations into problem solving and problem reduction in everyday situations. Just as in the other functions (e.g., S → M, S → E, E → P), there is an effect range of S on P in the vicinity of S = 0 which represents a more depressive or a more optimistic frame of attitude.

S → S

Success enhances and facilitates success, and the other way round, failure and therapeutic losses reduce the experience of success. The intensity of this autocatalytic effect of S depends on *m* (trait motivation, self-efficacy, and reward expectation) and *r* (resources and skills).

In the previous formulation of the model, the autocatalytic effect only referred to positive success, whereas in this newer actualized function the effects of failures and setbacks are represented. Disappointments can be catalyzed as well by downward-oriented "positive" feedback. The option of transforming moderate (sub-expectation) success into disappointment and of minor failures into feelings of success (depending on *m*) also was introduced.

The mathematical terms representing these functions are integrated into 5 coupled nonlinear difference equations. Each equation describes the development of a variable, depending on other variables, on itself, and on the involved parameters (see **Appendix**).

$$
\begin{aligned}
E_t &= f_1(E_t, I_t, P_t, S_t, c, r, m)\\
P_t &= f_2(E_t, S_t, c, r)\\
M_t &= f_3(P_t, S_t, r, m)\\
I_t &= f_4(E_t, M_t, S_t, a, c)\\
S_t &= f_5(E_t, I_t, M_t, P_t, S_t, a, c, r, m)
\end{aligned}
$$

The system was programmed in Excel 2007 and for reasons of validation also in Matlab (Matlab R2016a Ver. 9.0.0.341360, 64 Bit, www.mathworks.com). In this paper we focus on the deterministic functioning of the network dynamics which corresponds to the concept of deterministic chaos (Schuster, 1989). Further steps toward a more realistic simulation of a specific client would have to consider the trait or parameter dynamics, dynamic and measurement noise, and an empirical input function representing the therapeutic interventions onto the system (see Discussion).

RESULTS

The model can be seen as a repository of a large amount of empirical information and knowledge about psychotherapy. In the following results, we will show that this representation of a psychotherapy system is capable of generating plausible time series for the dynamical variables, and of displaying many of the complex phenomena associated with temporal process of psychotherapy (e.g., bi- or multistability and transitions related to interventions). In particular, the model is capable of chaotic dynamics. **Figure 3** illustrates an example of the irregular (chaotic) dynamics of the variables E, P, M, I, and S. The time-delay embedding of the time series shows the characteristic picture of strange or chaotic attractors (**Figure 4**). The impression is that of complex but ordered processes, with trajectories following the shape (Gestalt) of the attractor. Within this shape there is an exponential divergence of closely adjacent trajectories but also a convergent trajectory stream which keeps the dynamics within the attractor. The general impression of parallel trajectory pathways mirrors the deterministic generative mechanism of chaos which is quite different from noise or randomness (Kaplan and Glass, 1992).

One of the most prominent features of a chaotic processes is its sensitive dependency on initial conditions, with the potential for large differences over time arising from small minor fluctuations within the system, or via inputs from the outside. This so called "butterfly effect" is the reason why the principle of "strong causality" (similar causes have similar effects) does not hold for chaotic systems and also why any long-term prediction of such systems is impossible (see **Figure 5** for a realization of the variable S). The prediction horizon depends on the value of the system's Largest Lyapunov Exponent (LLE) (Schuster, 1989; Ott, 1993). The LLE of a time series is a measure of the exponential divergence of trajectories starting nearby in a phase space. The LLEs of the dynamics of E, P, M, I, and S as shown in **Figure 4** were calculated by the algorithm of Rosenstein et al. (1993) using 5,000 iterations (parameter values and initial conditions as in **Figure 4**) and an embedding dimension of 5. The LLEs are: E: 0.007 ($\tau = 31$), P: 0.008 ($\tau = 17$), M: 0.219 ($\tau = 1$), I: 0.225 ($\tau = 1$), S: 0.005 ($\tau = 24$). All LLEs are > 0, indicating chaotic dynamics.

As it is known from other model systems (e.g., the Feigenbaum scenario of the Verhulst map, May, 1976; Schuster, 1989) nonlinear systems do not always behave chaotically, but instead realize a spectrum of fix point dynamics, simple or more complex oscillations, and chaos of different degrees of complexity, depending on the respective parameter values. Our network model covers this spectrum of behaviors. This is visualized by bifurcation diagrams where the long-term behavior of a system is plotted against the parameter value which was used to create the dynamics (**Figure 6**). The realized states are plotted at the y-axis and the realized parameter values at the x-axis. The most interesting part of the system behavior are complex oscillations and chaos, which realizes many or, in a strict sense, an infinite number of states. The bifurcation diagrams illustrate that the chaotic regime which is realized at certain ranges of the corresponding parameters is interrupted by windows of regularly oscillating patterns. This illustrates the fact that chaos not only sensitively depends on initial conditions or microfluctuations, but also on parameter values.

The overall trends in the mean values of the variables E, P, M, I, and S demonstrate the plausibility of the parameter effects on the variables. If we take the mean of all realized values of a variable at a certain parameter value and correlate it with the parameter intensity of *a*, *c*, *r*, and *m*, all parameters are negatively correlated with problem intensity (P) and positively correlated with motivation to change (M) and therapeutic success (S). Following the interpretation of *a*, *c*, *r*, and *m* as cognitive, emotional, and behavioral competencies, this pattern of correlations means that more competent clients produce better outcomes. Cognitive competencies (*c*) correlate positively with insight (I), but not *a*, *r*, and *m*. E is negatively correlated with *a* and *m* (positive emotions and reduced "negative" emotions correspond to higher levels of working alliance and trait motivation), but E is positively correlated with *c* and *r* (which at first glance may seem to be counterintuitive) (**Table 1**).

As stated above, the system realizes not only chaotic, but also fix point and oscillating behavior. **Figure 7** illustrates attractors representing complex regular oscillations, embedded in a 3-dimensional phase space defined by E, M, and I (without time delay, **Figure 7A**), by E (time-delay coordinates, $\tau = 4$, **Figure 7B**), and by M (time-delay coordinates, $\tau = 3$, **Figure 7C**). The regular structure of the trajectories represents the recurrent oscillations of the time series.

The complexity of the dynamics not only appears in the chaoticity of the system, but also in its sensitivity to specific interventions. In the range of stable behavior, most interventions onto the system have no impact on its long-term behavior, and the existing attractor will be reestablished after the displacement

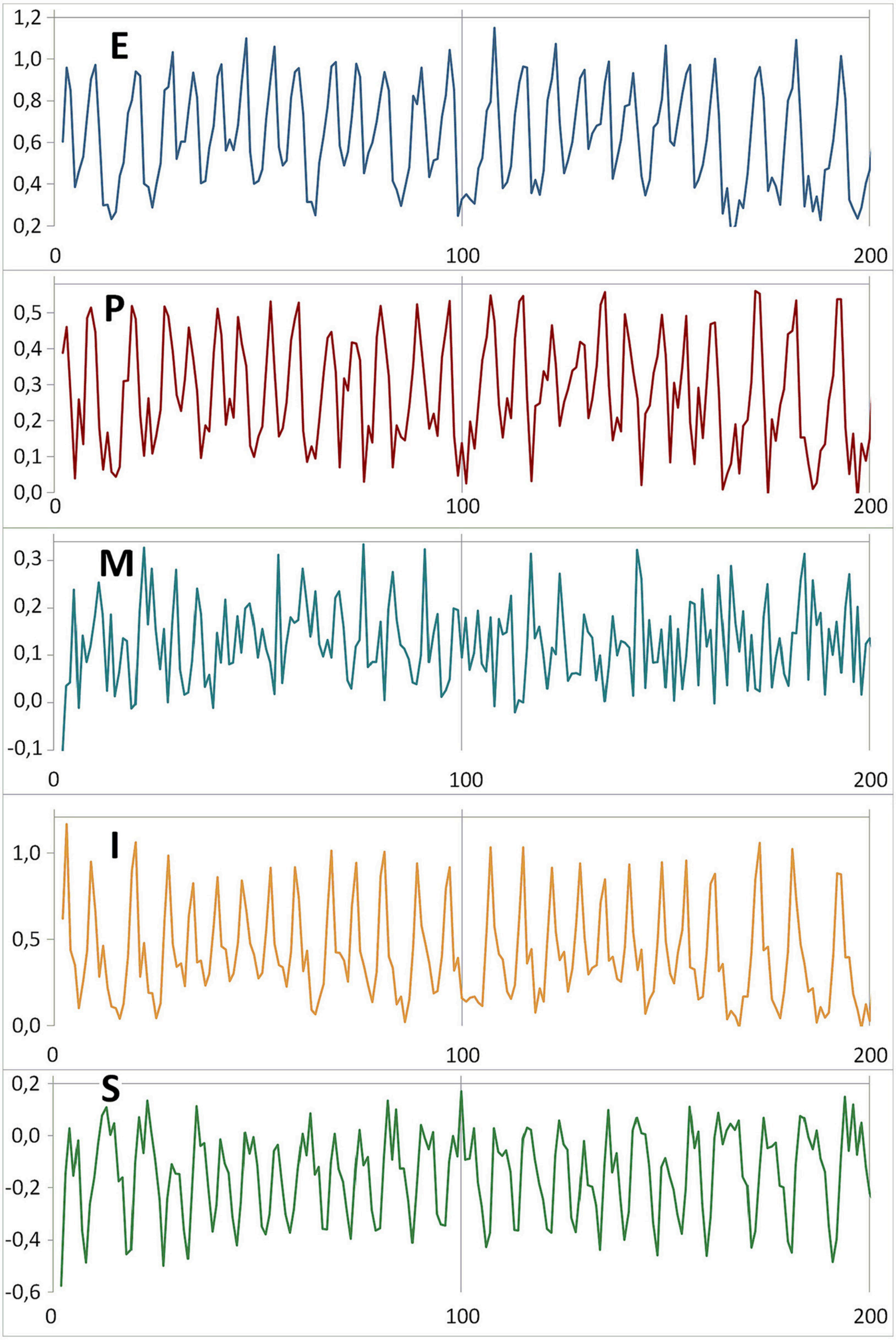

FIGURE 3 | Chaotic dynamics of the variables E, P, M, I, S. The initial conditions (values at $t = 0$) are E: 0.99, P: 0.57, M: −0.34, I: 0.01, S: −0.32. Here the time series from the first iteration at $t = 1$ until $t = 200$ are shown. The parameter values of this simulation run are a: 0.400, c: 0.675, r: 0.740, m: 0.475.

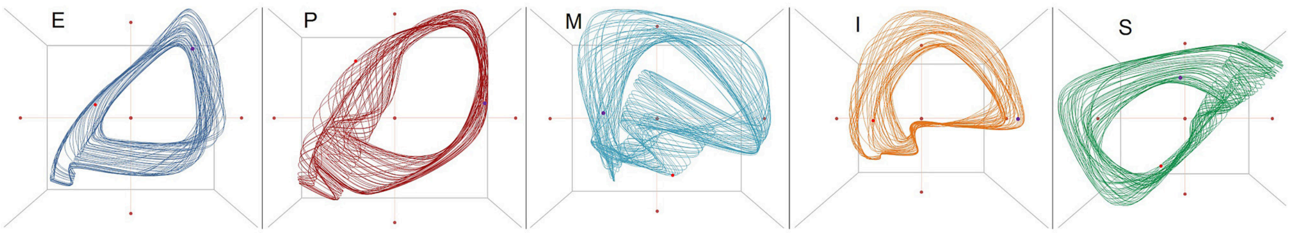

FIGURE 4 | The attractors of the variables E, P, M, I, S in a chaotic regime with parameters and initial conditions as in Figure 3: *a*: 0.400, *c*: 0.675, *r*: 0.740, *m*: 0.475; E: 0.99, P: 0.57, M: −0.34, I: 0.01, S: −0.32. Three-dimensional time delay embedding with $\tau = 1$. The attractors are based on 413 valid iterations (the last iterations from a simulation run of 5,000 iterations) splined by the Excel standard spline function.

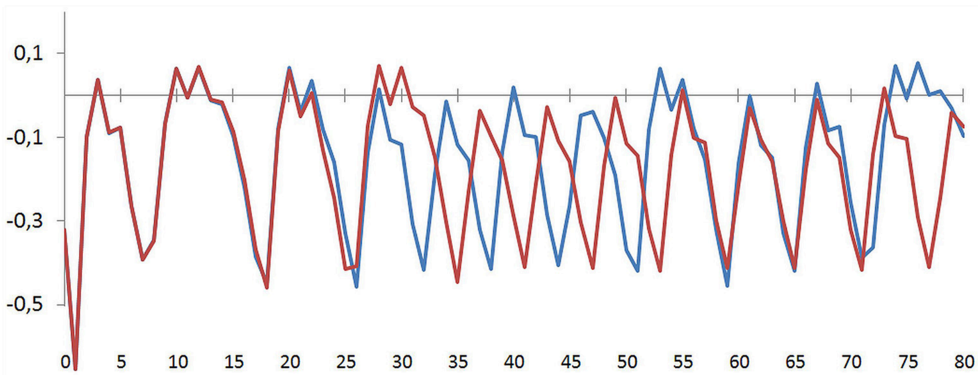

FIGURE 5 | Sensitive dependency of the dynamics on its initial conditions (variable S, 75 iterations of the simulation run). S starts at −0.3200 (blue line) and in a second realization at −0.3201 (red line). Initial values of the other variables (here not shown) as in **Figure 3**: E: 0.99, P: 0.57, M: −0.34, I: 0.01. Both simulation runs are realized at this parameter values: *a*: 0.400, *c*: 0.675, *r*: 0.740, *m*: 0.475. Even if after some cycles the dynamics of two separately started realizations reapproach, the dynamics follow their own and different ways within the global shape of the existing attractor.

(**Figure 8A**). However, in the range of instability, a small increase of the intervention strength can trigger the system into a quite different attractor (e.g., from a chaotic to a fix-point attractor, see **Figure 8B**). In this case, an indirect intervention was realized (on I with impact on M). At the edge of instability, interesting phenomena occur (**Figure 9**): a small input triggers the dynamics into another type of dynamics, and by a second input, the activated dynamics can be switched off (e.g., from complex regularity to chaos and back to regular oscillations). Given specific parameter values, it seems possible to switch the dynamic patterns on and off, but only at appropriate moments. This corresponds to the well-known "kairos" phenomenon of sensitive time windows for decisions or actions. Outside of these sensitive moments, similar interventions have no switching effects. The switching effect is a proof of the bi- or multistability of the system. This means that the system is able to create two or more dynamic patterns at the same set of parameter values. Depending on the initial conditions of the process, on a specific input, or even on small fluctuations, the system will manifest one of the different potentially available patterns.

Up to now, we referred to deterministic dynamics without considering any dynamic noise onto the system behavior. Dynamic noise means that noise from the outside or from the inside of a system is processed by the mechanisms of the system (other than measurement noise, which has no impact on further iteration steps, see Hütt, 2001). Dynamic noise is like continuous erratic interventions onto the system. Indeed, small degrees of dynamic noise create the mentioned switching effect, e.g., between irregular (chaotic) and regular dynamics, as it was created by specific time-sensitive interventions (**Figure 10A**, compare with **Figure 9C**), whereas higher degrees of dynamic noise blur this effect. As shown in **Figure 10B**, a switching between different dynamic patterns can only be presaged in the time series.

The most evident and sustainable effects on the dynamic patterns of a system are due to the shift of its parameter(s). Like in classical physical Synergetics, it is the control parameter that changes the dynamics of the order parameters (Haken, 2004), what is called a *phase transition*. The effect of a parameter shift in *c* is demonstrated in **Figure 11**. A continuous parameter shift (continuous stepwise increase) in the sensitive range of the parameter can produce a discontinuous jump of the system dynamics (order to order transition, Haken and Schiepek, 2010).

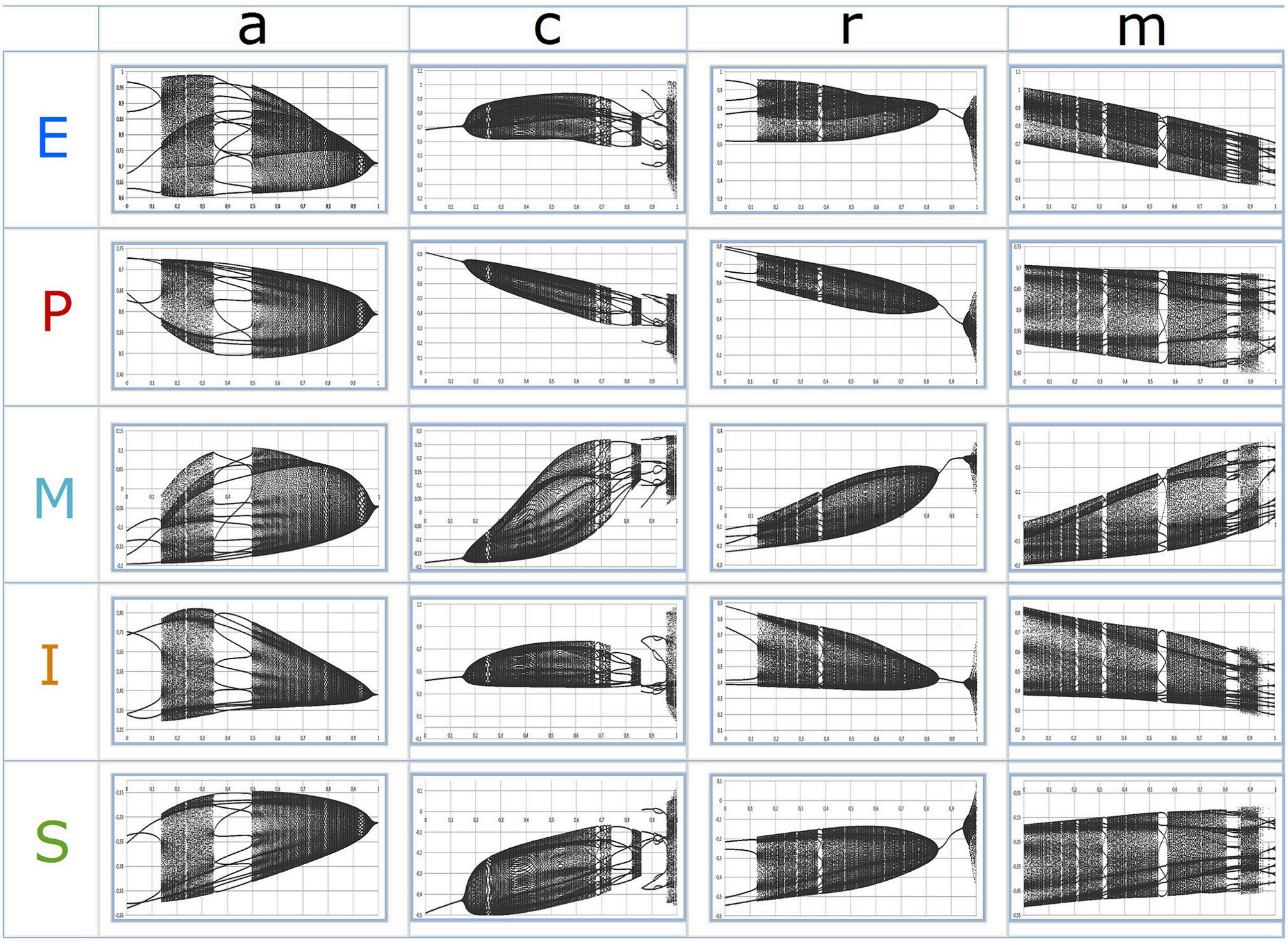

FIGURE 6 | Bifurcation diagrams. The x-axis of each diagram represents increasing parameter values, the y-axis the realized values of the variables at each parameter value. The first 200 iterations (transient dynamics on the way to a stable attractor) were removed, the following 250 iterations (number of values at the y-axis) are taken to create the vertical distribution of values at a certain point of the x-axis. The initial conditions of the variables are for all simulation runs: E: 0.99, P: 0.57, M: −0.34, I: 0.01, S: −0.32. The shown parameter range of each diagram is restricted to a certain window: *a*: 0.05–0.90; *c*: 0.35–0.71; *r*: 0.40–0.78; *m*: 0.50–0.65. Within the range, 500 steps of increasing parameter values are shown. The parameters which were not stepwise increased were kept constant at *a*: 0.55065; *c*: 0.50012; *r*: 0.55010; *m*: 0.55100. Outside of the shown parameter range the dynamics is characterized by fixed point or oscillating behavior.

DISCUSSION

This model and its dynamics illustrate that the assumptions and findings from common factors research and from related psychological topics (e.g., motivation, emotion regulation, information processing, and attachment) can be integrated into a comprehensive theory of change. This theoretical view takes seriously the notion that any conceptualization of psychotherapy should explain process and not only outcomes. Corresponding to empirical findings in psychotherapy research, the model is capable of producing chaotic dynamics, phase transition like phenomena, bi- or multi-stability, and phase transitions in response to parameter shifts. These are some of the most common dynamical features of therapeutic change processes observed in prior research. Therefore, the model may be seen as a first step toward a dynamic systems theory of psychotherapy, as well as a contribution to computational systems psychology.

One distinctive feature of the current approach compared to that of Liebovitch et al. (2011; Peluso et al., 2012), which focused on the co-evolution of emotional valences expressed by a therapist and his client, is that the current approach focuses on the psychological processes of clients in relation to their own experiences. The differential equations which were defined by the Libovich et al. group consist of segments of linear functions each defining the gradient of emotional changes which the client exerts on the therapist and vice versa. This leads to the prediction of stable fix-point attractors of the therapeutic relationship at the intercept of the valence functions, or to drop-outs, depending on the initial conditions in the two-dimensional phase portrait. Chaos is not possible within the scope of this model. Other actual mathematical models focus on dynamics of diseases, but not on psychotherapy. For example, Demic and Cheng (2014) reproduced different disease states of depression (depressive episode, recovery, relapse, remission) by a noise-driven dynamic systems model of one state variable. Huber et al. (2004) developed a nonlinear stochastic model of recurrent affective disorders. A mechanistic framework of brain network dynamics (Ramirez-Mahaluf et al., 2017) describes how abnormal glutamate and serotonin metabolisms mediate the interaction of vACC and dlPFC to explain cognitive and affective MDD symptoms and medical treatment effects (SSRI). Borsboom and Cramer (2013) and Wichers et al. (2015) model and analyze the features of cognitive and affective networks and their readiness to create psychopathological structures and dynamics. Previous simulation approaches used coupled nonlinear difference equations to understand the mechanisms and to reproduce the long-term evolutionary patterns of schizophrenia (Schiepek et al., 1992b). The current model adds to this body of computational approaches to understanding psychopathology and psychotherapy processes, providing a step toward a general theory at the intersection of each topic that is capable of producing each of the most relevant hallmarks of chaotic behavior and phase transitions.

TABLE 1 | The arithmetic mean of the dynamics of a variable at a certain parameter value is correlated with the respective parameter values of *a*, *c*, *r*, and *m*.

	a	*c*	*r*	*m*
E	−0.994	0.587	0.721	−0.893
P	−0.994	−0.999	−0.999	−0.734
M	0.994	0.992	0.997	0.874
I	−0.998	0.884	−0.982	−0.249
S	0.973	0.068	0.987	0.791

The parameter values were increased by steps of 0.01 from 0 to 1 (= 100 steps). For calculating the variables at each parameter step, the first 100 iterations representing the transient dynamics to the stable attractor were removed, and 250 iterations were taken for calculating the mean of the respective variable at each parameter step. Over all, higher competencies correlate with higher values of M and S, and lower values of P.

Epistemological Remarks

Although the model as it is presented in this paper is based on our best empirically founded knowledge, it cannot be excluded that alternative conjectures and hypotheses concerning the relations and functions of the model will also be plausible or empirically grounded. One example may be the hypothesis motivation not only increases insight, but also that insight creates motivation. A better understanding of the psychological mechanisms of one's own problems can be encouraging, and may motivate further change. Additionally, emotions perhaps are not really necessary to create insight. Perhaps creative work like idiographic system modeling (Schiepek et al., 2015, 2016c) even is impeded by intensely experienced emotions, and illuminating insight may trigger positive instead of negative emotions. This encouraging insight concept may be called "Heureka model" and can be contrasted with the "look into the abyss" concept we adopted here. We decided as a first step to use the classical "look in the abyss" model, because it follows the conceptualizations of such recognized psychotherapy researchers as Grawe (2004), Greenberg (2002), Horowitz (1987), Mergentaler (1996), or Silberschatz (2009). Historically, this concept has been modified by modern psychologists but still is motivated by old psychoanalytic concepts of suppressed conflicts. Whatever explanation is preferred, one of the benefits of computer simulations is that you may implement and test both concepts ("experimentum *in silico*"). It is a matter of one's preference in the model-building phase, but then finally one must examine the degree of fit to data in the model testing phase.

Another criticism may concern the specification of parameter values to create chaotic dynamics. Indeed, the range of the parameters was restricted for creating the bifurcation diagrams (**Figure 6**)—a procedure which is called "windowing"—and put to specific values for creating other diagrams. We know this from other well-known bifurcation diagrams like the famous "Feigenbaum scenario" where in a range from 0 to 4 of the control parameter the first bifurcation appears at 3 and the chaotic dynamics at >3.5 (Feigenbaum, 1983; Strunk and Schiepek,

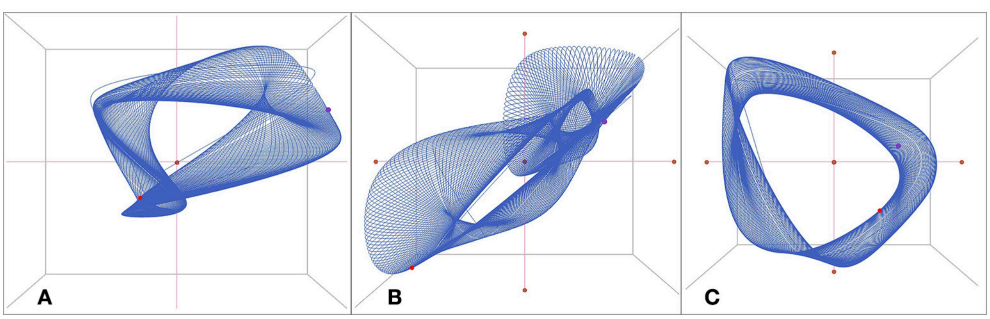

FIGURE 7 | Attractors based on complex but regularly oscillating time series. The attractors are realized at the following parameter values: *a*: 0.400, *c*: 0.477, *r*: 0.708, *m*: 0.503. The first 136 out of 450 iterations representing the transient dynamics to the stable attractor were removed. The attractors are reconstructed by the following 314 valid iterations splined by the Excel standard spline function. **(A)**: E, M, and I embedded in a 3-dimensional phase space without time-delay. **(B)**: E, embedded in a 3-dimensional phase space defined by time-delay coordinates, $\tau = 4$. **(C)**: M, embedded in a 3-dimensional phase space defined by time-delay coordinates, $\tau = 3$.

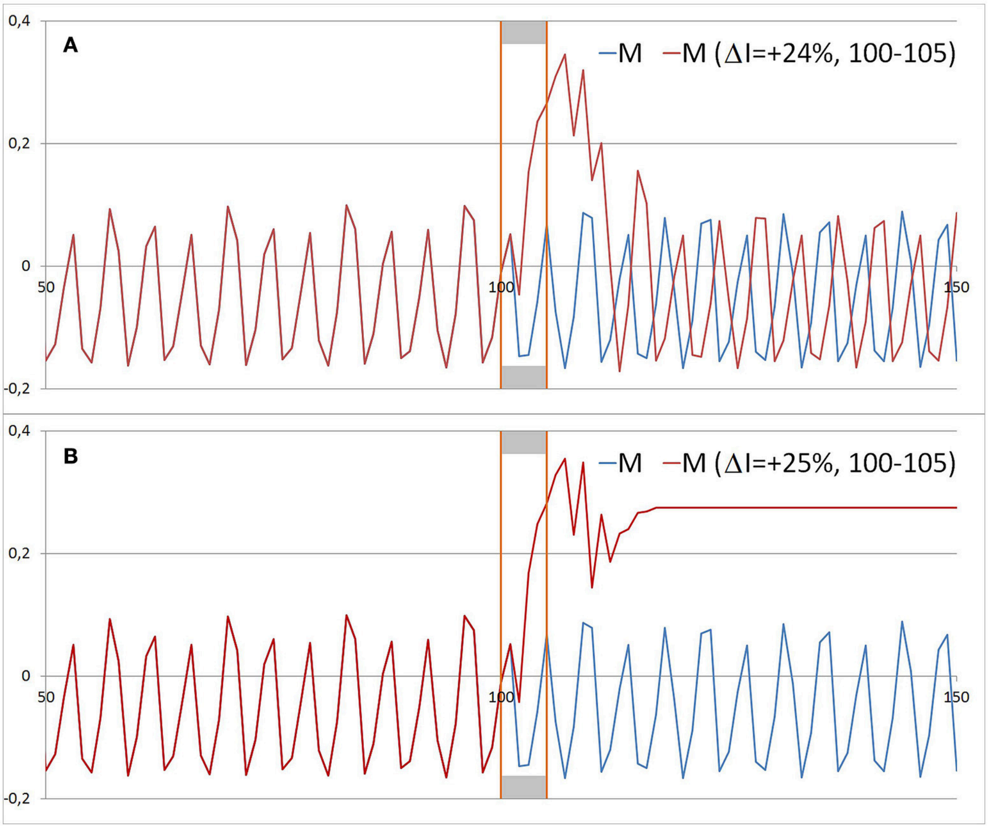

FIGURE 8 | Small differences in the intensity of interventions on I produce changed dynamics in M. Same initial conditions and parametrization as in **Figure 3**. **(A)** From iteration 100–105 an intervention of + 24% on I was realized. After a short period of iterations, a similar but not identical dynamics of M as before was realized. The dynamics runs within the same attractor, but not on the identical trajectory ("butterfly effect"). **(B)** Only a slightly increased intervention strength on I (+ 25% instead of 24%) turns the dynamics of M into a fix point attractor.

2006). Generally, nonlinear systems are able to produce chaotic dynamics, but its emergence as well as the "Gestalt" of the attractors depend on the fine tuning of specific parameter values (e.g., see the examples in Feigenbaum, 1983; Wolf et al., 1985; Schuster, 1989). Beyond mathematical models, the fine tuning of many parameters and natural constants in physics and biology for creating the world as we know it (from cosmology to the life of human beings) is a very universal phenomenon and an important topic in philosophy of nature—it is called the "anthropic principle" (Barrow and Tipler, 1988). The problem of fine tuning of parameters is fundamental, but in our case it is at least open to empirical verification if we are able to measure the parameters in each individual (see below).

The functions of the model are defined by specific shapes relating two or more constructs. This is necessary in order to concretize the nonlinear relations in terms of mathematical functions. Nevertheless, this does, to some extent, go beyond prior empirical findings. In many studies, findings are based on linear correlations or statistical testing of group differences. Here we defined psychological hypotheses as one would define physical laws. The defined relationships within the model are well justified, but realistically lack the same kind of rigor as physical laws. Thereby the functions idealize what we can know theoretically, while the field waits for future empirical specification and detailed definitions of psychological hypotheses. The functions as we defined them are by no means arbitrary, nor are they intentionally designed to create chaos. They were developed based on the most relevant knowledge in psychology and psychotherapy research (top-down), not by the dynamics they would produce or the search for optimally fitting functions (bottom-up).

The basic assumptions of our approach concern the nonlinearity of psychological mechanisms and the empirical findings on chaoticity and self-organization of psychotherapeutic change. This is why we used nonlinear dynamic systems theory, and in particular Synergetics, as the paradigmatic frame of this work. In this context, the distinction between order and control parameters plays an important role. The criteria for this differentiation is the reference to different time scales, the effects of control parameters on the shape of the functions interrelating the order parameters, and the knowledge of the systems under consideration (see Haken and Schiepek, 2010, for further clarification on this important topic).

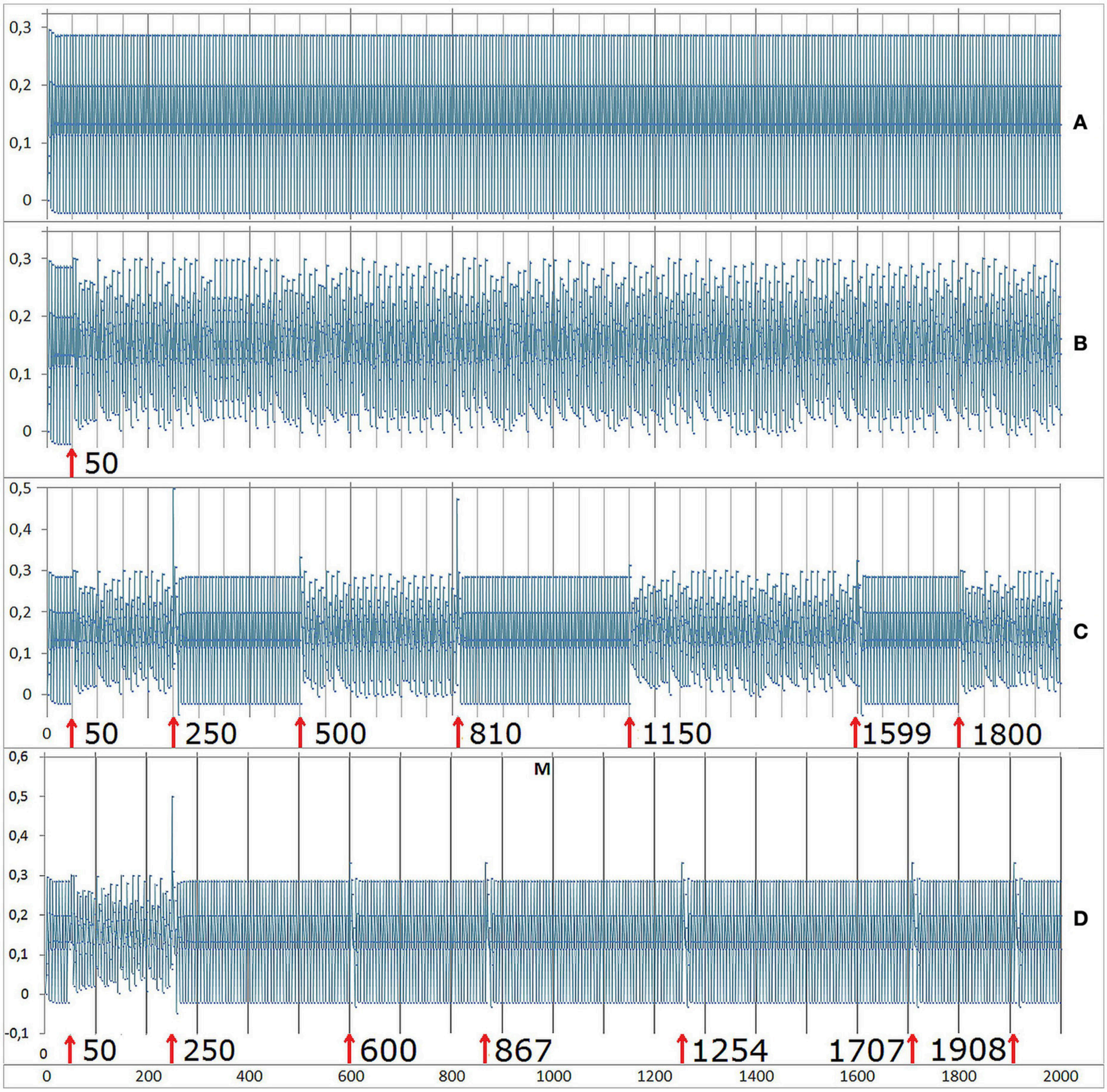

FIGURE 9 | Time-dependent effects of interventions onto the system at initial conditions of E: 0.99, P: 0.57, M: -0.34, I: 0.01, S: −0.32, and parameter values of *a*: 0.05, *c*: 0.71, *r*: 0.78, *m*: 0.65. Here the time series of M is shown. **(A)** Without interventions, M oscillates regularly. **(B)** An intervention of 20% at $t = 50$ shifts the dynamics from a regular oscillation to a chaotic regime. **(C)** Interventions (20%) at certain time steps produce instantaneous shifts between chaotic and regular oscillations. **(D)** Interventions (20%) at other time steps create only very short deviations from regularity. The oscillatory attractor is reestablished after some few iterations.

Limitations and Further Developments

One of the design decisions behind our model is, of course, the choice of a discrete time. It is well known that such choices can have strong effects on the resulting dynamics (Hütt, 2007; Strogatz, 2014). Finite-difference equations (or "maps") can show deterministic chaos already in dimensions smaller than three, as opposed to continuous-time models based on ordinary differential equations. The most prominent example of a one-dimensional map with chaotic dynamics is certainly the logistic map (May, 1976), but also the Kaplan-Yorke map, the tent map, or the Hénon map (Collet and Eckmann, 2009).

Therefore, it is an open question (and will require further investigation), whether a continuous-time model based on similarly plausible assumptions about the nonlinear relationships between the dynamical variables will also have a chaotic regime. It should be noted, however, that the dimension of the model ($D = 5$) would in principle allow for chaoticity also in continuous time. For the present investigation we decided to explore the discrete-time version of the model. Our argument here is that

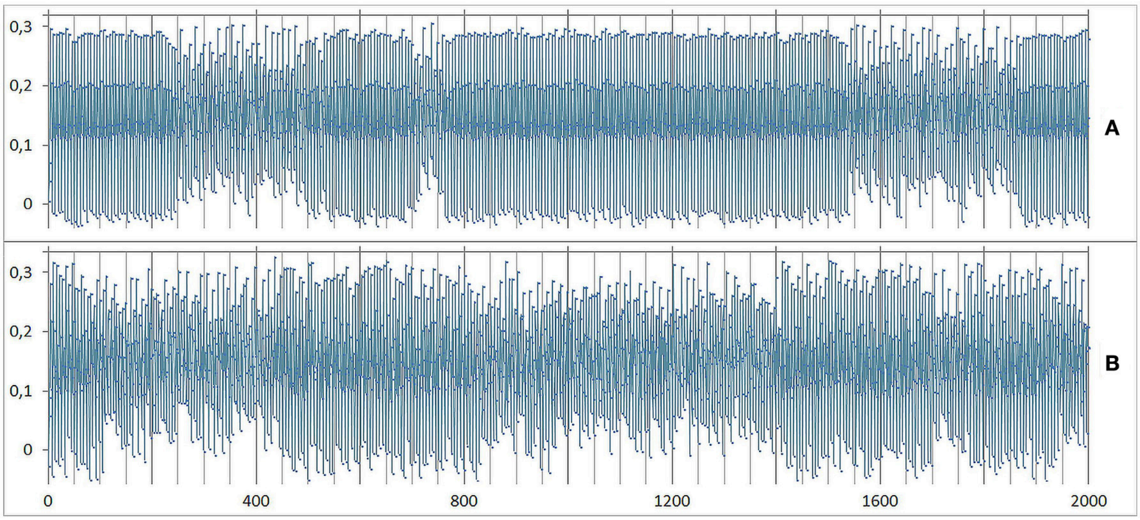

FIGURE 10 | Dynamic noise on M. Same initial conditions and parametrization as in Figure 9. (A) At a small level of noise (2%) the shifting pattern between regular oscillations and chaos emerges spontaneously. **(B)** At a noise level of 6% the shifting pattern disappeared or at least is completely smeared.

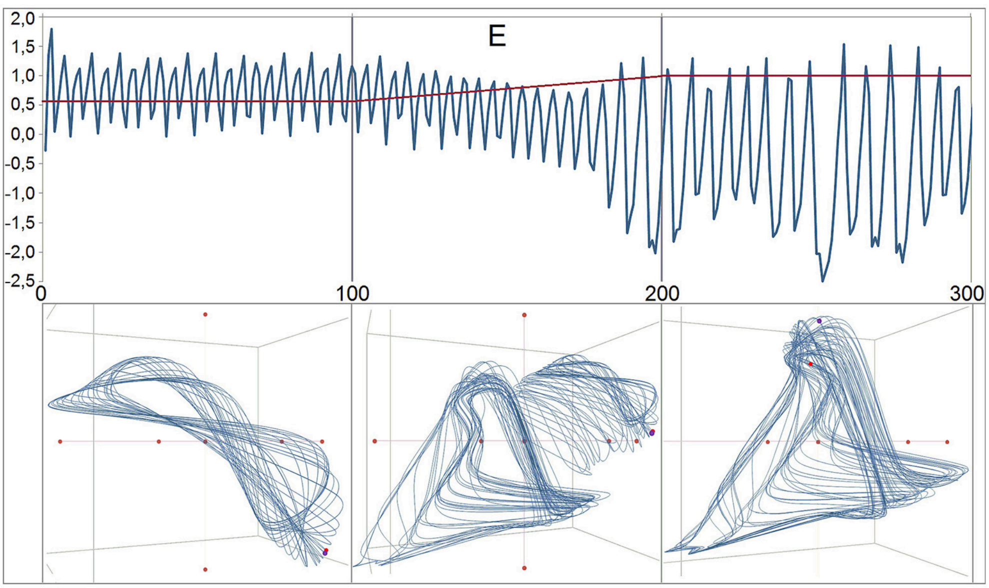

FIGURE 11 | Phase transition in the dynamics of the variable E. The numbers at the y-axis refer to the values of E and the parameter *c*. The transition of the pattern depends on a stepwise linear increase of the parameter *c* from 0.60 to 1.00 between iteration 100 and 200. From iteration 0–100 the parameter is kept constant at 0.60 creating a certain dynamic pattern (attractor), after the 200st iteration *c* is constant at 1.00, producing another pattern at a lower mean level, at a lower frequency, and with higher amplitudes of the chaotic oscillations. The attractors are shown below the time series. For the generation of the attractors the discrete iterations were splined by the Excel standard spline function. During the linear stepwise increase of the control parameter, the transient attractor combines features of the pre and the post-attractor and by this is more complex than each of both.

the dynamical variables indeed only exist at discrete time points. The process of filling out the TPQ on a daily basis, in our view, goes along with a process of inspection within the clients, where formally the client maps his/her complex emotional pattern to the standardized variables contained in the TPQ. In this sense, the measurement process, induced by the TPQ, forms these variables only at discrete times.

Formally, we can consider the psychotherapy dynamics (at least for the phase space given by the 5 dynamical variables discussed here) as a system periodically driven by the TPQ. It is well-known that such periodic driving can trigger a complex dynamical response (e.g., Glass, 2001, for a general discussion and Hütt et al., 2002, for an empirical example of a temperature-driven photosynthetic activity of a plant leaf). While we believe that the psychotherapy itself is not affected by such a driver, the dynamical variables extracted by the TPQ certainly may justify our choice of a discrete-time model.

Our model still contains a large number of parameters shaping the various influence functions such that they conform to a wide range of empirical knowledge about psychotherapy. In the long run, a more minimal model, capable of reproducing the main 'stylized facts' (in the sense of Buchanan, 2012) should be constructed. Such a minimal model could support the view adopted here, that chaotic behavior is indeed an unavoidable consequence of the nonlinear interactions among the 5 dynamical variables. Understanding more deeply which model elements are necessary and sufficient for a particular dynamical behavior (e.g., chaotic dynamics) is a highly nontrivial task (e.g., Yordanov et al., 2011, where such an investigation has been performed for the model from Brandman et al., 2005).

An empirical test of the completed realistic model should assess: the parameter levels of *a*, *c*, *m*, and *r* of a client, the daily input on E, I, M, P, and S as experienced by the client, the initial conditions of the variables at the beginning of the therapeutic process, and the concrete dynamics of the variables. This should be possible since the parameters are widely used psychological constructs which can be assessed by known questionnaires, and the variables of the model correspond to 5 factors of the TPQ (see Haken and Schiepek, 2010) which is administered once per day in routine practice. The administration of the questionnaires is realized by an internet-based device, the Synergetic Navigation System (Schiepek et al., 2015, 2016a,c). This study also should contribute to a better understanding of the interindividual differences of dynamic patterns corresponding to the parameters which refer to the individual dispositions (traits) of the clients.

Of course, an extended concurrent validity study on the TPQ should be carried out. This is actually a work in progress, which is based on about 1,000 valid cases with almost complete process and outcome data (time series data $<3\%$ missings). These data are mined in routine practice of real-time monitoring in 5 Austrian and German hospitals (inpatient psychotherapy) and will be used for a further explorative and conformative factor analysis of the TPQ in order to confirm and to better understand the factors which correspond to the constructs of this model.

The aim of this contribution was to illustrate some basic features of human change dynamics. Further steps toward a more realistic model should include the following: (1) The parameters of the model not only determine the dynamics by shaping the functions, but are shaped themselves by the states and the dynamics of the system. In psychological terms, traits influence states and state dynamics; but the reverse is also true in that states (i.e., concrete experiences, cognitions, emotions, and behavior) may generate the competencies and the dispositions (traits) of an individual. This is the essential process of personality development and is explicitly intended by most psychotherapy approaches. In mathematical terms, the model has to be extended using equations that describe the parameter drift at a slower time scale than the state dynamics of the variables. This is an important extension, because as humans we cannot turn on the control parameters of dispositions or traits. We can only indirectly influence traits over time through experiences, cognitions, and behavior. This makes even more necessary a concept describing how experiences (in this model: variables) can change dispositions (parameters). (2) Future work on this model should incorporate experiences in everyday life and fluctuations from the inside of a system. This may be implemented using dynamic noise, which is processed by the network mechanism (Hütt, 2001). (3) Measurement noise results from poor reliability and accuracy of the assessment procedure, and will need to be considered in future work. (4) The input onto the system results from intended and planned interventions by the therapist or the therapeutic environment (in case of inpatient treatment). Also unscheduled and not intended experiences (e.g., in the social network of a client) can be experienced as therapeutic input.

Practical and Theoretical Consequences

The consequences of a nonlinear conceptualization of psychotherapy, including the chaoticity of the dynamics, go far beyond theoretical reasoning (compare the Introduction section). Given the limited prediction horizon and the pronounced individuality of chaotic trajectories, manuals as guidelines for good practice are ruled out. Instead of dictating what has to be done by what steps in which session, the procedure has to be sensitive to the actual state of the dynamics, e.g., to its stability or instability. In other words, psychotherapy has to be client-centered in a dynamical sense. Indeed, when one examines empirical findings, the impact of manuals and manual adherence on therapy outcome is marginal (Webb et al., 2010; Wampold, 2015). Rather than predefined procedures, the role of real-time monitoring systems becomes significant, particularly if such systems not only assess and visualize the process, but also analyze its nonlinear features like dynamic complexity, pattern transitions, (in-)stability, or switching synchronization patterns (Schiepek et al., 2015, 2016a). The training of psychotherapists should communicate how to handle such systems (e.g., the Synergetic Navigation System) and how to use the results in a client-centered manner (continuous cooperative process control).

The model we outlined in this article supports the conceptualization of psychotherapy as encouraging and coaching the self-organizing processes of the client. Within this frame, interventions take different roles. First, they include all actions to realize the generic principles of psychotherapy (Schiepek et al., 2015). Second, interventions are the actions a therapist can arrange with the aim that the experiences of his client (in other words: the states of his variables E, I, M, P, and S) contribute to an improvement of the client's parameters, which in psychological terms correspond to dispositions or competencies. The way to change dispositions is by concrete experiences and behavior, because a direct modification of parameters (personality traits) seems to be impossible. Third, upon the backdrop of bi- or multistability within the client's psychological system, interventions may be viewed quite differently. Rather than mechanistic forces of invariant change, interventions are more like experimental inputs to explore the switching points, or to identify the triggers, which may turn on another attractor within the range of unique dynamic patterns of the system. In the metaphor of potential landscapes, the ball (the realized system behavior) is driven beyond the separatrix into another valley of the landscape—if it exists. The problem of this concept of interventions is that it should not be like poking around in the dark, but rather in close cooperation with the client, guided by mutual curiosity - a guided exploration of the capabilities of each client's unique personality.

Finally, the model is one piece of a larger puzzle toward an integrative conceptualization of psychotherapy. Besides a general theoretical framework or scientific paradigm, it needs for a concrete theory of change dynamics. This will allow for an optimizion of our understanding of the mechanisms of therapy in general, and in the particular case of each client, given that clients unique dispositions and initial conditions. There are numerous other pieces of the larger puzzle, such as array of available intervention tools. This might be the eclectic part of the whole with different psychotherapy schools as contributors to an intervention pool. A method of case formulation is needed, combining different perspectives and particular hypotheses into a systemic network model (Schiepek et al., 2016c). Theory-based heuristics will be important for the micro-decisions during the ongoing process of a continuous cooperative process control (generic principles, Schiepek et al., 2015). Similarly methods for therapy monitoring and therapy feedback, as it is given by the Synergetic Navigation System, along with outcome and process evaluation integrated into the routine practice of inpatient and outpatient psychotherapy will improve the field. Necessary for ongoing science and training will be the development of an idea of how to bridge the gap between practice and research, and how to use clinical practice as a research field. Finally an elaborated concept of the competencies a scientist-practitioner should be made available if he/she wants to understand, analyze, and manage complex, nonlinear, and self-organizing human systems (systems competence). Computer-based simulations as presented in this article can take a role in the training of how to manage therapies in complex, chaotic, and partially nontransparent systems (Mainzer, 2007; www.psysim.de by Schöller and Schiepek).

DEDICATION

This article is dedicated to Prof. Dr. Dr. h.c. mult. Hermann Haken, the founder of Synergetics, to his 90th birthday.

AUTHOR CONTRIBUTIONS

GS designed the psychological model of psychotherapeutic change dynamics, contributed to the mathematical formalization, and wrote the paper. KV and GS realized the mathematical formalization of the model. WA supported the realization of the project and prepares the empirical validation of the model. MH supervised the mathematical procedures and contributed important advices to the optimization of the project. KS contributed to the psychological underpinning of the model (e.g., by screening empirical findings) and prepares its empirical validation. DP provided edits and text to clarify use of English Language, grammar and style, as well as content expertise on dynamical systems concepts and psychotherapy. HS contributed to the mathematical formalization, performed the numerical simulations and produced the figures.

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APPENDIX

$$E(E, I, P, S, c, r, m) = \frac{1}{1 + e^{-10\,E}} - c + \frac{1}{1 + e^{-20\,I \cdot \left(1 - \frac{c+r}{2}\right) + 5}} + \frac{\frac{-1}{1 + e^{\left(2 + 3 \cdot \left(1 - \frac{c+m}{2}\right)\right) \cdot \mathbf{P}}} + 0{,}5 + 0{,}5 \cdot \left(1 - \frac{c+m}{2}\right)}{1 + e^{25 \cdot \left(1 - \frac{c+m}{2}\right) \cdot \left(\mathbf{P} - 0{,}2 - 0{,}75 \cdot \left(1 - \frac{c+m}{2}\right)\right)}} + \frac{1{,}25}{1 + e^{5\mathbf{S} - 0{,}5}} - 0{,}5 - 0{,}5\,m$$

$$I(E, M, S, a, c) = \frac{1}{1 + e^{-20\,E \cdot \left(\frac{a+c}{2}\right) + 5}} + \frac{1}{1 + e^{-20\,M \cdot \left(\frac{a+c}{2}\right) + 5}} + \frac{1}{1 + e^{-20 \cdot |S| \cdot c + 5}}$$

$$M(P, S, r, m) = \frac{1{,}261}{\left(1 + e^{(\mathbf{P} - 0{,}05 - 0{,}85\,m) \cdot (10{,}1 + 19{,}9\,m)}\right) \cdot \left(1 + e^{-(\mathbf{P} - 0{,}43 + 0{,}03\,m) \cdot (7 - 3\,m)}\right)} + \frac{-1}{1 + e^{5\,\mathbf{S}}} + \frac{r + m}{2}$$

$$P(E, S, c, r) = \frac{1}{1 + e^{-10\,E}}\,c + \frac{1{,}2}{1 + e^{5\,\mathbf{S} - 0{,}5}} - 0{,}2 - 0{,}8\,r$$

$$S(E, I, M, P, S, a, c, m, r) = \frac{1{,}3}{1 + e^{5\,E - 0{,}5}} - 0{,}65 + 0{,}35 \cdot (c + m - 1) + \frac{1}{1 + e^{-20\,I \cdot \frac{(a+m+r)}{3} + 5}} + \frac{1}{1 + e^{-20\,M \cdot \frac{(a+m+r)}{3} + 5}} - \frac{1}{1 + e^{20\,M \cdot \left(1 - \frac{(a+m+r)}{3}\right) + 5}} + \frac{1{,}25}{1 + e^{5\,\mathbf{P} - 0{,}5}} - 0{,}5 - 0{,}5 \cdot \left(1 - \frac{c+m}{2}\right) + \frac{1}{1 + e^{-10\,S}} + \frac{m + r}{2} - 1$$

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MONITORING CHANGE DYNAMICS –A NONLINEAR APPROACH TO PSYCHOTHERAPY FEEDBACK

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ABSTRACT

Innovations in information technology opened the way to monitor the nonlinear features of human change dynamics in real time. Especially the internet-based Synergetic Navigation System (SNS) was optimized for high-frequency assessment in real-world settings and for the nonlinear analysis of the collected time series data. The technology also has an impact on the conceptualization of psychotherapy feedback, e.g., concerning measurement frequencies and sampling rates, the variables to be assessed, the methods of time series analysis, the way how to practically use the technology, and how to do feedback-based interviews. One important aim is to identify order transitions and their precursors in psychotherapy and counseling. The options available in the SNS for analyzing and visualizing non-stationarities and related precursors are described and illustrated by Figures. The paper is completed by two perspectives on practice and theory – one on the individualization of measurement procedures and process-sensitive treatment designs, the other on the mathematization of models for understanding the complexity of change processes (computational systems psychology).

Keywords: change dynamics, psychotherapy feedback, ecological ambulatory assessment, order transitions, Synergetic Navigation System (SNS), precursors, personalization of measures and treatments

1. THE GAP BETWEEN OUTCOME MONITORING AND THE NONLINEAR DYNAMIC SYSTEMS APPROACH

The history of psychotherapy is characterized by a great variety of different approaches and confessions, in treatment as well as in research. There are hundreds of therapy schools (the exact number depends – beside other criteria – on the definition of what is a "psychotherapy school"), but there are also diverging and conflicting lines in research, e.g. between qualitative and quantitative approaches or between evidence-based practice

(practice should apply treatments which are validated by Randomized Controlled Trials) and practice-based evidence. Also the reaction to this tradition of heterogeneity is at least twofold: enjoying the creative diversity or missing integration and synergy effects.

Two actual developments in psychotherapy seem to reproduce again a gap instead of an integration which could make both development lines more powerful. One is the increasing interest in outcome monitoring and feedback on therapeutic progress which has been adopted by many mental health providers all over the world (e.g., Evans et al., 2002; Kraus et al., 2005; Lambert et al., 2005; Miller et al., 2005; Trauer, 2010). Lambert (2007, 2010) or Newnham and Page (2010) describe it as an important feature of good clinical practice and ask for an integration of monitoring procedures into routines of mental health care. Another field of emerging interest is the nonlinear dynamic systems approach, which refers to Synergetics, chaos theory, and other theoretical and methodological concepts in complexity science (Orsucci, 2006, 2015; Gelo & Salvatore, 2016; Haken & Schiepek, 2006; Strunk & Schiepek, 2006; Tschacher et al., 1992). Empirical studies produced evidence for chaotic dynamics and cascades of self-organized order transitions in human change processes – with far reaching theoretical and practical consequences (Haken & Schiepek, 2006; Schiepek et al., 2014a; Strunk & Schiepek, 2006). Both development lines have created social networks and scientific cooperations all over the world. E.g., the Society for Nonlinear Dynamics in Psychology and the Life Sciences was founded in 1991, and in the Society for Psychotherapy Research an Interest Group for complexity science was initiated by Franco Orsucci in 2016.

The usual practice in psychotherapy feedback is to assess outcome at therapy sessions and to compare it to an expected treatment course of reference clients (so called "standard track"; Lambert et al., 2005). In contrast to this, the message of nonlinear dynamics is that there is no standard track or expected treatment response of human change dynamics because of the limited predictability of chaotic dynamics, the highly individualized and complex patterns of change, and the occurring order transitions between quasi-attractors. For practical purposes of successful interventions it is more important to know when the system shifts into a critical instability than if the trajectory is "on track" or not. In a strict sense, a chaotic, self-organizing system will never be "on track". From the point of view of complex dynamic systems, standard tracks (expected change trajectories) are more likely an artefact of low frequency and non-equidistant data collection and widely used linear assumptions than of the actual linearity of the phenomena under consideration. In consequence, therapy feedback can and should be fitted to the requirements of nonlinear dynamic systems by some methodological adaptations. New technological developments like the Synergetic Navigation system (SNS) allow for the identification of precursors and correlates of non-equilibrium order transitions in human change processes.

2. BRIDGING THE GAP

If psychotherapy is basically the adaptive realization of conditions for self-organization, that is, for cascades of order to order transitions (Haken & Schiepek, 2006; Schiepek et al., 2015), a monitoring instrument for this kind of dynamics is needed. On this way we have to go some methodological steps which are outlined in the following.

In Session vs. Ecological Momentary Assessment

The majority of practitioners who use feedback routines ask clients for outcome ratings during therapy sessions (e.g., de Jong et al., 2014; Delgadillo et al., 2017; Lambert et al., 2002, 2005; Lutz et al., 2013). The consequence is long and varying periods of time between measures – in outpatient settings, but also in day treatment or inpatient settings (Newnham et al., 2010 a,b). Therapy feedback then loses the advantages of ecological momentary assessment, because experiences of every-day life aren't reported in close timely proximity to their actual occurrence. In contrast, daily assessment can reduce memory biases, distortions by state-dependent memory effects in distal settings, and the urge for implicit averaging over many events or days, resulting in enhanced ecological validity of the data (Ebner-Priemer & Trull, 2009; Fahrenberg et al., 2007; Wenze & Miller, 2010). For data collection in everyday settings, web-based devices such as smartphones, tablets, or laptops yield easy access to questionnaires whenever and wherever needed.

Outcome vs. Common Factors Monitoring

Feedback procedures focus almost exclusively on outcome measures (e.g., the Outcome Questionnaire (OQ-45; Lambert et al., 2004) and many others, see Delgadillo et al., 2017; Evans et al., 2002; Newnham et al., 2010a,b; Trauer, 2010). Focusing entirely on – albeit important – outcome excludes process-mediating aspects and general therapeutic ingredients. In order to grasp these aspects of therapy, the monitoring should also cover factors as resources, motivation for change, engagement, emotions, self-relatedness, expectancies, self-esteem, self-efficacy, or working alliance and ward atmosphere (Duncan et al., 2010; Norcross & Lambert, 2011). Besides outcome, therapy feedback should be sensitive to features of change processes like early rapid responses, sudden gains or losses (Lutz et al., 2013; Stiles et al., 2003), or rupture-repair sequences in the working alliance (Gumz et al., 2012; Stiles et al., 2004). Combining the common factors approach with therapy monitoring could result in a real-time assessment of common factor dynamics – which may be nonlinear and chaotic (Schiepek et al., 2014 a,b; Schiepek et al., 2017).

Irregular vs. Frequent and Equidistant Time Sampling

As stated above, it is often the sequence of therapy sessions that defines when patients give survey-based feedback. De Jong et al., (2014) report on a feedback study in outpatient settings with about 50% OQ administrations out of 32.3 (SD: 41.4) therapy sessions. De Beurs et al., (2011) administered the Brief Symptom Inventory four times during a sequence of more than 50 sessions. Such sampling rates represent outcome states at a certain time, but do not allow for the identification of dynamic patterns and pattern transitions. Figure 1 illustrates how the dynamics of a time series (daily ratings of self-esteem from a patient with Borderline Personality Disorder) is distorted and the information on the dynamic pattern is lost if measurement points are successively omitted. The rapid cycling during the first weeks of a treatment vanishes if ratings are only made on every fourth day (Figure 1c), weekly (Figure 1d), or at mixed weekly and fortnightly intervals, which is the most common periodicity of therapy sessions (Figure 1 e,f). Corresponding to the loss of information, the presented time series appear more and more linear with the shape of the curve depending on the chosen measurement points.

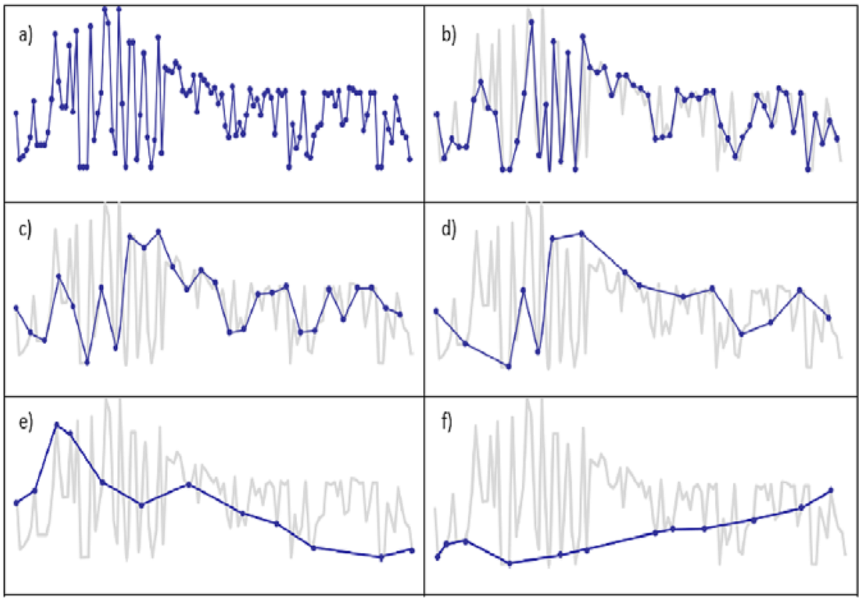

Figure 1. Illustration on how dynamic patterns depend on sampling rates and can be deformed by the arbitrariness of measurement time. (a) Empirical time series of "self-esteem" based on daily ratings of a client diagnosed as "Borderline Personality Disorder" (112 measurement points = days). (b) Only each second measurement point is taken. The pattern is less differentiated, but the curve has still a similar shape compared to the original one. It should be considered that analysis methods (e.g., on dynamic complexity, degree of synchronization) implemented in the SNS are based on running windows. For applying dynamic complexity (Schiepek & Strunk, 2010) or inter-item correlation a window width of 7 points reveals valid results. Reducing the measurement density by 2 would require a proportional enlargement of the window width with consequences for the actuality of analysis results. Actuality is crucial if treatment decisions should be based on such results. (c) Each forth measurement is taken from the original time series. The fluctuations dominating the first third of the process now are eliminated. (d) The time series corresponds to an assessment once per week, with a slight randomness (± 2 days) around a rhythm of exactly 7 days. (e, f) Varying measurement distances from 7 to 14 days correspond to a realistic session by session rhythm in outpatient settings. Depending on the exact day of the assessment, the shape of the curve and the resulting judgement on success or deterioration is drastically changed. Conclusion: Given a solid data base in time series the outcome of a therapy could not only be judged by pre-post measures but also by changing dynamic patterns. There is no "real" or "true" dynamics of psychotherapy since it depends on the selected theoretical constructs and measures, the sampling rate, and the system levels under consideration.

In order to get deeper insight into human change processes, it is important to perform frequent, continuous, and equidistant measurements (regular time sampling). Only regular and frequent assessments through process questionnaires allow for meaningful application of time series analysis methods in the domains of frequency (e.g., Fast Fourier Transformations, Time-Frequency Distributions, Cohen, 1989) and of nonlinear dynamics

(Haken & Schiepek, 2006; Heath, 2000; Kantz & Schreiber, 1997). In consequence, there should be just as much emphasis placed on standardizing the sampling rates as there is currently on standardizing the instruments used for measurement (e.g., questionnaires). When aiming at (a) a complete recording of therapies (not only as an irregular event sampling), (b) frequent and (c) continuous measurements, and (d) considering practicalities of data collection, daily measurements appear to be a good and achievable way.

Linear vs. Nonlinear Dynamics

Most therapy feedback applications utilize linear models of psychological change. However, there are accumulating findings supporting nonlinearity and chaoticity of psychotherapy and change dynamics (e.g., Granic et al., 2007; Haken & Schiepek, 2006; Halfon et al., 2016; Hayes et al., 2007a,b; Heinzel et al., 2014; Kowalik et al., 1997; Schiepek et al., 1997; Schiepek et al., 2014a,b, 2017; Tschacher et al., 1998). Chaos implies different degrees of irregularity and complexity of the dynamics, including its sensitive dependency on initial conditions, on minimal input onto the system, or on micro-fluctuations (Schuster, 1989; Strunk & Schiepek, 2006). This so called "butterfly effect" restricts the predictability of systems' behavior dramatically.

Another well-known feature of human change processes is phase-transition-like behavior as modelled by theories of self-organization (especially Synergetics, Haken, 2004; Haken & Schiepek, 2006; Schiepek et al., 2014 a,b). Sudden changes (gains or losses) during psychotherapies may directly correspond to such phase transitions. Both critical fluctuations at instability points of the system dynamics and the deterministic chaos of the process – confounded with stochasticity in real-world systems – result in high complexity and inter-individual diversity of the dynamics. Synergetics predicts the occurrence of critical fluctuations and the increase of data-variability just before transitions from one pattern to another take place (Haken, 2004; Haken & Schiepek, 2006; Kelso, 1995; Schiepek et al., 2014 a,b).

Focus on Cases at Risk of Deterioration vs. Continuous Cooperative Process Control by Applying Decision Rules to All Cases

There is increasing evidence that feedback not only supports therapy in cases of threatening deterioration (Lambert et al., 2002) but also in prosperous therapies (Anker et al., 2009; de Jong et al., 2014; Lambert et al., 2005), or at least reduces average treatment duration and costs (Delgadillo et al., 2017). It appears to be especially beneficial if both - client(s) and therapist - exploit feedback (de Jong et al., 2014). In consequence, feedback tools should become part of everyday routine practice in different psychotherapeutic settings and the information produced should be shared by clients and therapists. A diversity of dynamic features shift into focus, and, as predicted by the theory of self-organization, critical instabilities and crises are utilized as common and necessary transients on the way to therapy effects. Therapists should be able to read these markers of self-organizing processes and encourage the client to communicate his/her experiences corresponding to the feedback results. As a result, clients will be accompanied towards further therapeutic steps and strengthened for (micro-) decisions on the way to therapeutic success. Herein the therapist continuously realizes a threefold reference: (i) to the information given by the client, (ii) to the theory (e.g., the theory of self-organization), and (iii) to the process data and analysis results. An important background are the decision criteria or heuristics given by the so called "generic principles" which are derived from Synergetics (Haken & Schiepek, 2006; Schiepek et al., 2015). They cover eight important conditions for successful self-organizing processes of a client: 1 create stable boundary conditions, 2 identification of relevant systemic patterns, 3 sense of significance, 4 control parameters and motivation for change, 5 destabilization and amplification of fluctuations, 6 kairos, resonance, and synchronization between client and therapist, 7 purposeful symmetry breaking, 8 stabilization of new patterns.

3. THE IDENTIFICATION OF ORDER TRANSITIONS – CONVERGING EVIDENCE FROM DIFFERENT METHODS IMPLEMENTED IN THE SYNERGETIC NAVIGATION SYSTEM (SNS)

From the perspective of self-organization, one of the most important aims of therapy feedback is to get early warning signals on upcoming order transitions. Periods of critical instability preceding such transitions are often sensitive to minor interventions, personal decisions, or new and encouraging activities. These periods are critical moments which in the ancient Greek mythology are called "Kairos" (see the 6th generic principle). However, critical instabilities can also be decisive moments for a development to the worse, e.g., to suicidal states (Fartacek et al., 2016).

The first and most simple way to identify precursors of order transitions is the inspection of raw data time series by the naked eye. This is by no means an objective method but given some experience in pattern recognition it provides a good first visual impression which can be consensually validated by the reports and electronic diaries of the client. Figure 2 shows some examples of order transitions as presented by the diagrams of the Synergetic Navigation System (SNS). In many cases critical instabilities can be identified before an order transitions takes place (Figure 2a), in other cases a transient deterioration may be a precursor (Figure 2 b,c). A next step is the presentation of the factor dynamics. Factors are subscales of a process questionnaire combining the information from several items. In the SNS, the items contributing to a factor are averaged and z-transformed (Figure 3). The SNS also allows for the superposition of several time series in a diagram, which creates an optimized picture of critical instabilities and order transitions (Figure 3a). In many cases the z-transformed factor dynamics shows the shape of a process more pronounced than the time series of the items. Figure 4 shows an example of a client diagnosed by the label of "dissociative identity disorder" (for a detailed description of this case see Schiepek et al., 2016). The time series of the raw data are quite noisy and fluctuating (Figure 4a), whereas the factor dynamics shows a much clearer "Gestalt" with one dominating order transition (Figure 4b).

Colored raw data diagrams transform the values of all included time series as given by the items of a process questionnaire into rainbow color scales. These diagrams create a synopsis of the evolution pattern of multiple time series (Figure 5).

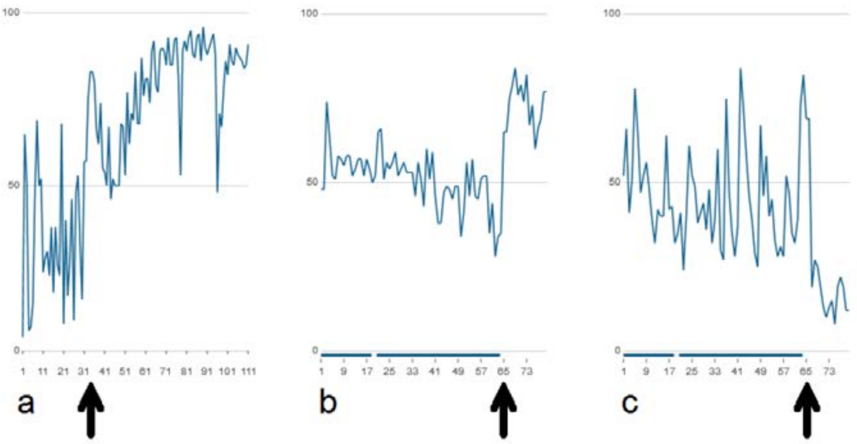

Figure 2. Time series of single items (raw data, Therapy Process Questionnaire-Revised, TPB-R). (a) "Today I felt joy," (b) "Today I felt decided to change my problems," (c) "Experienced intensity of problems and symptoms" (time series (b) and (c) are taken from the same client, see also Figures 3b,c, 5a, 9, 13). (a) shows a critical instability before the transition (comp. Figures 3a, 5a, and 7), (b) and (c) show a transition after a short period of deterioration. The arrows indicate significant order transitions.

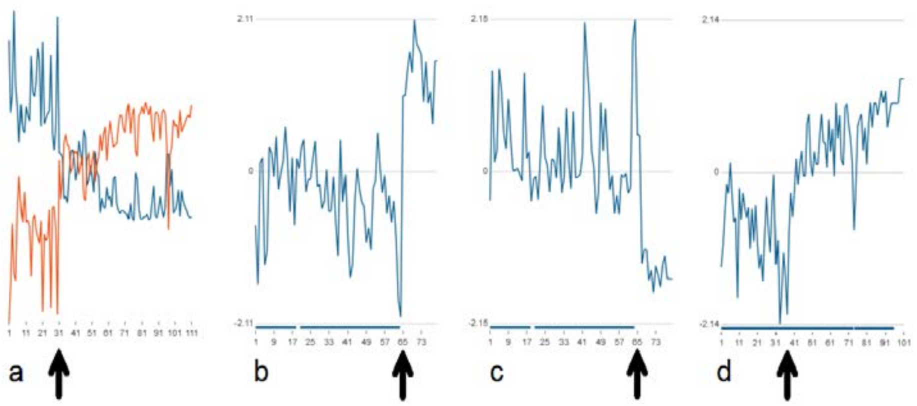

Figure 3. Time series of factors (Therapy Process Questionnaire, TPB-R). (a) Two factors superimposed: "Problem and symptom severity" (blue) and "Self-awareness/body experience" (red; same client as in Figures 2a and 5b). (b) "Therapeutic progress / confidence / self-efficacy," (c) "Problem and symptom severity." (b) and (c) refer to the same client as Figures 2b,c, 5a, 9, 11, and 13), (d) "Therapeutic progress/confidence/self-efficacy" (another client). The arrows indicate significant order transitions.

Pattern transitions not only appear in changed mean levels of a time series, but also in their variability, rhythms, frequency distribution, complexity, or other dynamic features (see Figure 1a). The option of a superposition of time series in a diagram (Figure 3a) or the visualization of coloured raw data diagrams can show such synchronized or anti-synchronized rhythms in multiple time series (Figure 6a). In some cases, order transitions are characterized by the emergence or submergence of synchronized rhythms.

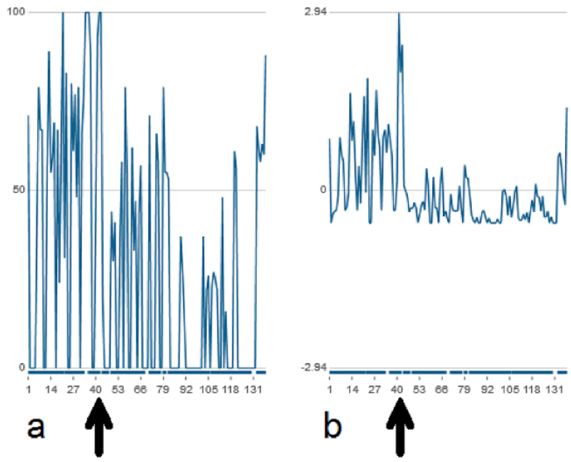

Figure 4. (a) Time series of the item “Today I experienced stress.” (b) Time series of the factor “Stress and coping with stress.” The items of this factor correspond to a child-related ego state of a client diagnosed as “dissociative identity disorder” (see also Figures 6, 10, 12, and 14, which refer to the same client). The arrows indicate the dominating order transition.

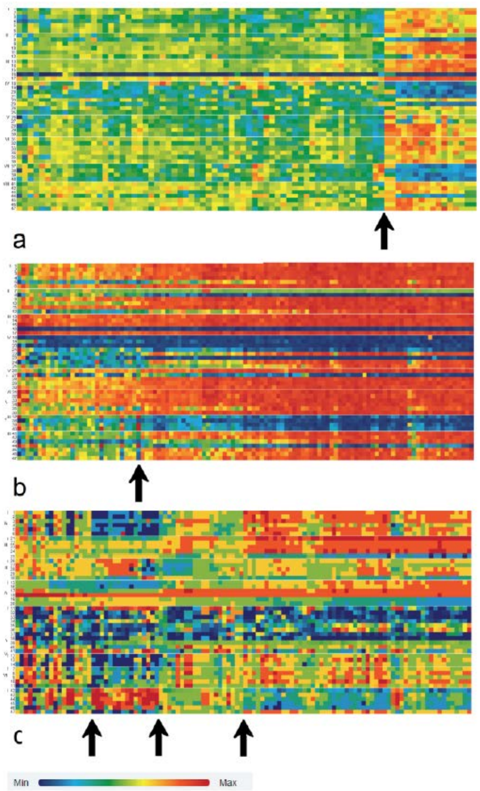

Figure 5. Colored raw data diagrams. The arrows indicate significant transitions. (a) Same client as in Figures 2b,c, 3b,c, 9, 11, and 13; (b) same client as in Figures 2a, 3a, and 7; (c) same client as in Fig. 3d.

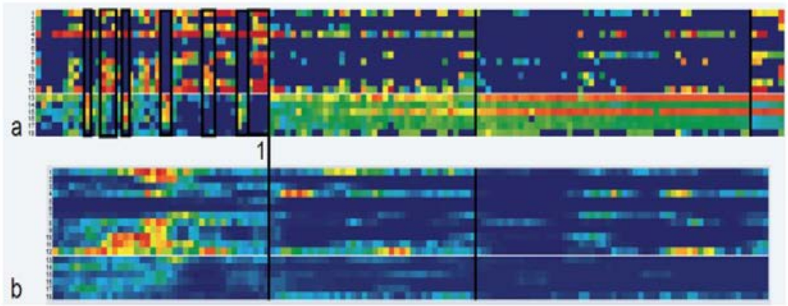

Figure 6. (a) Colored raw data diagram of a client diagnosed as “dissociative identity disorder.” Blue colors represent low intensities, yellow to red colors represent high intensities of the ratings. The vertical line (1) indicates the significant order transition of this therapy. Before this transition an alternating pattern between the items corresponding to two ego states can be identified. Black frames underline periods of alternating item scores and manifestations of states. Items 1 to 12 correspond to a “child” state, shown above the thin white line in the diagram; items 13 to 18 correspond to an “adult” state, shown under the thin white line. (b) Complexity resonance diagram of this client’s change process. The cluster of high dynamic complexity occurs especially in the items of the “child state” before the order transition, corresponding to the intensely fluctuating and mutually exclusive states.

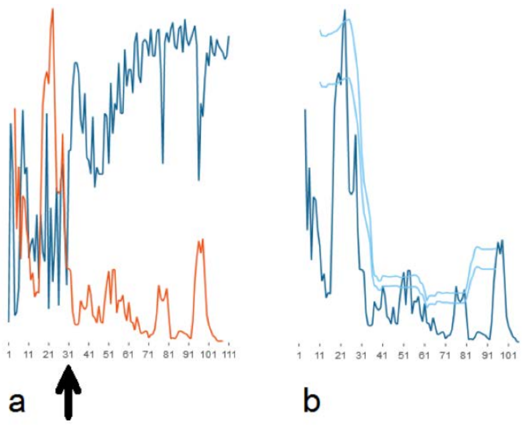

Figure 7. (a) The dynamic complexity (red) of the time series “Today I felt joy” (see Figure 2a). In the SNS diagrams, the dynamic complexity curve can be superimposed onto the time series of raw data or factors. The complexity peak precedes the order transition. (b) Over the dynamic complexity dynamic confidence intervals are calculated in a running window (95% [lower] and 99% [upper] thin blue line). Here the width of this running window is 21.

A common precursor of order transitions is critical instability (Haken, 2004; Haken & Schiepek, 2006). In the SNS this is represented by the measure of dynamic complexity, which combines the amplitude, the frequency, and the distribution of the values of a signal over the available range of a scale. All three features (amplitude, frequency and distribution) are calculated within a gliding window which runs over the complete time series (given daily measures the usual window width is 7 days) (Haken & Schiepek, 2006; Schiepek & Strunk, 2010). The evolution of dynamic complexity can be presented as time series (Figure 7) or as colored complexity resonance diagrams (Figure 8). In the resonance diagrams, vertical columns or sudden decreases of complexity over many items indicate order transitions. Another way of representing dynamic complexity is not to include all complexity values from all items and to transform them into colors, but to calibrate the complexity values within each time series. The 10 highest complexity values of an item's time series are transformed into grey steps (from black corresponding to the highest to a bright grey as the lowest complexity value, all others are white). This procedure is more sensitive for low complexity values and shows the synchronization of intra-item calibrated complexity in a grey-steps diagram (Figure 9).

In some cases, the weekly assessed symptom or stress intensity may indicate an upcoming transition. In the example presented in Figure 10a, the intensities of depression and stress are increased just before the order transition takes place. After this transition, the values are significantly reduced. In our routine practice, depression, anxiety, and stress are assessed once per week by the short form of the Depression-Anxiety-Stress Scales (DASS-21; Lovibond & Lovibond, 1995).

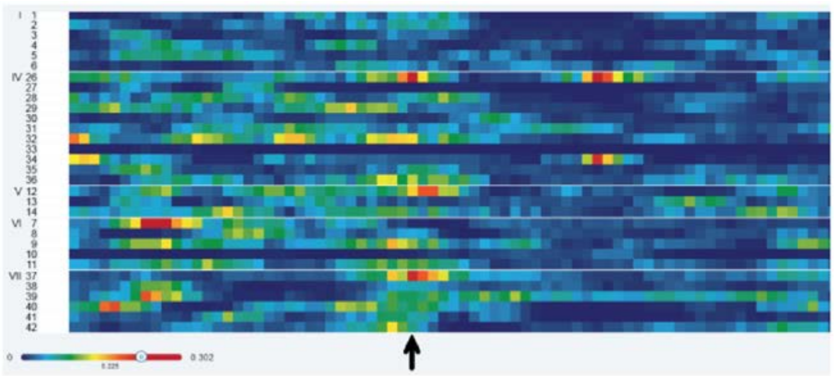

Figure 8. Complexity Resonance Diagram. The dynamic complexity is calculated in overlapping running windows (window width = 7 days). The maximum score of the dynamic complexity is depicted by a full red pixel, while all other values are graded according to that maximum (red = high, yellow = medium, blue = low complexity). The order transition is marked by the arrow.

Another precursor of order transitions is increased synchronization of the emotions and cognitions of a client, as represented by the items of a process questionnaire. In the SNS, the absolute (sign-independent) values of inter-item correlations of a questionnaire are averaged within a moving window and presented as averaged correlation strengths over time. This is a measure of coherence of the dynamics (Figure 10b, Figure 11). The changes of all inter-item correlations are presented in a sequence of correlation matrices with color-coded correlations (from –1 [dark red] over 0 [white] to +1 [dark green]). The correlation matrices are calculated within a running window (the window width is up to free choice, here: 7). A marker can be dragged along the time points to display the change in synchronization patterns over time. The local increase of the absolute inter-item synchronization together with a more pronounced correlation pattern corresponds in many cases to a qualitative change of the correlation pattern. Figure 12 illustrates this pattern transition in the case of the client diagnosed as "dissociative identity disorder." Before the first order transition, the correlation matrix represents the alternating ego states (high positive intra-state correlations of cognitions and emotions [green], high negative inter-state correlations [red]) which is dissolved after the order transition.

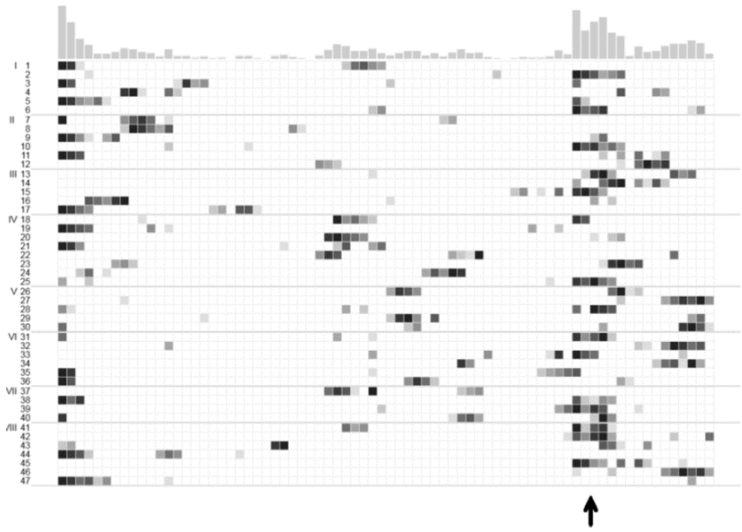

Figure 9. Complexity Resonance Diagram, based on an intra-item calibration of the dynamic complexity. The 10 highest complexity values of each item are coded by grey steps. The arrow indicates the order transition (same client as in Figures 2b,c, 3b,c, 11, 13).

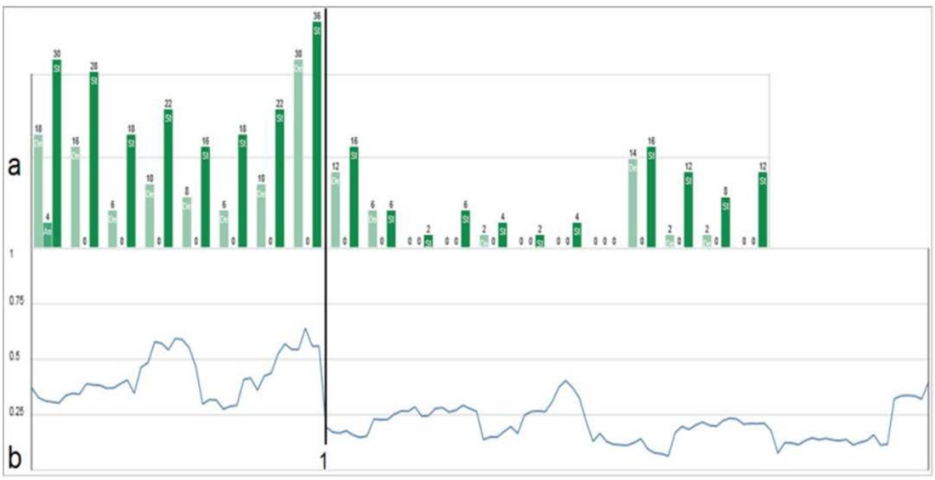

Figure 10. (a) Intensity of depression (light green), anxiety (except for the first week always at 0) and stress (dark green) (assessed once per week by the DASS-21, Lovibond & Lovibond, 1995). Just before the order transition (vertical line, comp. Fig. 6) the values are increased, after it the values decrease immediately to a lower level. (b) Averaged inter-item correlation calculated in a running window of 7 measurement points. The first part of the process is characterized by a pathological over-synchronization with the maximum just before the order transition (vertical line) (same client as in Figures 4, 6, 12, and 14).

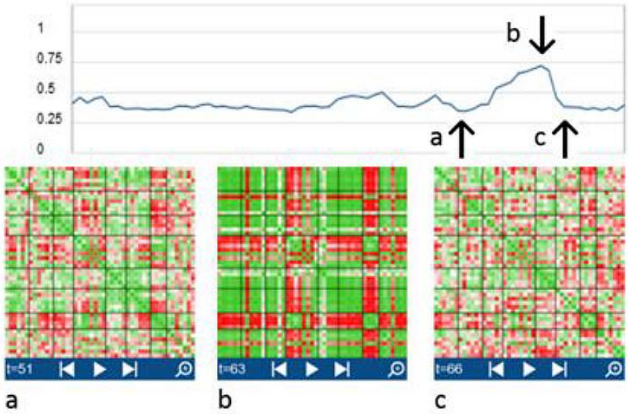

Figure 11. Locally increased inter-item synchronization during the period of an order transition (arrow b). The inter-item correlation matrices show an intensified and more pronounced pattern during the order transition compared to the matrices before and after the transition (a before, b during, c after). Each cell depicts the correlation of a respective item with another item on a gradual green (positive correlation values, $0 < r < 1$) or red (negative correlation values, $-1 < r < 0$) scale (white cells correspond to a correlation of 0) (same client as in Figures 2b,c, 3b,c, 5a).

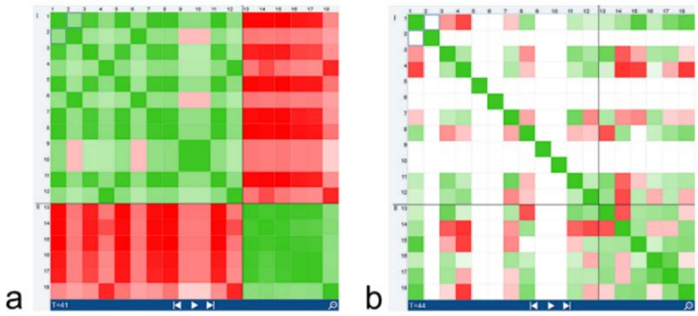

Figure 12. (a) Color-coded inter-item correlation pattern characterizing the first third of the monitoring period (before the vertical line (1) in Figures 6 and 10). The black lines differentiate the items of factor I and factor II. The left matrix (t = 41-47) is characterized by high positive within-factor item correlations (green colors) and negative between-factor item correlations (red colors). (b) Only some days later (t = 49-56), but after the main transition of the therapy (occurring at the vertical line in Figures 6 and 10), this pattern dissolved. The change of correlation patterns coincides with the client's reports of increasing integration of her separate ego states throughout the therapeutic process.

A method which identifies recurrent patterns within a time series in a time×time diagram is Recurrence Plots (Eckmann et al., 1987; Webber & Zbilut, 1994). Snippets of a longer time series are embedded in a phase space defined by time-delay coordinates. Each snippet represents a vector point in the phase space (each measurement point is represented on an axis). The Euclidean distances between the vector points can be binary coded according to a selected threshold or, alternatively, the distances can be color coded. By this, recurrent patterns and their transients (periods of critical instability) become apparent. Usually, Recurrence Plots and CRDs show complementary patterns: transient periods (yellow to red colors; out-of-attractor dynamics) correspond to periods of critical instabilities, and hence, increased dynamic complexity, whereas recurrent periods (turquoise to blue) represent more or less stable quasi-attractors. Figure 13 illustrates the transition from one stable pattern to another (blue rectangles), with a short transient period in between (yellow to orange pixels).

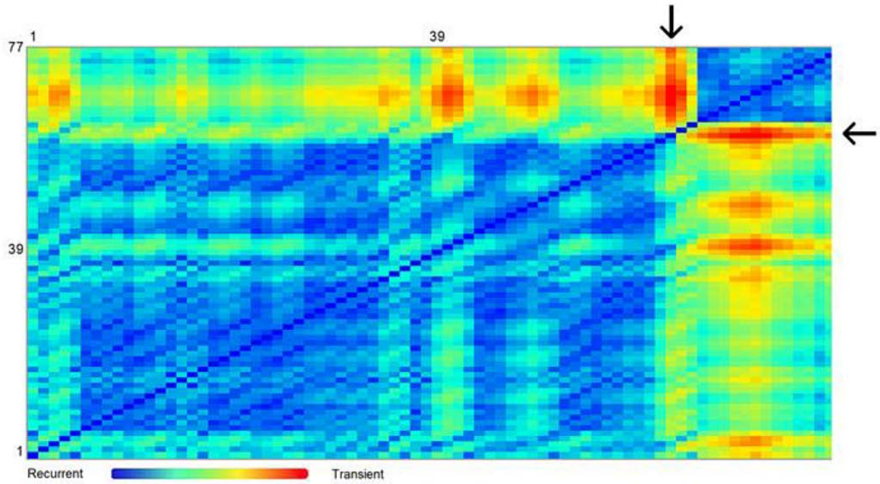

Figure 13. Recurrence Plot. The arrows refer to a short transient period (coded by yellow to red colors) between two more stable quasi-attractors (compare Figures 2b,c, 3b,c, 5a, and 9).

Beside the transition markers implemented in the SNS there are others, like increased local frequencies as identified by the wavelet-based method of Time Frequency Distributions (Cohen, 1989, see Haken & Schiepek, 2006, pp. 402ff.) or change points which can be identified by the method of Change Point Analysis (James & Matteson, 2014). It should be noted that the coincidence of more than one transition marker or precursor is needed to identify an order transition.

4. PERSPECTIVES ON PRACTICE AND THEORY

Feedback procedures are able to capture the nonlinear features of human dynamics. Ten years of experience with the Synergetic Navigation System allowed for a deep insight into these features in many cases (e.g., Heinzel et al., 2014; Schiepek al., 2014ab, 2015, 2016). Actually, a data set of 942 valid cases (average time series length: 73.5 daily measures (SD: 38.5), average missing data: < 3%) is available from different treatment centers. This continuously increasing data base opens the door to the investigation of many research questions and to a further validation of the mainly used process questionnaire (TPQ-R). In times of upcoming doubts on research results based on small samples it is important for psychotherapy science to go into the world of big data. Perhaps more important is the option to combine big data with the individualization of measures and treatment procedures (e.g., Fisher, 2015; Fisher & Bosley, 2015).

Individualization of Treatments and Measurement Procedures

After decades of focusing on therapy schools and on disease-related treatment programs it becomes evident that important challenges to psychotherapy and public health ask for new ways of problem solving which have to be focused on the unique client. These challenges concern the great interpersonal range of treatment outcomes, including non-responders and deteriorations, missing sustainability and stability of treatment effects, or treatments which are not sufficiently fitted to the complexity of client's problem configurations, living conditions, treatments goals, co-morbidities, and also to the dynamics of change processes (e.g., Lambert, 2013; Newman et al., 2010). The hope exists that personalized and tailored treatments can meet these challenges by optimized case formulations, personalized procedures, the dynamic adaptation of therapeutic procedures to the process, specific after-care programs, and also by using personalized measures. An advanced approach in personalized psychotherapy is the Synergetic Process Management (Haken & Schiepek, 2010) which uses individualized process monitoring based on a specific method of case formulation – the idiographic system modelling (Schiepek, 2003).

The method of idiographic system modelling starts by a semi-structured interview which produces a list of important psychological and social variables constituting the cognitive, emotional, and social system of the client. Starting off at a general picture of the client's life in the last couple of months, the therapist takes notes throughout the interview on important factors such as psychological problems, problem-solving methods, coping strategies, and impact on social life. These notes will form the basic components of the idiographic model (Schiepek et al., 2015). Therefore, practically any topic of importance to the client can be part of the interview and enter the system. It is advisable to try to capture the actual terms of the client's language, in order for client and therapist to create mutual understanding and producing the client's very own individual model. After the interview, all variables are being checked for their terminology and content, to make sure that the client can find himself in these. It is important that the components are expressed as variables that can change throughout time. In a perfect case, therapist and client manage to capture all important bio-psycho-social aspects of the client's life, incorporating cognitions, emotions, motives, behavior, or physiological states, using the client's own language and terminology as well as by using psychological constructs.

Subsequently, the inter-connections of these variables are mapped, creating a personal landscape of relevant aspects of the client's mental functioning – the idiographic system model (ISM). Using a flipchart, a variable A is written down and the list is being checked for other variables that are connected to it. Writing down a second connected variable B, both are linked with an arrow and a "+" or "–" symbol, indicating whether there is a positive relation (same directedness: increase in A leads to increase in B and decrease in A leads to decrease in B) or a negative relation (opposite directedness: increase in A leads to decrease in B and decrease in A leads to increase in B). An example is given by Figure 14. The client described that an increase in "dissociation" is accompanied with a decrease of the distraction through "disturbing voices", indicated by a "–" between the two variables. In contrast and symbolized by a "+," the more "rage/aggression" she experiences, the more she needs to toggle her "movie in the head (head-cinema)," and a decrease in aggression makes that coping-mechanism less necessary.

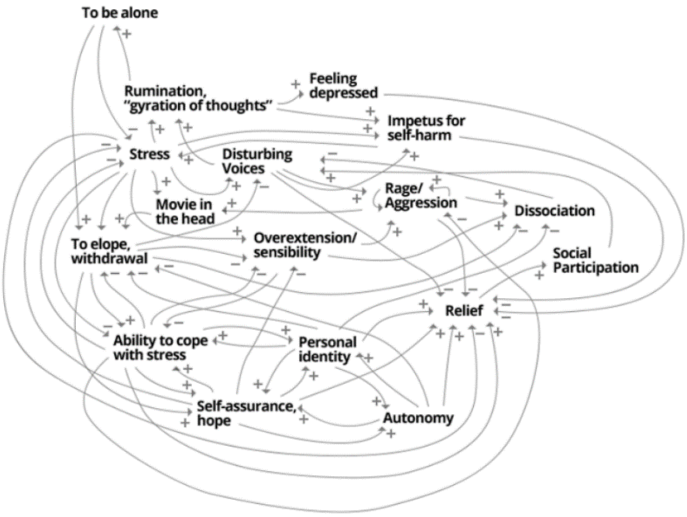

Figure 14. The idiographic system model of the client diagnosed as "dissociative identity disorder" (comp. Figures 6, 10, and 12). The items of her personalized process questionnaire correspond to the variables of this model. The client attributed many of the variables to be differentially prominent in separate ego states. The understanding of the model was the basis of seeing patterns, what before was experienced as volatile and erratic alternations of ego states. In contrast to her everyday life experience, the ISM represented a systemic synopsis of her psychological and social life, making amnestic separations of ego states visible. Consequently, this understanding allowed trauma-focused therapy and intensive work directed towards the ego states.

Most clients achieve to create a complete ISM in a session of about three hours, being in a "focused flow." They report to find themselves represented by their own model referring to it as "the map of their soul." ISMs help clients to better understand patterns of their behavior, and how in a systemic fashion, cognitions, emotions, and behaviors trigger each other. If it makes sense to the client, the variables and also the relations between them can be taken as targets of interventions and new experiences. The questionnaire editor of the SNS can be used to create a personalized process questionnaire, with usually one variable of the ISM corresponding to one item (comp. Fig. 6). Given the procedure of creating an ISM, clients have an optimized understanding of these personalized items. In consequence, the data produced by this kind of questionnaires are perhaps more valid than that produced by standardized questionnaires. The teamwork of client and therapist continuously refers to the ISM as well as to the time series produced by the personalized questionnaire (cooperative continuous process control).

Theoretical Modelling Psychotherapeutic Processes

The conceptual framework of self-organizing systems and the new data base given by nonlinear feedback technologies also have consequences on theoretical modelling. Efforts have intensified to understand how psychotherapy works, taking seriously that the "explanandum" is the change process and that an important key to understanding change lies within the change process itself rather than in the input onto it. During the last years our research group worked on a theoretical model which is able to simulate the nonlinear dynamics of change processes including important features of deterministic chaos: irregularity of the dynamics, sensitive dependency of the process on initial conditions and on small but well-timed interventions, global stability of the system's behavior within its (more or less stable) attractors, and the dependency of the actually realized attractor on the control parameters of the system, resulting in attractor shifts during the change process (Schiepek et al., 2017).

The model includes four variables or order parameters: (E) emotions; (I) insight, new perspectives; (M) motivation to change; (P) problem intensity; symptom severity; (S) success, therapeutic progress, goal attainment. Four control parameters mediate the interactions between the variables: (a) working alliance, capability to enter a trustful cooperation with the therapist, quality of the therapeutic relationship; (c) cognitive competencies, capacities for mentalization and emotion regulation; (r) behavioral resources or skills that are available for problem solving; (m) motivation to change as a trait, self-efficacy, positive expectations in one's development. Depending on their values, the effect of one variable on another is intensified or reduced, activated or inhibited (Figure 15).

A property of the model is the circular causality between states and traits (Figure 16). Traits are competencies or dispositions which modify the shapes of the nonlinear functions describing the effects of one state (variable) to another. In terms of personality psychology, traits are qualities of a person which influence states (cognitions, emotions, or behavior varying from moment to moment). In terms of Synergetics, states correspond to the order parameters of the model and traits correspond to its control parameters. Control parameters change at a slower time scale than the variables or states (separation of the time scales). In self-organizing systems the change of control parameters drives the phase transitions of the system (Haken, 2004; Haken & Schiepek, 2006).

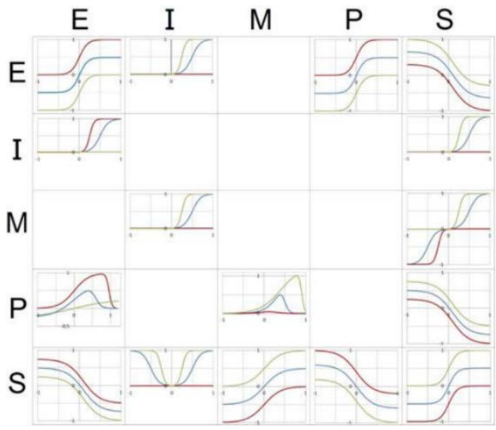

Figure 15. The 16 functions of the model (for a detailed description see Schiepek et al., 2017). The variables noted on the left of the matrix (lines) represent the input, the variables noted at the top (columns) represent the output. Each function is represented by a graph in a coordinate system (x-axis: input, y-axis: output). Green function graphs correspond to the maximum of the respective control parameter(s) (= 1), red graphs to the minimum of the parameter(s) (= 0). Blue graphs represent an in-between state (0 < parameter value < 1).

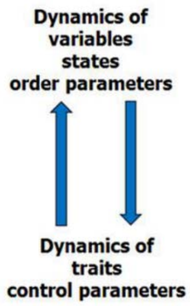

Figure 16. Circular causality between states (order parameters) and traits (control parameters).

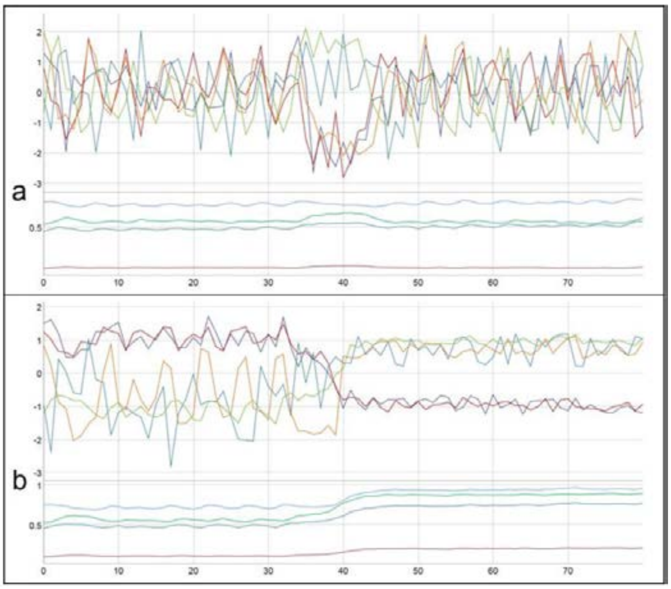

Figure 17. Two simulation runs of the model at the same levels of dynamic noise (a, b). Upper part of both diagrams: Dynamics of the variables or states (order parameters): E (dark blue), I (yellow), M (light blue), P (red), S (green). Lower part: Dynamics of the traits (control parameters): a (red), m (green), c (bright blue), r (dark blue). In both cases, the initial values of variables and parameters are identical. The added dynamic noise is 10% on E and P, 5% on M, I, and S, continuously. (a) A transient instability, but no order transition occurs. (b) The dynamic noise triggers an order transition.

Technically the model is realized by nine coupled nonlinear difference equations. Five represent the state or order parameter dynamics (E, I, M, P, S) and four represent the trait or control parameter dynamics (a, c, r, m) (Schöller et al., under review). The model explains how the circular interaction between control and order parameters can create stable effects at the personality level, or why in some cases dynamic noise can have important consequences whereas in other cases it has no impact (Figure 17). Other results of the model concern the different impact of punctual interventions vs. continuous interventions, or the significant time-dependency of interventions during the process.

The conclusion is that new methods of process monitoring and feedback are part of a new paradigm in psychotherapy. The Synergetic Navigation System opens the black box of human change processes and their nonlinear features, and in consequence, it also requires the individualization of treatments and measurement procedures. Finally, the design of theories on how psychotherapy works has to be developed according to the paradigm shift towards computational systems psychology and nonlinear complexity science.

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Prozessfeedback in der Psychotherapie

Methodik, Visualisierung und Fallbeispiel

Psychotherapeutische Veränderungsprozesse weisen in vielen Fällen komplexe und sprunghafte Dynamiken auf. In der psychotherapeutischen Praxis ist es hilfreich, solche dynamischen Muster auf der Höhe des Geschehens zu erkennen. Dies setzt ein hochfrequentes „real-time monitoring" voraus, das aber auch praktische Fragen aufwirft, wie die nach der Compliance oder der Nutzbarkeit von Therapiefeedback bei Patienten mit Grübelneigung und Antriebsschwäche. Auch stellt sich die Frage, ob und wie Feedback mit anderen therapeutischen Angeboten zusammenwirkt.

Hintergrund

In der Entwicklung der Psychotherapie lassen sich seit einigen Jahren mehrere interessante Strömungen beobachten. Eine besteht in der zunehmend intensiveren Beforschung des Veränderungsprozesses. Phänomene wie sprunghafte Verbesserungen („sudden gains"), sprunghafte Verschlechterungen („sudden losses"; z. B. Lutz et al. 2013) oder passagere Krisen in der therapeutischen Beziehung („crisis-repair sequences", z. B. Gumz et al. 2012) wurden ebenso beschrieben wie nichtlineare Dynamiken und komplexe Übergangsszenarien im therapeutischen Prozess (z. B. Hayes et al. 2007; Heinzel et al. 2014). Punktuelle Messungen des Outcomes werden nun also ergänzt durch den Einblick in den Verlauf. Eine andere Strömung besteht in der Nutzung von elektronischem Therapiefeedback (de Jong et al. 2014; Lyon et al. 2016; Schiepek et al. 2016). Während frühe Studien zeigten, dass mögliche Verschlechterungen damit rechtzeitig erkannt und verhindert werden können, lassen aktuellere Studien auf generelle positive Effekte in unterschiedlichen therapeutischen Settings schließen (Einzel- und Paartherapie, ambulante und stationäre Therapie, z. B. Anker et al. 2009; de Jong et al. 2014; Lambert et al. 2005; Newnham et al. 2010). Die Datenerfassung erfolgt in unterschiedlichen Abtastfrequenzen: hochfrequent (z. B. im Rahmen von Studien zum „ecological ambulatory assessment" im Abstand von wenigen Stunden, „time-sampling") oder bei Auftreten bestimmter Ereignisse (z. B. Stresserfahrungen, „event sampling"; Ebner-Priemer und Trull 2009; Myin-Germeys et al. 2003), oder – wie in Psychotherapiestudien üblich – im Rahmen von Therapiesitzungen (Lambert et al. 2005; Lutz et al. 2013). Eine dritte Strömung besteht im zunehmenden Interesse an der Funktionsweise komplexer, nichtlinearer Systeme (Gelo und Salvatore 2016; Haken und Schiepek 2006; Strunk und Schiepek 2006). Zahlreiche Autoren gehen davon aus, dass das Zusammenspiel von therapeutischen Wirkfaktoren und therapierelevanten psychologischen Mechanismen nichtlinearer Art ist und damit selbstorganisierende, komplexe und nur begrenzt vorhersehbare Verlaufsmuster produziert (z. B. Schiepek et al. 2017).

Alle 3 Entwicklungslinien lassen es sinnvoll erscheinen, psychotherapeutische Prozesse auf der Höhe des Geschehens zu erfassen und ihre nichtlinearen Eigenschaften erkennbar zu machen, z. B. Ordnungsübergänge, die sich als diskontinuierliche Sprünge im Prozess manifestieren. Klinische Erfahrungen (Schiepek et al. 2013; Stöger-Schmidinger et al. 2016) und empirische Studien (de Jong et al. 2014; Lambert et al. 2005) legen nahe, dass das Feedback über die Prozessmuster der Therapie selbst katalysierende und therapieförderliche Effekte hat.

Im Folgenden wird anhand eines Fallbeispiels aus der stationären Psychotherapie der Frage nachgegangen, ob und inwieweit hochfrequentes Prozess-Monitoring praxistauglich ist, ob ein therapeutischer Nutzen davon zu erwarten ist, oder ob regelmäßige Selbsteinschätzungen nicht sogar negative Selbstwahrnehmungen oder Grübelneigungen verstärken. Zudem sollen die Methodik und die Möglichkeiten der Visualisierung von Musterveränderungen im Therapieprozess exemplarisch illustriert werden.

Fragen aus der Praxis

Komplexe Verlaufsmuster lassen sich erfassen, wenn engmaschige und regelmäßige (äquidistante) Messungen durchgeführt werden. Die Routinepraxis an der Klinik der Autoren hat sich vor Jahren auf tägliche Selbsteinschätzungen der Patienten festgelegt. Es handelt sich dabei nicht um eine technische Notwendigkeit des eingesetzten Monitoring-Systems (Synergetisches Navigationssystem, SNS) – im Gegenteil: das System lässt hinsichtlich der eingesetzten Fragebogen und Messfrequenzen alle Freiheiten –, sondern um eine therapeutische und methodische Entscheidung, um die in Psychotherapien auftretenden selbstorganisierten Musterwechsel rechtzeitig erkennen und therapeutisch nutzen zu können

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(Schiepek et al. 2013). Die Compliance-Raten sind gut bis sehr gut (Schiepek et al. 2016), trotzdem stellt sich die Frage, ob auch stark antriebsgeschwächte depressive Patienten mit dieser Messfrequenz zurechtkommen. Da die Patienten die Möglichkeit haben, ein Kommentarfeld zu nutzen, um ihre Tageseindrücke, Erfahrungen und Gedanken niederzuschreiben (elektronisches Tagebuch), ist nicht auszuschließen, dass depressive Patienten mit starker Grübelneigung (Rumination) durch die damit angeregte Selbstreflexion nicht in eben dieser Neigung verstärkt werden. Rumination gehört zu den essenziellen Merkmalen der Depression (Nolen-Hoeksema 2000), aber auch anderer Störungsbilder.

Wenn es denn zutrifft, dass Therapiefeedback zu katalysierenden und therapieförderlichen Effekten führt, so ist doch offen, wie diese Effekte zustande kommen und ob es Synergieeffekte mit anderen therapeutischen Angeboten gibt. Theoretische Modelle zur Interaktion von Wirkfaktoren postulieren autokatalytische Effekte von wahrgenommenem Erfolg, positiven und negativen Emotionen sowie nichtlineare Wechselwirkungen zwischen Faktoren wie Veränderungsmotivation, erlebten Fortschritten, Problembelastung oder Einsicht (Schiepek et al. 2017). Allerdings gibt es bislang kaum Praxisberichte über derartige Synergieeffekte.

Schließlich ist von Interesse, welche Frühindikatoren es für diskontinuierliche Sprünge in der Veränderungsdynamik gibt. Beschrieben wurden in der Literatur v. a. kritische Fluktuationen, die sich in einer lokalen, d. h. zeitlich begrenzten Zunahme von dynamischer Komplexität vor Ordnungsübergängen manifestieren (Haken und Schiepek 2010; Heinzel et al. 2014; Schiepek und Strunk 2010). Auch die lokale Zunahme der Synchronisation der beteiligten Prozesse und Subsysteme kann ein solcher Frühindikator sein (Haken und Schiepek 2010; Scheffer et al. 2009). In diesem Beitrag soll eine aufschlussreiche Kasuistik einen Beitrag zur Beantwortung dieser Fragen liefern. Die Kasuistik reiht sich ein in andere Falldarstellungen, die unter Nutzung von engmaschig erfassten Zeitreihendaten publiziert wurden (z. B. Kratzer et al. im Druck; Kronberger und Aichhorn 2015; Sammet et al. 2015; Schiepek et al. 2013; Stöger-Schmidinger et al. 2016). Generell trägt ein Prozess-Monitoring mit implementierten Verfahren der Zeitreihenanalyse und der damit möglichen Kombination von quantitativen und qualitativen Beschreibungen zu einer Förderung der Forschungstradition von Kasuistiken bei.

Einige Fachbegriffe

Nichtlineare Systeme. Die Elemente dieser Systeme interagieren in nichtlinearer Weise, was bedeutet, dass in den Feedbackschleifen exponentielle oder multiplikative Zusammenhänge wirksam sind. Neben dieser Nichtlinearität erfordern komplexe Dynamiken (z. B. Chaos) auch gemischtes, also aktivierendes (positives) *und* inhibierendes (negatives) Feedback.

Chaotische Dynamik. Irregulär aussehende Dynamik, die unter bestimmten Aktivierungsbedingungen von einem nichtlinearen System erzeugt wird. Kleine Veränderungen in den Ausgangsbedingungen oder im aktuellen Systemzustand können zu deutlich veränderten Verläufen führen, was eine mittel- und langfristige Vorhersage unmöglich macht. Trotz ihres scheinbar irregulären Verhaltens realisieren chaotische Dynamiken verschiedene Arten komplexer Ordnung.

Ordnungsübergang. Spontaner Musterwechsel im Systemverhalten, der von inneren und äußeren Bedingungen abhängen kann. Ordnungsübergänge sind also nicht notwendigerweise die Folge eines Inputs (z. B. einer Intervention) und können sich in veränderten Rhythmen, Varianzen, Synchronisationsmustern oder auch im Niveau (Mittelwert) einer Dynamik manifestieren.

Kritische Fluktuation. Schwankungen im Systemverhalten, die meist vor einem Ordnungsübergang auftreten.

Dynamische Komplexität. Kennwert für irreguläres Systemverhalten. Dieser kombiniert die Höhe der Schwankungen einer Zeitreihe (Amplitude), die Frequenz (Häufigkeit der Richtungsänderung) und die Verteilung der Werte im Skalenbereich (Range) zu einem Kennwert (zur Berechnung: Schiepek und Strunk 2010).

Prozesserfassung und Prozessfeedback

Das SNS wurde an der Klinik der Autoren vor 11 Jahren eingeführt. Es handelt sich um ein internetbasiertes generisches System, das die Nutzung unterschiedlicher Fragebögen zu Zwecken von Evaluation und Prozessabbildung ermöglicht. Hierbei sind die Taktfrequenzen der Dateneingabe frei wählbar (z. B. täglich, wöchentlich, prä-post, zu unregelmäßigen Zeitpunkten wie bei Therapiesitzungen oder eventbasierten Eingaben). Der hier wie bei allen anderen Patienten verwendete Fragebogen ist der revidierte Therapie-Prozessbogen (TPB-R, 47 Items, täglich zu beantworten auf visuellen Analogskalen), wie er vom Team der Autoren auf Grundlage der ursprünglichen Fassung des TPB (Haken und Schiepek 2010) entwickelt wurde. Der Fragebogen orientiert sich an folgenden 8 Faktoren: I Therapeutische Fortschritte/Zuversicht/Selbstwirksamkeit, II Atmosphäre an der Klinik/Beziehung zu Mitpatienten, III Beziehung und Vertrauen zu den Therapeuten, IV Emotionen, V Perspektivenerweiterung/Systemverständnis, VI Veränderungsmotivation, VII Beschwerden und Problembelastung, VIII Selbstfürsorge und Körpererleben. Eine neue explorative und konfirmatorische Faktorenanalyse des TPB-R liegt vor (Publikation in Vorb.). Neben dem TPB-R werden auch verschiedene Outcome-Fragebogen in größeren zeitlichen Abständen (z. B. wöchentlich) verwendet.

Neben dem TPB-R können – natürlich unter Berücksichtigung der Lizenzrechte – beliebige andere Fragebogen benutzt werden, z. B. die deutsche Fassung des Outcome-Questionnaire 45.2 (OQ; Evaluations-Bogen 45, EB-45; Lambert et al. 2002), der Individual Therapy Process Questionnaire (ITPQ; Mander et al. 2015) oder das therapeutische Faktoreninventar für Gruppen (TFI-S; Mander et al. 2016). Der TPB-R wurde speziell für tägliche Selbsteinschätzungen in der Klinik oder im persönlichen Lebensumfeld der Patienten entwickelt, wobei ein breites Spektrum an Themen (z. B. Emotionen und Körpererleben) und Faktoren aus einer vorwiegend ressourcen- und entwicklungsorientierten Perspektive abgefragt werden. Andere Fragebögen wie der ITPQ thematisieren entweder die jeweilige Therapiesitzung oder sind – wie der OQ – eher defizitorientiert, was diesen für einen hochfrequenten Einsatz problematisch macht.

Prozesseinschätzungen werden im SNS zunächst als Zeitreihen dargestellt (**Abb. 1**). Zusätzlich zur Darstellung in Zeitreihendiagrammen können die Werte einer Zeitreihe einfach in Farben übertragen werden. In den *Rohdaten-Resonanz-Diagrammen* des SNS wird jede Zeitreihe (eine pro Item eines Prozessfragebogens in einer Zeile) in Farbausprägungen dargestellt, wobei blau minimale und rot maximale Ausprägung bedeutet (s. Abschn. „Musterwechsel", **Abb. 2**).

Im SNS sind weitere Analyseverfahren implementiert: Die Stabilität oder Instabilität der Prozesse am Rande von Ordnungsübergängen lässt sich durch die dynamische Komplexität der Zeitreihen in einem Gleitfenster (Fensterbreite: 7 Messpunkte) erfassen. Die *dynamische Komplexität* verbindet Amplitude, Frequenz und die Werteverteilung über die verfügbare Skala einer Messreihe (Haken und Schiepek 2006; Schiepek und Strunk 2010). Man kann für jedes Item eines Prozessfragebogens den Zeitverlauf der dynamischen Komplexität entweder in Regenbogenfarben (Kalibrierung über alle Zeitreihen) oder in Graustufen (Intra-Item-Kalibrierung) in ein Diagramm übertragen (eine Zeile pro Item, sog. *Komplexität-Resonanz-Diagramme*). Vertikale Strukturen erhöhter Komplexität weisen auf Destabilisierungen im Prozess hin, wie sie im zeitlichen Umfeld von Ordnungsübergängen stattfinden (s. Abschn. „Musterwechsel", **Abb. 3**).

Eine weitere Möglichkeit, dynamische Muster und deren Veränderung zu erfassen, besteht darin, die Synchronisation zwischen einzelnen Erfahrungs- und Erlebnisaspekten eines Patienten, d. h. zwischen den Items eines Prozessfragebogens zu betrachten. Hierfür berechnet man die Korrelationen zwischen den

Zusammenfassung · Abstract

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Prozessfeedback in der Psychotherapie. Methodik, Visualisierung und Fallbeispiel

Zusammenfassung

Therapiefeedback auf Grundlage eines hochfrequenten Prozess-Monitorings findet in der Psychotherapie zunehmend Anwendung und Interesse. Damit eröffnen sich Möglichkeiten, nichtlineare Prozesse und diskontinuierliche Musterwechsel zu erfassen. Methodisch stellt sich die Frage, wie solche Musterwechsel (Ordnungsübergänge) auf der Grundlage von Prozessdaten dargestellt werden können, und ob es hierfür geeignete Frühindikatoren gibt. Praktische Fragen beziehen sich auf die Eignung von Therapiefeedback bei antriebsgeminderten depressiven Patienten und auf die Erkennbarkeit von Ordnungsübergängen im Einzelfall. Die Prozesserfassung erfolgt in der vorgestellten Kasuistik eines depressiven Patienten mit dem Synergetischen Navigationssystem (SNS), ein internetbasiertes System zur kontinuierlichen Datenerfassung mit implementierten Methoden der nichtlinearen Zeitreihenanalyse und Möglichkeiten der Visualisierung der Ergebnisse. Die Falldarstellung illustriert mehrere Möglichkeiten, Ordnungsübergänge und deren Frühindikatoren in der Psychotherapie zu visualisieren und verdeutlicht, dass ein hochfrequentes Therapie-Monitoring auch bei Zuständen von Antriebsminderung und Grübelneigung sinnvoll einsetzbar ist. Deutlich wird auch, dass regelmäßige Selbsteinschätzungen und feedbackbasierte Reflexionsgespräche zusammen mit anderen therapeutischen Angeboten zu Synergieeffekten führen können.

Schlüsselwörter

Monitoring · Psychotherapie-Feedback · Ordnungsübergang · Depression · Rumination

Process feedback in psychotherapy. Methods, visualization and case example

Abstract

Therapy feedback based on high-frequency process monitoring is applied by an increasing number of practitioners. The technology allows the assessment of nonlinear dynamics and discontinuous pattern transitions. The methodological question is on the data-based representation of such transitions and its precursors in the change dynamics of each single case. Practical questions concern the feasibility and usefulness of high-frequency monitoring in depressed and ruminating patients. In this case study we used the synergetic navigation system (SNS) which is an internet-based device for data collection (e. g. daily self-ratings by a process questionnaire) with implemented methods of nonlinear time series analysis and the visualization of the results. This case study illustrates different methods for the visualization of pattern transitions and its precursors in a psychotherapeutic process. It demonstrates the usefulness of therapy feedback in a case of depression with reduced activity level and rumination. Therapy feedback based on daily self-assessment combined with other therapeutic activities co-creates the emergence of an order transition and effective outcome.

Keywords

Monitoring · Psychotherapy feedback · Order transitions · Depression · Rumination

Zeitreihen in einem Gleitfenster. Wenn man die Korrelationsstärken wiederum in Farben überträgt (von $r = -1$ in Rotabstufungen zu $r = 0$ [weiß] zu Grünabstufungen bis $r = +1$) und die Korrelationen zwischen allen Items in einer Matrix darstellt, lassen sich die sich verändernden Synchronisationsmuster als Farbmusterwechsel wie in einem Film visualisieren. In gedruckten Bildern sind allerdings nur einzelne Schnappschüsse der Dynamik von Synchronisationsmustern darstellbar (s. Abschn. „Musterwechsel", **Abb. 4**).

Die Veränderung dynamischer Muster zeigt sich in „recurrence plots", die die Ähnlichkeit oder Unähnlichkeit von Prozessmustern in kurzen Zeitabschnitten eines längeren Prozesses vergleichen und in Farbe darstellen. Rot bis orange bedeutet unähnlich; türkis bis blau bedeutet ähnlich. Recurrence plots sind

Zeit · Zeit-Diagramme, was heißt, dass eher blaue Felder als dynamisch homogene Abschnitte in einem Prozess interpretierbar sind, während gelb-orange-rote Muster auf Inhomogenität und sog. Transienten (dynamische Übergangsszenarien) hinweisen. Parallelen zur Diagonalen (Diagonalschraffuren) verweisen auf eine bestimmte Rhythmik im Prozess. Mit solchen Recurrence plots lassen sich Ordnungsübergänge (Musterwechsel) sehr schön visualisieren (s. Abschn. „Musterwechsel", ◘ **Abb. 5**).

Die visualisierten Therapieprozesse werden auch mit Bezug auf die Tagebucheintragungen mit dem Patienten in regelmäßigen Abständen besprochen, wobei dies in den Einzeltherapiesitzungen geschieht.

Das folgende Fallbeispiel illustriert die Möglichkeit, die im SNS verfügbaren Methoden der Prozessanalyse und Visualisierung gewinnbringend einzusetzen. In diesem und in vielen anderen Fällen ist erkennbar, dass die quantitativen Zeitreihendaten und deren Analyse, die Tagebucheintragungen und auch der klinische Eindruck gut zueinander passen und sich in ihrem Informationswert ergänzen. Dies ist sinnvoll und notwendig, da diese Informationen in regelmäßigen SNS-basierten Therapiegesprächen zur Prozessreflexion und -steuerung genutzt werden. Der hier beschriebene Fall weist nicht nur ein interessantes Verlaufsmuster auf, sondern macht auch deutlich, wie das SNS als autokatalytisches Feedbacksystem selbst therapeutisch wirksam wird.

Fallbeispiel

Vorgeschichte

Bei dem hier vorgestellten Patienten (Herrn A.) handelt es sich um einen jungen Mann, der in einem ausgeprägt depressiven Zustand und mit Suizidneigung in die Tagesklinik kommt (ICD-10[1]-Diagnose: F33.1 rezidivierende depressive Störung). Seine subjektive Befindlichkeit ist durch innere Leere, Antriebslosigkeit und ausgeprägtes Grübeln geprägt, weiterhin durch eine hohe Bereitschaft zur Anpassung, Schuldgefühle sowie Trennungs- und Verlustängste. Seit mehr als 6 Jahren nimmt er psychotherapeutische Unterstützung in Anspruch, allerdings ohne eine substanzielle Veränderung in seinem Lebensgefühl und seiner Befindlichkeit zu erreichen. Gelernt hat er eine sehr differenzierte Selbstwahrnehmung und Kompetenzen der Selbstreflexion, die sich mit seiner Grübelneigung kombinieren. Auch selbst beschreibt er sich als „überreflexiv": eine „Denkerei", die ihn erschöpft. Lauf- und Krafttraining sind für ihn eine Möglichkeit, sich zu regulieren und dem ruminierenden Denken, dem depressiven Sog und auch dem Leeregefühl zu entkommen.

[1] Internationale statistische Klassifikation der Krankheiten und verwandter Gesundheitsprobleme. 10. Aufl.

Therapieverlauf

Den TPB-R füllt er täglich aus (80 Messpunkte), über den kompletten tagesklinischen Aufenthalt hinweg. Dabei bedient er sich der Tagebuchfunktion ausführlich und beschreibt seine Befindlichkeit sowie seine therapeutischen Erfahrungen detailliert. Seine Antriebslosigkeit und innere Leere halten ihn also nicht davon ab, das internetbasierte Therapie-Monitoring ohne einen einzigen Fehltag zu nutzen. Tage, an denen er (meist sehr ausführliche) Tagesreflexionen schreibt, sind in den Diagrammen der ◘ **Abb. 1** durch kleine blaue Punkte markiert.

Herr A. zeigt sich sehr motiviert, verlässlich, zuvorkommend, immer lächelnd, als müsste er sich der Zuneigung der Therapeuten versichern. Er engagiert sich in allen Therapieangeboten der Tagesklinik, und schnell kommen im Rahmen der Einzelpsychotherapie auch seine relevanten Lebensthemen zur Sprache. Die Achtsamkeitsgruppe sowie die Lektüre eines Buches zum Thema Achtsamkeit eröffnen ihm Möglichkeiten eines nichtentwertenden Umgangs mit sich selbst. Gleichzeitig gewinnt man den Eindruck, er wolle achtsam mit seiner Depression umgehen und sie sich wie ein kostbares Gut bewahren. Die ihm vertraute und kompetent nutzbare Strategie der Selbstreflexion hat offenbar eine Doppelfunktion: stabilisierendes Grübeln, aber auch öffnende, sogar katalysierende Perspektivenerweiterung. Selbstreflexion ist eine für ihn gangbare Strategie, zunehmend mehr therapeutische Erfahrungen und Impulse aufzugreifen und weiter zu prozessieren.

Allerdings ist es ein behutsames Annähern. Deutliche therapeutische Fortschritte gibt es nicht, ähnlich wie in den langen Jahren von ambulanter Therapie. Es scheint sich hier seine Erfahrung therapeutischer Unproduktivität zu wiederholen. Trotzdem: Auch wenn es keine umfassenden und konkreten Fortschritte gibt, spürt er, dass innerlich ein Prozess in Gang kommt: „Im Großen und Ganzen habe ich das Gefühl, dass einige Dinge in mir arbeiten, und ich hoffe, dass ich die richtigen Türen offenhalten kann, um nachhaltig etwas in meinem Erleben zu verändern." (Dieses und folgende Zitate entstammen seinen Tageskommentaren im SNS.)

Auf dem Weg zum Ordnungsübergang

Der therapeutische Prozess intensiviert sich im Laufe eines langen Erwärmungsprozesses, bis es etwa 2 Wochen vor Therapieende zu einem entscheidenden Wendepunkt (Ordnungsübergang) kommt. Rückblickend benennt Herr A. folgende Erfahrungen, die zusammen das Wirkgefüge für diesen Wendepunkt ausmachen:

Ein SNS-basiertes Feedbackgespräch zu seinem bisherigen Therapieverlauf habe ihm seine Indifferenz verdeutlicht und aufschrecken lassen. Bei vielen Themen, so auch der Beziehung zu Therapeuten und Mitpatienten, die über den gesamten Prozess hinweg sehr synchron verlaufen (◘ **Abb. 1b**), habe er sich nie klar entschieden; seine Einschätzungen pendelten oft um die Mittellinie. In der Einzeltherapie war über eine Symbolarbeit auf der Tischbühne (innere Anteile werden mithilfe von Symbolen externalisiert und in Beziehung zueinander gestellt) seine „Wertlosigkeit" aufgetaucht. In früheren Therapien habe er auch schon darüber gesprochen, aber durch die Symbolarbeit könne er die Wertlosigkeit erstmals emotional spüren, und es sei ihm auch der entsprechende Veränderungswunsch deutlich geworden.

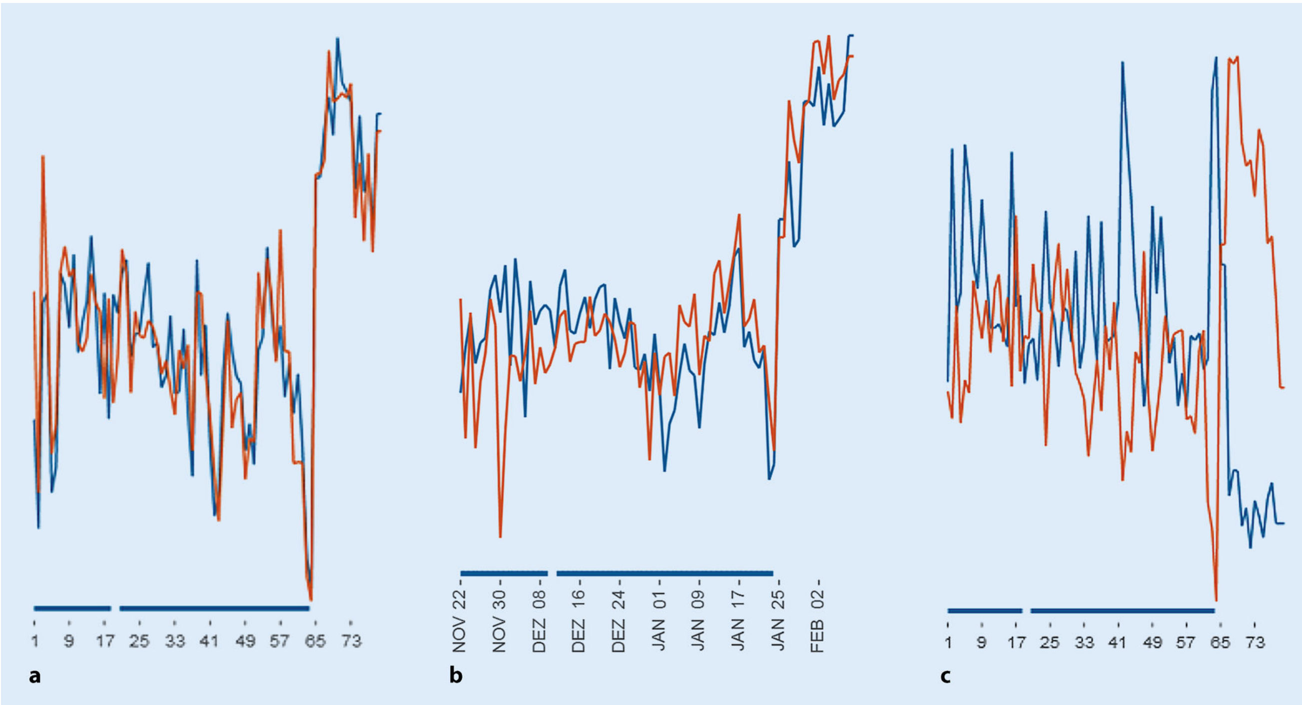

Abb. 1 ▲ Zeitreihen des Therapieprozesses. **a** Faktor I „therapeutische Fortschritte" (*blau*) und VI „Veränderungsmotivation" (*rot*), **b** III „Beziehung und Vertrauen zu den Therapeuten" (*blau*) und II „Beziehung zu den Mitpatienten" (*rot*), **c** VII „Beschwerden und Problembelastung" (*blau*) und VIII „Selbstfürsorge/Körpererleben" (*rot*). *x-Achsen* in (**a**) und (**c**): Messzeitpunkte (1–80). Jeder 8. Messpunkt (Tag) ist mit einer Zahl beschriftet: 1, 9, 17 usw. (**b**): Datum, vertikale Linien: Wochenenden. *y-Achsen*: z-transformierte Darstellung der Faktorenausprägung. Im Synergetischen Navigationssystem ist es möglich, die Beschriftung der x-Achse von einer fortlaufenden Nummerierung der Messpunkte (wie in **a** und **c**) zu einer Angabe des Datums mit eingezeichneten Wochenenden per Klick zu ändern

Nun kommt auf mehreren Ebenen und in mehreren therapeutischen Kontexten gleichzeitig ein sich selbst verstärkender Prozess in Gang: In der Psychodramagruppe bleibt er nicht mehr im Vagen, Unbestimmten – was ihm bisher trotz äußerlich aktiver Teilnahme gelungen war –, sondern lässt sich ein und übernimmt beim Wut-Thema einer Mitpatientin eine ihn berührende Rolle: „sehr wertvoll für mich". In der Bewegungstherapie wird ihm bewusst, wie er körperlich reagiert („Gefühl, nicht genug Luft zu bekommen – nein, nicht genug abzuatmen"). In der Einzeltherapie kommt er auf die Symbolarbeit der letzten Stunde zurück, in der er sich mit dem Gefühl der Wertlosigkeit konfrontierte – jetzt taucht eine dazu passende biografische Szene auf, die ihn sehr berührt. In der Psychosomatikgruppe sollten die Teilnehmer für sich einen positiven Satz formulieren, was ihm nicht gelingt. Erst unter großem Drängen der anderen sagt er spontan in die Gruppe hinein: „Ich bin einzigartig!" Lachen in der Gruppe, er fühlt sich missverstanden, ist gekränkt und verärgert, schließlich habe er es ja so gemeint, dass jeder Mensch einzigartig sei, somit nichts Besonderes. In der Einzeltherapie (Monodrama) greift er im Anschluss das Thema auf: seinen Ärger über die Gruppe, aber auch die Wertlosigkeit von vor einer Woche – vielleicht ist er ja doch einzigartig? Und in der Achtsamkeitsgruppe (dieselbe Zusammensetzung wie die Psychosomatikgruppe) bringt er sehr direkt seinen Ärger vom letzten Mal ein. Es gibt eine positive Resonanz, und er fühlt sich bestärkt.

Musterwechsel

All diese Erfahrungen liegen wenige Tage vor einer substanziellen Veränderung in der Therapie. Auch in den Tagesnotizen im SNS kommt es zu einer Veränderung der Beschreibung seiner Gefühlslage. Es tauchen erstmals Bilder auf, die intensiv und bewegt, nicht mehr nur „gedacht" sind: „Zurzeit fallen mir immer wieder Bilder ein für Gefühle bzw. Gefühlslagen oder für mein allgemeines Befinden bzw. wie es sich im Verhältnis zu einer gewissen Sache darstellt. Und irgendwie so aus heiterem Himmel, ohne dass ich lang danach suchen muss, es ‚passiert' – in etwa so, ich werde mir einer Gefühlswahrnehmung bewusst, und kurz darauf ist dann auch das Bild da, mit dem ich diese Wahrnehmung ausdrücken kann."

Danach beschließt er, die Selbstreflexion in den Tagesnotizen (*blaue Punkte* am unteren Rand der Diagramme in ◘ **Abb. 1**) zu beenden: „Als ob ich den Faden verloren hätte … irgendwie ist grad die Luft bei mir raus … hab keinen Nerv, das hier jetzt zu erzählen bzw. zu beschreiben" (◘ **Abb. 1**). Es kommt zu einer Krise in seiner Befindlichkeit mit deutlich belastenden Emotionen und einem erlebten Rückfall, aus dem er sich schnell erholt und sprunghaft in ein anderes, erheblich selbstbewussteres, aktiveres und nicht mehr grübelndes Gesamtmuster findet. Dies betrifft mehr oder weniger sämtliche im TPB-R angesprochenen Erfahrungsbereiche. In den

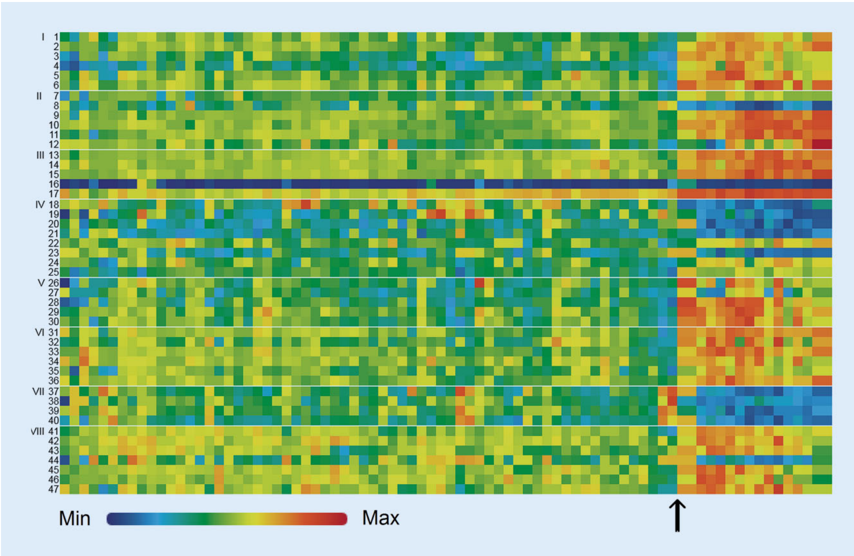

Abb. 2 ▲ Rohwerte-Resonanz-Diagramm mit Farbkodierung der Messwerte. Die Werte der einzelnen Items (Itemnummerierung in arabischen Ziffern) des revidierten Therapie-Prozessbogens, die hier in Zeilen übereinanderliegen, werden in eine Regenbogenfarbskala übertragen. *Pfeil* Ordnungsübergang. (Erklärung der Faktoren *I–VIII* s. Abschn. „Prozesserfassung und Prozessfeedback")

Zeitreihen ist ein sehr synchroner Verlauf der Faktoren I (Therapiefortschritte) und VI (Veränderungsmotivation) zu erkennen (◘ **Abb. 1a**), und ein antisynchroner Verlauf der Faktoren VII „Beschwerden und Problembelastung" und VIII „Selbstfürsorge/Körpererleben", d. h., an Tagen, an dem es ihm gelingt, auf sich, seine Bedürfnisse und Körpersignale zu „hören", erlebt er weniger Beschwerden und depressive Symptome – und umgekehrt (◘ **Abb. 1c**). Das Erleben der interpersonellen Beziehungen – sowohl zu Therapeuten als auch zu Mitpatienten – vollzieht diese Dynamik mit (◘ **Abb. 1b**). Im farbigen Rohwerte-Resonanz-Diagramm (◘ **Abb. 2**) ist erkennbar, dass sich die Werte in fast allen „positiven" und fortschrittsbezogenen Items sprunghaft erhöhen (*orange und rote Farbtöne*), „negative" und belastende Items dagegen reduzieren (*blaue Farbtöne*).

Klinisch ist der Übergang durch eine deutliche Verbesserung seiner Stimmungslage und die Entwicklung einer positiveren, zuversichtlichen Einschätzung seiner beruflichen Zukunft geprägt. Er fühlt sich wacher und energiereicher, seine dauernde belastende Müdigkeit verschwindet, ebenso das intensive Grübeln und Nachdenken über seine psychische Verfasstheit. Trauer, Schuld und Schamgefühle reduzieren sich nicht nur in seinen SNS-Einschätzungen, sondern auch in seiner Alltagsbefindlichkeit; sein Selbstwertgefühl steigt. Im sozialen Umgang schließlich wirkt er deutlich kontaktfreudiger und spontaner.

Der Übergang ist in diesem Fall nicht, wie sonst sehr häufig, durch eine starke kritische Instabilität geprägt, die sich in einer lokalen Zunahme der dynamischen Komplexität manifestieren würde, sondern durch einen kurzfristigen Rückfall („transient relapse"). Im Farb-Komplexität-Resonanz-Diagramm (hier nicht gezeigt) sind daher an dieser Stelle keine ausgeprägten Komplexitätsspitzen erkennbar. Jedoch zeigt die sensitivere, da am Komplexitätsverlauf *innerhalb* eines Items kalibrierte Komplexität-Resonanz-Darstellung eine synchrone Zunahme der Komplexität fast aller Items im Bereich des transienten Rückfalls (◘ **Abb. 3**). Hierbei wirkt sich nicht die zunehmende Fluktuation der Zeitreihen, sondern die hohe Amplitude der Schwankung aus. Die Graustufen des Diagramms markieren von schwarz bis hellgrau die 10 höchsten Komplexitätswerte innerhalb eines Items.

Interessant ist auch, dass während dieses Übergangsszenarios die dynamische Synchronisation aller Items des TPB-R zunimmt. Der Verlauf der mittleren absoluten (d. h. ohne Berücksichtigung des Vorzeichens berechneten) Inter-Item-Korrelation weist in dieser Periode ein Maximum auf (Haken und Schiepek 2010; Scheffer et al. 2009; Stöger-Schmidinger et al. 2016). Die Matrizen der Inter-Item-Korrelation (berechnet in einem Siebentagegleitfenster) sind vor (◘ **Abb. 4b**) und nach (◘ **Abb. 4d**) dem Ordnungsübergang blasser, d. h., sie weisen geringere Korrelationsausprägungen auf und zeigen zudem ein unschärferes Muster als die Korrelationsmatrix während (◘ **Abb. 4c**) des Ordnungsübergangs.

In den meisten Farb-Recurrence-Plots der Items und Faktoren (◘ **Abb. 5** ist der Recurrence Plot von Faktor I gezeigt) sieht man den transienten Rückfall als ausgeprägte Transiente (*orange-rot* markiert) zwischen den beiden vergleichsweise stabilen Phasen des Therapieverlaufs (*blau* eingefärbte Blöcke). Die Rhythmen in der langen stabilen Phase des Prozesses manifestieren sich an den Schraffuren parallel zur Diagonale.

Auch in der Symptombelastung zeigt sich der Ordnungsübergang, nicht nur im Faktor „Symptombelastung" des TPB-R, sondern auch in der wöchentlich ausgefüllten Depressions-Angst-Stress-Skala (DASS-21; Lovibond und Lovibond 1995). In den 11 Wochen vor dem Ordnungsübergang, der hier als „sudden gain" imponiert, betrug der mittlere Depressionsscore 14,7 (SD ± 5,2), das Angstniveau 5,5 (SD ± 3,0) und das Stressniveau 12,4 (SD ± 2,5). In der letzten Messung, also nach dem Ordnungsübergang, betrug der Depressionsscore 2, der Angstscore ebenfalls 2 und der Stressscore 6.

Diskussion

Therapiefeedback bei depressiven Patienten und Erkennbarkeit von Ordnungsübergängen

Das Fallbespiel macht deutlich, dass auch depressive Patienten von einem hochfrequenten Therapiefeedback profitieren können. Diese Einschätzung beruht nicht allein auf dem hier dargestellten Einzelfall, sondern auf langjähriger Erfahrung mit feedbackgestützten Therapien depressiver Patienten. Entscheidend ist,

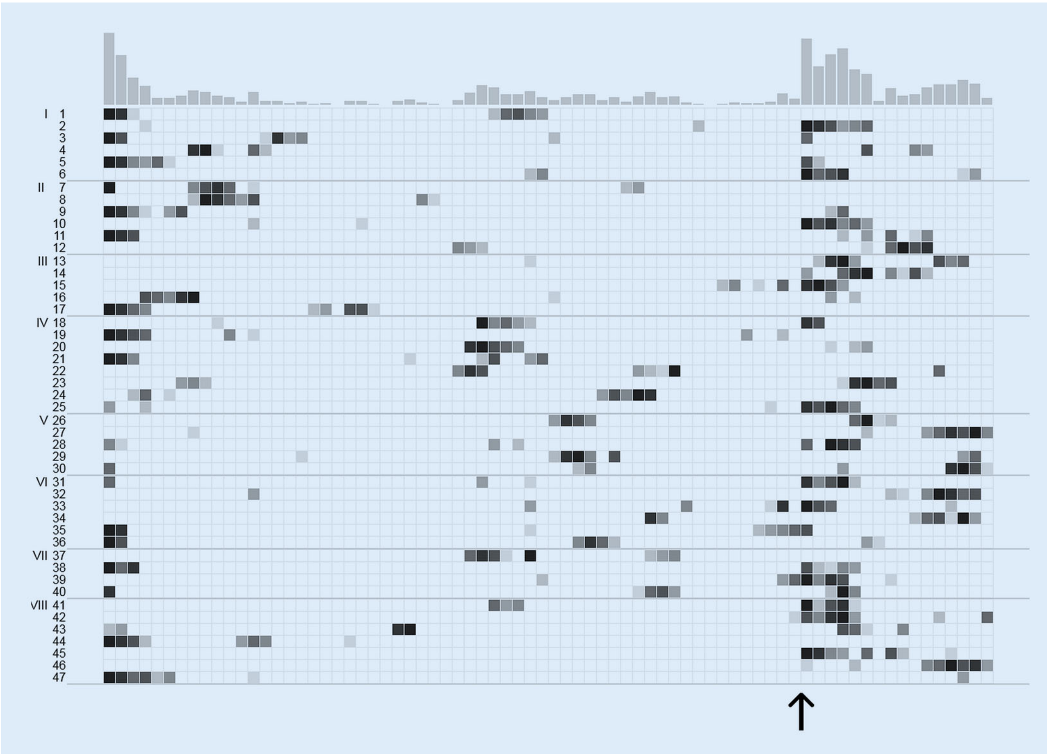

Abb. 3 ◀ Komplexität-Resonanz-Diagramm mit Übertragung der 10 höchsten Komplexitätswerte pro Item (*Zeile*) in Graustufen. *Pfeil* Ordnungsübergang. (Erklärung der Faktoren *I–VIII* s. Abschn. „Prozesserfassung und Prozessfeedback")

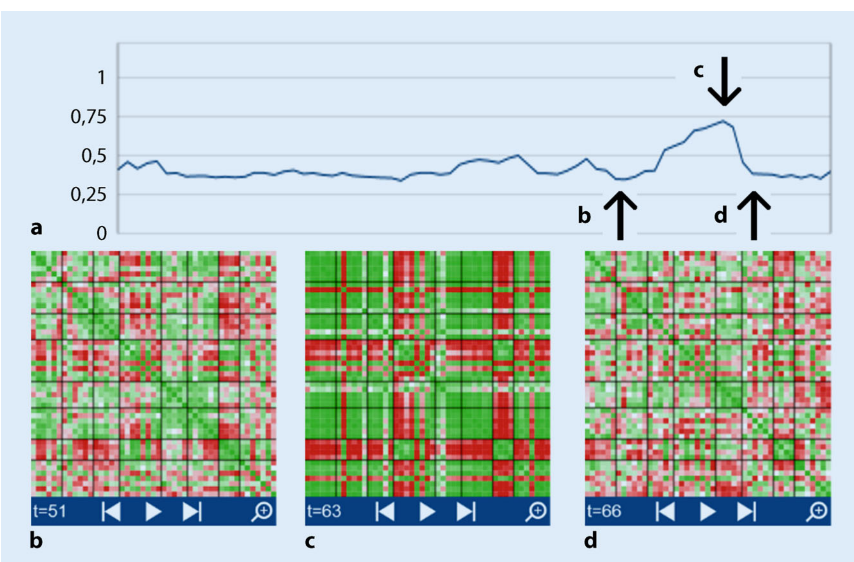

Abb. 4 ▲ Verlauf der mittleren absoluten Inter-Item-Korrelation (**a**). Darunter die Inter-Item-Korrelationsmatrizen vor (**b**), während (**c**) und nach (**d**) dem Ordnungsübergang

dass der visualisierte Prozess regelmäßig in SNS-gestützten Therapiegesprächen reflektiert wird (Anleitungen zu solchen Gesprächen: z. B. Schiepek et al. 2015). Auch in späten Phasen einer Therapie können noch Ordnungsübergänge auftreten, die sich im Hinblick auf den Therapieeffekt als „sudden gains" manifestieren. Solche Ordnungsübergänge sind in den seltensten Fällen (so auch hier nicht) eine direkte Reaktion auf eine spezifische Intervention (Fallbeispiele: Haken und Schiepek 2010; Kronberger und Aichhorn 2015; Sammet et al. 2015; Schiepek et al. 2015; Stöger-Schmidinger et al. 2016), sondern das Resultat eines Selbstorganisationsprozesses.

Der markante Ordnungsübergang dieser Therapie wird durch einen kurzfristigen Rückfall mit intensiven belastenden Emotionen, kollabierender Veränderungsmotivation und verstärkter Problembelastung eingeleitet. Frühwarnindikatoren („precursors") sind (a) eine synchronisierte dynamische Komplexität (Intra-Item-Kalibrierung der signifikanten Komplexität) vieler Aspekte des persönlichen Erlebens, d. h. vieler Items des Prozessfragebogens, (b) die lokale Zunahme der Inter-Item-Korrelation als Indikator verstärkter Synchronisation der Items des Prozessfragebogens, (c) eine kurze, in den Recurrence plots orange bis rot eingefärbte transiente Periode, und schließlich (d) die in vielen Items und insbesondere in den Faktoren erkennbare Rückfallphase, die wie ein Anlaufnehmen zu einem Sprung in die Verbesserung wirkt.

Die Selbstreflexionskompetenz des Patienten hat sich in dieser Therapie konstruktiv ausgewirkt. Sie erwies sich als Ressource, die ihm geholfen hat, neue Erfahrungen zu fokussieren und Therapieangebote in sein inneres Pro-

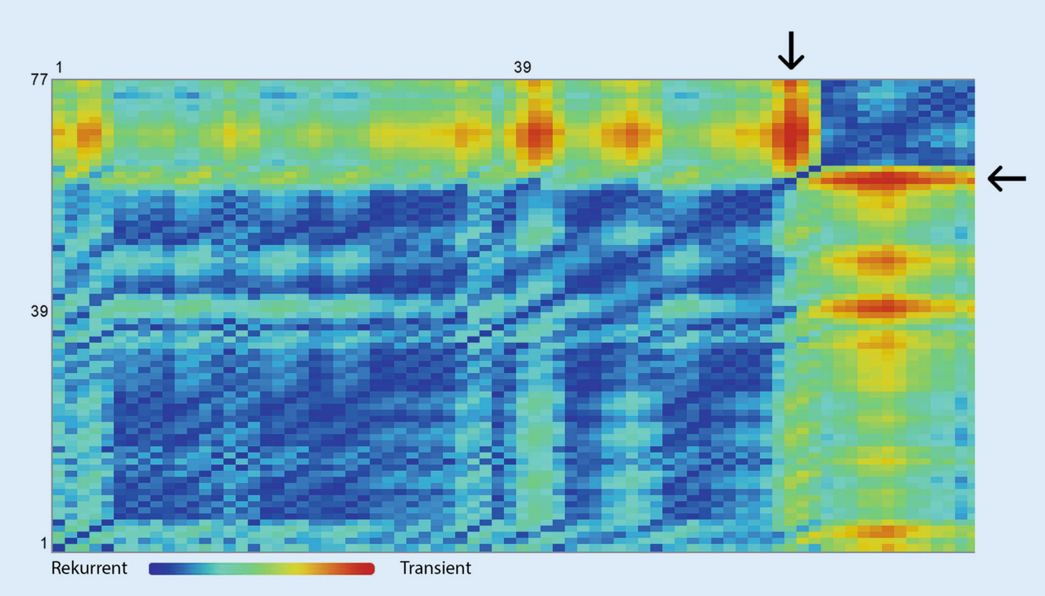

Abb. 5 ◀ Farb-Recurrence-Plot. *Pfeile* transiente Periode zwischen den Ordnungszuständen. Die Ziffern links und am oberen Rand des Diagramms beziehen sich auf Messzeitpunkte (77 aufgrund von 80 Messzeitpunkten minus 3 Einbettungsdimensionen)

zessieren zu integrieren. Freilich hätte man auch auf die Idee kommen können, die Nutzung eines elektronischen Therapietagebuchs als mögliche Verstärkung der „ruminations" zu unterbinden, aber es hat sich in diesem Fall als sinnvoll erwiesen, den TPB-R mit Kommentarfunktion anzubieten. Neben der Einladung zum offenen und frei assoziierenden Schreiben könnte man die Tageskommentare natürlich auch auf Ressourcenaktivierung und Therapiefortschritte fokussieren.

Limitationen

Die Zeitdauer eines neuen Ordnungszustandes am Ende der Therapie war sehr kurz. Über dessen Stabilität und über die Nachhaltigkeit der Verbesserungen nach Ende des tagesklinischen Aufenthalts gibt es keine Informationen. Es wäre sicher sinnvoll gewesen und kann nur empfohlen werden, das Therapie-Monitoring über einen Nachsorgezeitraum hinweg weiterzuführen. Erstens kann es nach Entlassung stabilisierende und unterstützende Funktionen übernehmen, und zweitens erweist es sich auch für nachsorgende Therapeuten im ambulanten Setting als wertvolles Instrument: Therapie-Monitoring als roter Faden und Bezugspunkt für die Kommunikation zwischen Klinik und ambulanter Psychotherapie.

Therapiefeedback eignet sich für viele, aber nicht für alle Patienten. Über hohe Compliance-Raten wurde berichtet, weitgehend unabhängig von Symptombelastung und Diagnosen (Schiepek et al. 2016). Trotzdem kommt es vor, dass einzelne Patienten überfordert sind, v. a. wenn einzelne Items starke emotionale Reaktionen auslösen oder sich Patienten von standardisierten Items nicht angesprochen fühlen. Die höchste Motivation zeigt sich bei Benutzung individualisierter Prozessfragebögen. Solche individualisierten Fragebögen werden zusammen mit dem Patienten in einer intensiven Fallkonzeption mit idiographischer Systemmodellierung entwickelt. Für ambulante Psychotherapie macht es Sinn, eine kürzere Version des TPB-R zu benutzen, an der gerade gearbeitet wird. Auch im ambulanten Setting erweisen sich individualisierte Fragebögen als therapeutisch am nützlichsten. Unser Patient hat wohl recht: Menschen sind einzigartig. Ein limitierender Faktor aufseiten der Therapeuten ist bekanntlich die Zeit, da aber Feedbackgespräche Teil der Einzeltherapie sind, kommt kein weiterer Zeitaufwand auf die Therapeuten zu.

Perspektiven

Die Funktionen des SNS gehen über die hier angesprochenen Tools hinaus. Beispielsweise steht ein Fragebogen-Editor zu Verfügung, mit dem bestehende oder individuelle Fragebögen in das System eingegeben werden können, ebenso ein Ampel-Editor, mit dem sich spezielle Kennwerte für die Entwicklung eines Patienten aus einzelnen Items konfigurieren lassen (z. B. zur Suizidgefährdung). Auch eine SNS-App zur „Off-line"-Datenerfassung und mit weiteren Funktionen liegt inzwischen vor. In einem speziellen Analyse-Tool lassen sich Patienten nach bestimmten Merkmalen zusammenfassen, um Therapieeffekte und Effektstärken im Sinne einer Gruppenstatistik zu berechnen.

Fazit für die Praxis

- **Hochfrequentes Prozess-Monitoring ist auch mit depressiven Patienten möglich.**
- **Es gibt im Einzelfall erkennbare Frühindikatoren für therapeutische Ordnungsübergänge.**
- **Regelmäßige Feedbackgespräche auf der Basis von Prozessdaten und deren Analysen sind sinnvoll und notwendig.**
- **Therapiefeedback (Tagesreflexion mithilfe von Skalen und elektronischen Tagebüchern sowie regelmäßige Feedbackgespräche) kann mit anderen Therapieangeboten in nützlicher und sich wechselseitig katalysierender Weise interagieren.**

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Einhaltung ethischer Richtlinien

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Die Mathematik der Psychotherapie

Lassen sich psychotherapeutische Prozesse im Computermodell simulieren?

In der Psychotherapie der Zukunft lassen sich, mithilfe von Simulationen der Netzwerkdynamik psychischer Störungen, therapeutische Prozeduren ableiten und im Modell prüfen.

GÜNTER SCHIEPEK, HELMUT SCHÖLLER, KATHRIN VIOL, MARC HÜTT, KATHARINA SUNGLER UND HANS MENNING

Seit Jahren wird daran gearbeitet, die Wirkfaktoren der Psychotherapie zu identifizieren, und seit neuerer Zeit hat ein engmaschiges, Internet-basiertes Prozessmonitoring in die psychotherapeutische Routinepraxis Einzug gefunden. Beides zusammen erfordert eine Modellbildung, welche die (nichtlinearen) Wechselwirkungen dieser Wirkfaktoren formalisiert und damit Prozesse (in Form von Zeitreihendaten) erklärt, mit anderen Worten, die Netzwerkdynamik von Psychotherapie simuliert. Damit kommen Verfahren der mathematischen Modellbildung zum Zug. Beispielhaft wird hier über ein solches Projekt berichtet. Darüber hinaus werden einige Kriterien und Zielsetzungen der mathematischen Modellierung in der Psychotherapieforschung diskutiert.

Mathematische Modellierungen sind in der Psychologie selten und ungewöhnlich und in der Psychotherapieforschung noch seltener und ungewöhnlicher. Doch derartige Bemühungen um Formalisierung sind nicht neu. So hat der deutsche Psychologieprofessor Günter Schiepek bereits vor 25 Jahren die 1976 von den Schweizer Psychiatern Luc Ciompi und Christian Müller beschriebenen Verlaufsmuster der Schizophrenie in einem 5-Variablen-Modell simuliert.

In den systemischen Neurowissenschaften sind mathematische Modellierungen unverzichtbar, wie der deutsche Neurophysiologe Wolf Singer 2007 konstatierte: «Offensichtlich hat die Evolution das Gehirn mit Mechanismen zur Selbstorganisation ausgestattet, die in der Lage sind, auch ohne eine zentrale Instanz globale Ordnungszustände herzustellen. (...) Wir werden zur Analyse und Beschreibung dieser Systemzustände mathematisches Rüstzeug und den Einsatz sehr leistungsfähiger Rechner benötigen. Und wir werden das gleiche Problem haben, mit dem die moderne Physik konfrontiert ist. Die Modelle werden unanschaulich sein und vermutlich auch unserer Intuition von der Verfasstheit unserer Gehirne widersprechen.» Simulationen neuronaler Netzwerke sind für innovative Methoden unentbehrlich, beispielsweise im Rahmen einer Therapie bei chronischem Tinnitus, wie der deutsche Neurowissenschaftler Peter Tass zeigen konnte.

Prüfung therapeutischer Prozeduren im Modell

In der Psychotherapie der Zukunft lassen sich therapeutische Prozeduren ableiten und im Modell prüfen. Dies dank Simulationen der Netzwerkdynamik psychischer Störungen. Zum *experimentum in vitro* und *in vivo* käme das *experimentum in silico*, also im Computer simulierte Prozesse, wie es der deutsche Philosoph und Physiker Klaus Mainzer formulierte. Ein Thera-

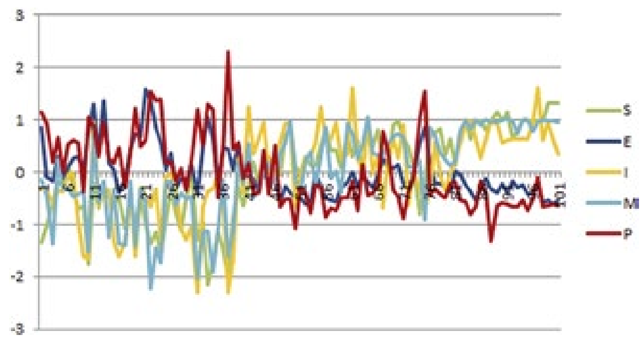

Abbildung 1a

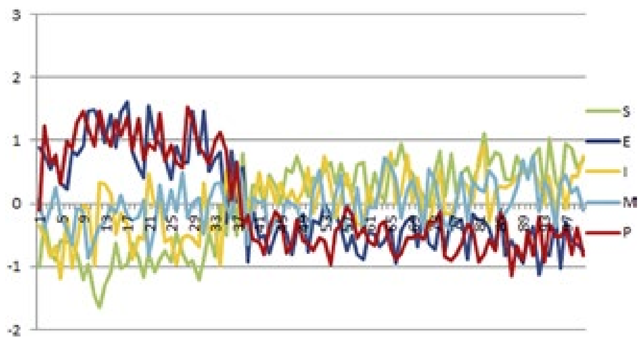

Abbildung 1b

Abbildung 1a: Verlauf eines psychotherapeutischen Prozesses. Die Darstellung beruht auf 100 (täglichen) Messzeitpunkten, erfasst mit Hilfe des Synergetischen Navigationssystems (SNS). Problem- und Symptomausprägung (P), therapeutische Fortschritte, Erfolg (S), Veränderungsmotivation (M), Emotionsintensität (E), und Einsicht bzw. Entwicklung neuer Perspektiven (I).
Abbildung 1b: Simulierter Therapieverlauf. Beide Verläufe zeigen in den ersten 30 Tagen hohe Ausschläge von P und E, danach einen Anstieg von S, I und M (Ordnungs-Ordnungs-Übergang).

peut oder eine Therapeutin würde am Anfang der Therapie die idiosynkratischen Determinanten in Form von Variablen und Parametern der Patientinnen und Patienten eruieren und in eine Software einspeisen. Die Simulation würde möglicherweise ergeben, dass vor allem an der hohen Emotionalität und Impulsivität gearbeitet werden muss und dass «Einsicht» und Perspektivenentwicklung wenig Erfolg versprechen. Vielleicht würde sich sogar zeigen, dass der Appell an Einsicht zu einer Verschlimmerung der Symptomatik führt.

Für die Psychotherapieforschung wäre die computergestützte Modellierung eine Goldgrube: Bisher haben mehrere Psychotherapieforscher die Beiträge der einzelnen Wirkfaktoren zum Therapie-Outcome geschätzt. Die Psychotherapieforscher David Orlinsky und Ken Howard entwickelten in ihrem «Generic Model» ein qualitatives Modell des Zusammenwirkens. Doch eine Formalisierung der nichtlinearen und rekursiven Interaktion der psychotherapeutischen Wirkfaktoren hat noch niemand vorgenommen. Dieser Prozess kann seit einigen Jahren mit Internet-basierten Verfahren wie dem Synergetischen Navigationssystem (SNS) auch engmaschig erfasst und abgebildet werden, wie Günter Schiepek zeigen konnte (siehe Abbildung 1). Das Explanandum der Psychotherapieforschung ist der Prozess.

Nun braucht man nur eins und eins zusammenzuzählen: Netzwerkmodelle der Wirkfaktoren müssen in dynamischer Weise formalisiert werden, beispielsweise in gekoppelten Differenzengleichungen, um Prozesse und dynamische Muster zu erzeugen. Ein Theorieprojekt am Institut für Synergetik und Psychotherapieforschung der Paracelsus Medizinischen Privatuniversität Salzburg bezieht sich auf fünf Variablen beziehungsweise Wirkfaktoren: Problem- und Symptomausprägung (Problems, P), therapeutische Fortschritte (Success, S), Veränderungsmotivation (Motivation, M), Emotionsintensität (Emotions, E), sowie Einsicht beziehungsweise Entwicklung neuer Perspektiven (Insight, I). Genau diese fünf Variablen der Klientinnen und Klienten werden in einem standardisierten Therapieprozessbogen des SNS als Faktoren erfasst. Die Therapierenden sowie Klientinnen und Klienten können nun «live» den Verlauf der Therapie beobachten und haben die Möglichkeit, das Modell zu validieren und die Therapie zu «steuern».

Das Modell (siehe Abbildung 2 auf Seite 30) formuliert Annahmen über die Wirkung der einzelnen Variablen aufeinander, die in nichtlinearen Funktionen beschreibbar sind. Die vier (Kontroll-)Parameter des Modells modulieren die Form der Funktionen und damit die Wechselwirkung zwischen den Variablen. Inhaltlich bedeuten die Parameter: Qualität der Arbeitsbeziehung (a), kognitive Kompetenzen wie Mentalisierungsfähigkeit und Emotionsregulation (c), Ressourcen und Skills (r), sowie Selbstwirksamkeit und Belohnungserwartung (m). Das Modell enthält nun fünf gekoppelte nichtlineare Differenzengleichungen, wobei jede die Veränderung einer Variablen über die

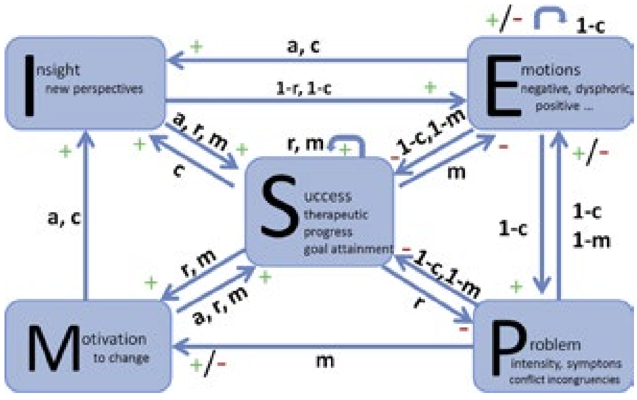

Abbildung 2a

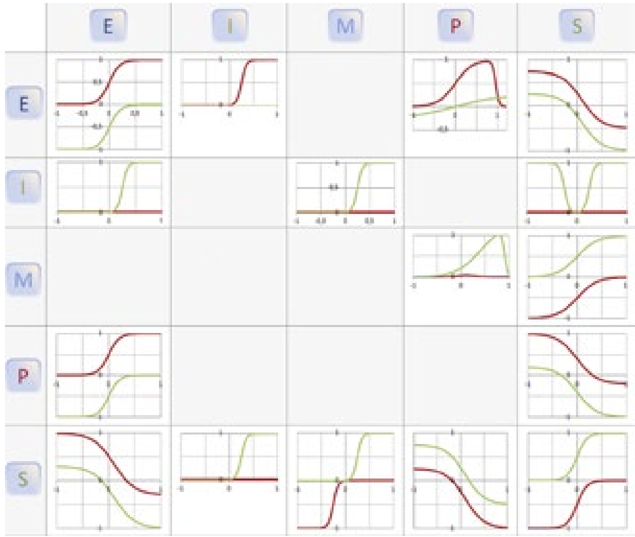

Abbildung 2b

Abbildung 2a: Die Struktur des Wirkfaktorenmodells: die Variablen P, S M, E, I wirken über die Parameter a, c, r, m aufeinander.
Abbildung 2b: Grafische Veranschaulichung der Funktionen, welche die Wirkung der Variablen aufeinander vermitteln. Die genaue Form der Funktionen wird durch die Ausprägung der Parameter bestimmt. Rot entspricht einer niedrigen Ausprägung der Kompetenzen (Parameter), grün einer hohen.

Zeit in Abhängigkeit von anderen Variablen und gegebenenfalls von sich selbst sowie in Abhängigkeit von den Parametern beschreibt.

Die Modellierung reproduziert wesentliche Merkmale psychotherapeutischer Verläufe, beispielsweise chaotische Dynamik, kritische Instabilitäten, die einer Verhaltensänderung vorausgehen, parameterabhängige Phasenübergänge (entsprechen einer Verhaltensänderung), plausible Relationen zwischen den Variablen, Multistabilität, geringe oder keine Wirkung von Interventionen in stabilen Phasen und bei konstanten Parameterwerten, dagegen deutliche Wirkung in kritischen Phasen und eine verlaufsabhängige Modulation der Parameter (entspricht einer Persönlichkeitsänderung). Die Dynamik des Systems hängt nicht nur von den Startwerten und vom Input ins System ab, sondern wesentlich auch von den Parametern. Diese definieren in der inhaltlichen Interpretation des Modells die Kompetenzen und Vorbelastungen eines Patienten (Traits) und werden umgekehrt selbst von den konkreten Erfahrungen in der Therapie und im Leben (Dynamik der Variablen, States) verändert. Ohne Parameteränderung keine nachhaltigen Therapieeffekte. Die kontinuierliche Veränderung der States verändert die Traits, die sich wiederum kreiskausal auf die States auswirken.

Unter bestimmten Bedingungen verlaufen reale und simulierte Therapieprozesse sehr ähnlich (siehe Abbildung 1). Über diese Ähnlichkeit hinaus leisten formale Modellierungen noch Weiteres. Formalisierungen zwingen uns, Selektionen und Abstraktionen des Modells explizit zu machen. Man kann nicht im Vagen bleiben, sondern muss jeden Schritt transparent machen und mathematisch ausformulieren. Es wird erkennbar, welche Zusatzannahmen erforderlich sind, um bestimmte Effekte zu erzielen. Diese Präzision macht die Modellierungen aber auch angreifbar, weil durchschaubar: Was bei rein verbalen Beschreibungen kaum entdeckt würde, wird offensichtlich. Rhetorische Nebelbomben werden wirkungslos.

Mathematische Modelle dienen der Generierung von Prozessen, deren Verständnis im Grunde von allen Theorien des Lernens, der Entwicklung und der Veränderung erwartet wird. Nur in Prozessen finden sich Phänomene wie Chaos, selbstorganisierte Kritikalität, emergente Schwellen, Stabilität und (kritische) Instabilität, Phasenübergänge, differenzielle Reagibilität auf Interventionen oder die Modulation von Prozessmustern durch dynamisches Rauschen (Dynamic Noise).

Eine gute Simulation des Therapieprozesses zeigt die Plastizität und Potenzialität des «Systems Mensch».

Der Mehrwert von Simulationen liegt in den (emergenten) dynamischen Eigenschaften, die nicht schon als Annahmen hineingepackt wurden.

Nichtlineare Modelle der Psychotherapie erweitern unsere Vorstellung von Interventionen über einen simplen Input-Output-Mechanismus hinaus. Unter bestimmten Bedingungen (Multistabilität) geht es darum, mit explorativen Strategien das Systemverhalten in einem anderen (aber potenziell vorhandenen) Attraktor zu «kicken», die Kontrollparameter des Systems zu beeinflussen oder einfach das System unspezifisch anzuregen. Diese Anregung kann als dynamisches Rauschen angesehen werden, als die normale, dynamische Fluktuation der Variablen. Allein schon dadurch sind Ordnungsübergänge möglich.

Über Computersimulationen lassen sich Therapiespiele generieren, die für die Therapieausbildung von immensem Nutzen sein können, weil sie zeigen, wie kontraintuitiv und unvorhersehbar sich Menschen verhalten können: Das Gegenteil von «gut» ist auch im Rahmen einer Therapie oft «gut gemeint». Modelle lassen uns in der Computersimulation testen, was wir aus praktischen oder ethischen Gründen *in vivo* nicht können. So könnte eine neue Intervention zuerst im Modell getestet werden, etwa die Konfrontation eines Suchtkranken mit dem Suchtmittel. Zudem sind Modelle sehr hilfreich bei der Generierung von Hypothesen und kreativen Designs bei Validierungsstudien. Ob mathematische Modelle im Einzelfall die präziseren Vorhersagen liefern als Intuition oder Statistik, sei dahingestellt, aber sie zeigen einen Raum der Möglichkeiten auf.

Potenzialität des «Systems Mensch»

Wir bewegen uns mit mathematischen Modellierungen und Simulationen nicht nur auf einer interessanten Spielwiese, sondern sind auf dieses Instrumentarium angewiesen. Eine gute Simulation des Therapieprozesses zeigt die Plastizität und Potenzialität des «Systems Mensch». Simulationen beruhen auf präziser Modellbildung, die über Allgemeinaussagen wie: «Der Mensch ist die Summe seiner Kindheitserfahrungen», oder: «Der Mensch ist die Summe seiner (sozialen) Lernerfahrungen» weit hinausgehen. Aus dieser neuen Generation mathematischer Theoriebildung entstehen auch «Therapiesimulatoren». Und mit dem Verfahren der «idiografischen Systemmodellierung» lassen sich solide individuelle Modelle im Rahmen von Fallkonzeptionen «live» und «von unten» (zusammen mit den Klientinnen und Klienten) aus den Variablen und Parametern des «Klientensystems» entwickeln. Die Konsequenzen für Praxis, Ausbildung und Forschung sind also weitreichend. ◆

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Eine vollständige Referenzliste kann beim Autor bezogen werden.

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Systemische Fallkonzeption und State-Dynamik bei einer Patientin mit struktureller Dissoziation der Persönlichkeit

Übersicht: Das Fallbeispiel beschreibt die Vorgehensweise des synergetischen Prozessmanagements in einem tagesklinischen Setting. Dargestellt wird der therapeutische Prozess einer Patientin mit Borderline-Persönlichkeitsstörung und komplexer dissoziativer Störung. Die Entwicklung der Patientin wurde begleitet und reflektiert mit einem Prozessmonitoring, welches auf einem täglich ausgefüllten persönlichen Fragebogen beruht. Am Beginn des Monitorings und des regelmäßigen Prozessfeedbacks, das im Rahmen der therapeutischen Einzelgespräche stattfand, stand die Entwicklung eines idiographischen Systemmodells, welches in einer etwa dreistündigen Arbeit zusammen mit der Patientin entwickelt wurde. Für die Patientin war es entscheidend zu erkennen, wie ihre verschiedenen Persönlichkeits-States in den Komponenten des Modells repräsentiert waren und wie sich die Übergänge zwischen den States und deren jeweilige Trigger psychologisch nachvollziehen und erklären ließen. Der mit dem »Synergetischen Navigationssystem« (SNS) mögliche Einblick in die Dynamik und die Verlaufsmuster ihrer Persönlichkeitszustände (erfasst mithilfe täglicher Selbsteinschätzungen) lieferte die Grundlage für einen veränderten Umgang mit diesen. Die Effekte im Bereich der selbstbezogenen Informationsverarbeitung und Identitätsentwicklung waren bemerkenswert. Die idiographische Systemmodellierung und das SNS in Kombination ermöglichten sowohl der Therapeutin als auch der Patientin ein umfassendes Verständnis der persönlichen Psychodynamik und der Prozessmuster der Therapie.

Schlüsselbegriffe: idiographische Systemmodellierung, systemische Fallkonzeption, Therapiefeedback, Synergetisches Navigationssystem (SNS), strukturelle Dissoziation der Persönlichkeit, Borderline-Persönlichkeitsstörung

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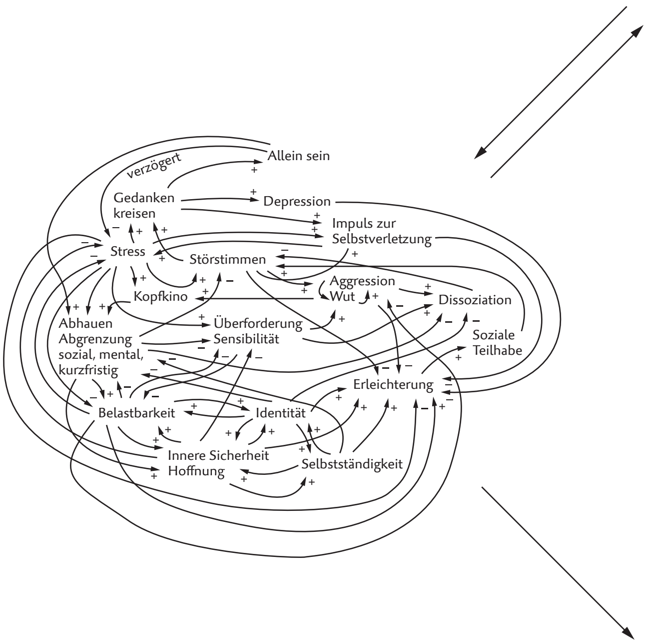
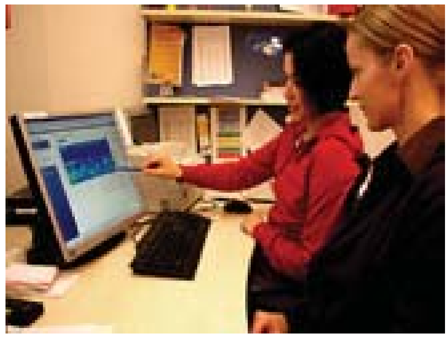
Fragestellung

Die vorliegende Falldarstellung und die therapeutische Arbeit an diesem Fall waren von der Frage motiviert, ob sich eine systemische Vorgehensweise auch in der Arbeit mit PatientInnen, deren Erleben durch eine strukturelle Dissoziation der Persönlichkeit (van der Hart, Nijenhuis & Steele, 2008) geprägt ist, nutzbar machen lässt. Während Erfahrungen mit anderen klinischen Zustandsbildern vielfach vorliegen (z. B. Kronberger & Aichhorn, 2015; Schiepek & Matschi, 2013), betreten wir hier Neuland. Das Vorgehen beinhaltet

- ein Ressourceninterview,
- die Erarbeitung eines idiographischen Systemmodells der Psycho- und Soziodynamik,
- davon ausgehend die Erstellung eines persönlichen Fragebogens für das tägliche Prozessmonitoring,
- regelmäßige Therapiegespräche, die auf das Prozessmonitoring Bezug nehmen, und
- die Weiterführung des Prozessmonitorings über den eigentlichen Therapiezeitraum hinaus (Nachsorge).

Dieses Therapierationale wurde als synergetisches Prozessmanagement beschrieben und benutzt die weiter unten beschriebene Informationstechnologie des »Synergetischen Navigationssystems« (SNS), um Therapiefeedback zu geben und die Therapie zu steuern (Schiepek, Eckert & Kravanja, 2013; Schiepek et al., 2015, 2016; Schiepek & Matschi, 2013; Schiepek, 2016) (vgl. Abb. 1). Tägliche Selbsteinschätzungen mit einem individuell entwickelten Prozessfragebogen werden dabei meist mit einem wöchentlich vorgelegten, eher symptomspezifischen Fragebogen (z. B. der Depressions-Angst-Stress-Skala, s. u.) kombiniert.





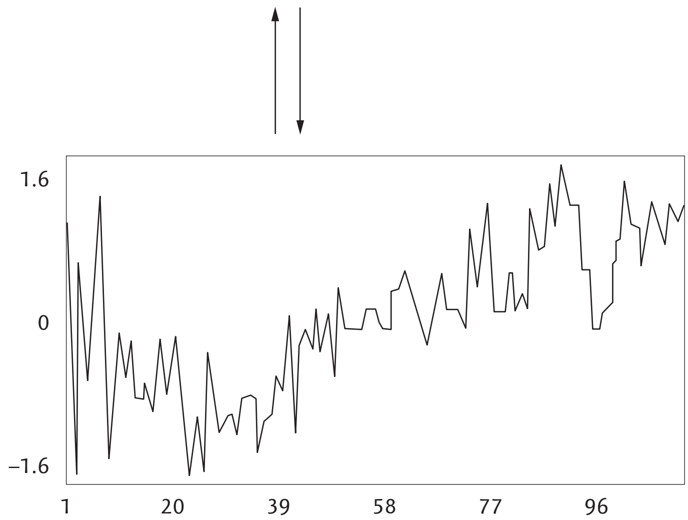


Abb. 1: Systemische Therapie als rekursiver Prozess aus idiographischer Systemmodellierung, Prozessmonitoring und SNS-basiertem Prozessfeedback.

Problemlage

Die Patientin (Frau A.) war eine 37-jährige Frau, die lange in einer Steuerkanzlei gearbeitet hatte und in einer süddeutschen Kleinstadt wohnte. Privat lebte sie nach mehreren Partnerschaften mit Männern, in denen sie jahrelange, oft sadistische Gewalt erlitten hatte, nun in einer lesbischen Beziehung mit einer gleichaltrigen Frau. Bei Antritt der tagesklinischen Behandlung war sie bereits längere Zeit krankgeschrieben und hatte schon vor über einem Jahr einen stationären Klinikaufenthalt absolviert. Trotz langjähriger Traumatisierungen seit Kindheit (z. B. Mobbing in der Schule, soziale Außenseiterposition in der Pubertät, Gewalterfahrungen in Beziehungen) war sie in den 15 Jahren ihrer engagierten Berufstätigkeit in der Lage, ein geordnetes Leben zu führen, was sich mit Ende der Anstellung, bedingt durch eine Fremdübernahme »ihrer« Kanzlei, drastisch geändert hatte. Dominant wurden nun Selbstverletzungen, wechselnde dissoziative Persönlichkeitszustände, die füreinander amnestisch waren (mit der Folge von Zeitlücken, die eine andauernde Unsicherheit bewirkten, ob sie vergessen haben könnte, was sie in einem anderen Ich-Zustand getan oder erlebt hatte), Unkonzentriertheit und Gefühle von Derealisation (z. B. fühlte sie sich bei einem bestimmten Lichteinfall in Szenen ihrer Kindheit zurückversetzt). Die Amnesien betrafen zum Teil ganze Tage. Die Exploration dieser Erfahrungen im SKID-D (Gest, Oswald & Zündorf, 2000) legte die Diagnose einer »komplexen dissoziativen Störung« (NNBDS, engl. DDNOS) nahe. Diagnosen nach DSM-5: »Borderline Personality Disorder« (301.83) und »Other Specified Dissociative Disorder« (300.15). In der Einteilung von Nijenhuis (2016, vgl. auch Nijenhuis & van der Hart, 2011) handelte es sich um eine »Minor Dissociative Identity Disorder« im Sinne einer tertiären strukturellen Dissoziation. Neben den klinischen Auffälligkeiten war sie von der Sorge erfüllt, ob sie jemals wieder ein gesundes Leben führen und eine eigene, klare Identität entwickeln könnte. Ihr Selbstbild war das eines »leeren Blattes«, auf das jeder schreiben kann, was er will – womit sie sich auch immer wieder als gefügiger Spielball für Fremdinteressen und Übergriffe jeder Art anbot.

Systemische Fallkonzeption[2]

Im Ressourceninterview gab Frau A. als ihre wichtigsten Herausforderungen an: »Abgrenzung von Geräuschen und Störstimmen« (gemeint sind nicht psychotische Stimmen, sondern übermäßig störend und als in sie eindringend empfundene Stimmen von Personen, z. B. am früheren Arbeitsplatz), »Stabilität im Leben«, und »Arbeit finden«. Von dieser letztgenannten Herausforderung, die sie seit ihrem Berufsausstieg intensiv beschäftigte, sollte sie sich im Laufe der Therapie allerdings verabschieden. Als Ressourcen nannte sie ihre Lebensgefährtin und die Liebe zu ihr, Musik hören (womit sie sich von den störenden Stimmen abgrenzen konnte), Stricken, ihr (trockener) Humor, in Gesprächen mit anderen Menschen gut zuhören zu können, Geduld und Durchhaltevermögen, Verlässlichkeit, positive Erinnerungen (z. B. an Gerüche aus ihrer Kindheit) sowie ihr »Kopfkino«. Damit sind aggressive Phantasien gemeint, die sie innerlich erzeugte, um sich an den Verursachern der von ihr als intensiv empfundenen akustischen Belästigungen abzureagieren.

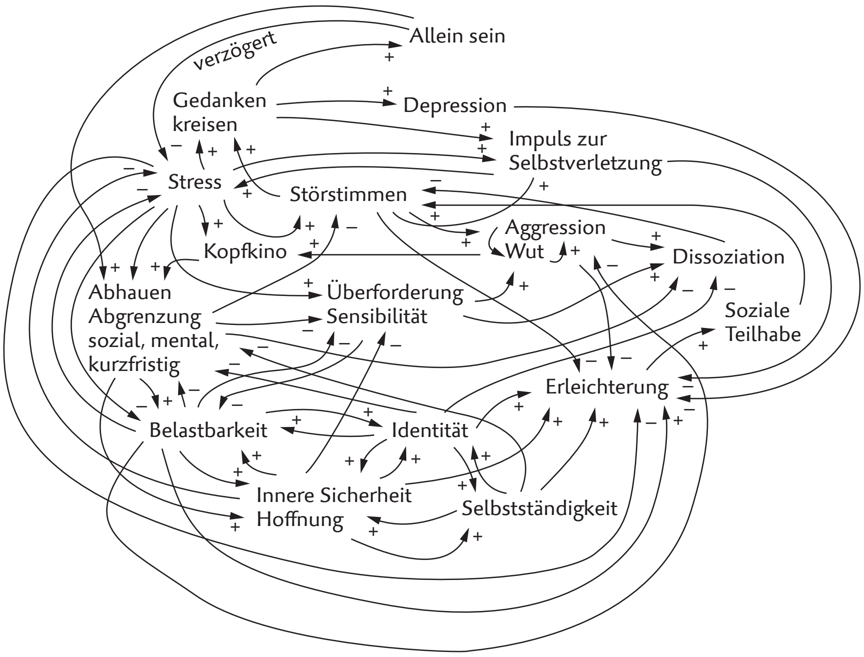


Abb. 2: Das idiographische Systemmodell als eine Synopse der Psycho- und Soziodynamik entstand in einem etwa dreistündigen kooperativen Konstruktionsprozess.

Das Systemmodell (Abb. 2) wurde in einer etwa dreistündigen Sitzung erarbeitet, in der sie mit nur einer kurzen Pause wie in einem Flow-Zustand intensiv mitarbeitete. Die Unterbrechungen durch kurzzeitige Unkonzentriertheit waren marginal, was angesichts der im Alltag immer wieder auftretenden dissoziativen Absencen erstaunlich war. Das Vorgehen der Systemmodellierung (Schiepek, 1986) besteht darin, sich zunächst das Problemszenario der letzten Wochen und Monate schildern zu lassen. Dabei kann man zum besseren Verständnis vertiefend nachfragen und auch Problemlöseversuche, Copingstrategien, Ausnahmen von Problemen und konstruktive Umgangsformen mit diesen thematisieren. Während der Erzählung macht sich die Therapeutin Notizen zu den Aspekten, Teilprozessen oder Begriffen, die dann als Komponenten des Modells verwendet werden. Danach gehen Patientin und Therapeutin die notierten Begriffe noch einmal durch und rekapitulieren oder modifizieren deren Bedeutung. Ein präzises gemeinsames Begriffsverständnis ist wichtig, ebenso die Wortwahl, welche für die Patientin wirklich zutreffend sein muss. Die begrifflichen Komponenten eines Systemmodells sind »Variablen«, also Größen, deren Ausprägung sich in der Zeit verändert. Die Variablen bezeichnen intraindividuelle oder interpersonelle Aspekte eines bio-psycho-sozialen Systems, z. B. Kognitionen, Emotionen, Motive, Verhaltensweisen, physiologische Zustände und Ähnliches. Sie werden in Form von theoretischen Konstrukten der Psychologie oder aber in der Alltagssprache benannt.

Nachdem die Systemkomponenten gesammelt sind, stellen sich Patientin und Therapeutin gemeinsam an ein Flipchart und versuchen, die Wirkungen der einzelnen Komponenten des Modells aufeinander graphisch darzustellen. Diese Wirkungen werden in Form von Pfeilen aufgemalt, welche im einfachsten Fall durch + oder – qualifiziert sind. + bedeutet eine gleichgerich-

[2] Es sei angemerkt, dass der Begriff der systemischen Therapie nicht gleichbedeutend mit Paar- oder Familientherapie benutzt wird. »Systemisch« bezieht sich hier auf die Netzwerkdynamik eines näher zu bezeichnenden (also nicht a priori festgelegten) Systems, z. B. eines intrapsychischen Systems in seiner Lebenswelt (worauf wir in diesem Beitrag primär Bezug nehmen), eines neuronalen Netzwerks, eines interpersonellen Systems oder einer Kombination aus solchen Systemen (Mehrebenenansatz). Therapie meint die Unterstützung und Förderung selbstorganisierender Prozesse eines Systems, um Veränderung bzw. Weiterentwicklung von Struktur und Funktion zu ermöglichen. Die explizite Modellierung der Systemstruktur (hier mit der Methode der idiographischen Systemmodellierung) und die Erfassung der Systemdynamik bzw. Veränderungsprozesse sind zentrale Bestandteile systemischer Praxis (zur Begründung dieser erweiterten bio-psycho-sozialen Konzeption systemischer Therapie s. Schiepek, 1986; Schiepek et al., 2013).

tete Relation (z. B. »Je intensiver der erlebte Stress, umso intensiver die Störstimmen«). – bedeutet eine gegengerichtete Relation (z. B. »Je ausgeprägter die Dissoziation, umso mehr treten die Störstimmen in den Hintergrund, d. h. sie werden geringer« oder »Mit zunehmender Erfahrung von innerer Sicherheit reduziert sich das Erleben von Überforderung und Sensibilität«) (vgl. Abb. 2).

Frau A. fand sich in »ihrem« Modell sehr gut wieder, und in den darauffolgenden Therapiesitzungen brachte sie das Blatt, auf dem das ursprünglich in Flipchart-Größe gemalte Modell nun verkleinert dargestellt war, immer wieder mit – es sei die »Landkarte ihrer Seele«. Es machte ihr verständlich, wie die Aktivierungsmuster ihrer Erfahrungsaspekte in systemischer Weise »funktionierten« und welche Kognitionen, Emotionen und Verhaltensweisen in welcher Weise getriggert wurden. In diesen Sitzungen konnte sie Teilaspekte des durchaus komplexen Netzwerks mit ihrer Therapeutin durchsprechen und spezifische Zusammenhänge verstehen. Im Laufe dieser Arbeit wurde ihr klar, dass bestimmte Variablen bzw. Erlebnisaspekte bestimmten Persönlichkeits-States (im Folgenden States genannt) oder Ich-Zuständen entsprachen. Im Unterschied zum Alltagserleben, in dem die States wie zufällig alternierten und oft füreinander amnestisch waren, lagen sie hier nun synoptisch vor Augen – systemisch und systematisch. Damit war auch eine vertiefte traumafokussierte Therapie und States-Arbeit (Nijenhuis, 2015, 2016; van der Hart, Nijenhuis & Steele, 2008) möglich, von der sie gut profitierte. Im Sinne der generischen Prinzipien leistete das Prinzip 2, nämlich die Modellierung des Systems (Fallkonzeption) und das kontinuierliche Prozessmonitoring, einen wichtigen Beitrag zum Prinzip 1, der emotionalen und strukturellen Stabilität für selbstorganisierende Prozesse. Hinzu kamen die gute therapeutische Beziehung zur Bezugstherapeutin, zu den Fachtherapeuten und zum Pflegepersonal sowie die strukturelle Sicherheit des Stationsalltags. Auch die Prinzipien 3 (Sinnhaftigkeit der therapeutischen Arbeit) und 4 (Veränderungsmotivation) wurden durch die Fallkonzeption und das Prozessmonitoring unterstützt.

Prozessmonitoring und State-Dynamik

Nachdem ein idiographisches Systemmodell entwickelt worden ist, werden die Komponenten (Variablen) des Modells in Fragen eines persönlichen Prozessfragebogens übersetzt, der im Laufe der Therapie mithilfe des SNS täglich ausgefüllt wird. Daraus ergibt sich eine visuelle Darstellung des Veränderungsprozesses »in Echtzeit«. Wenige Tage nach der Systemmodellierung wurde der persönliche Fragebogen von Frau A. mithilfe des Fragebogeneditors im SNS angelegt. Tab. 1 zeigt, in welche Formulierungen persönlicher Fragen sie die Variablen des idiographischen Systemmodells übertrug. Die Formulierungen bestimmt ausschließlich die Patientin und diktiert sie der Therapeutin in die Hand bzw. in den Fragebogeneditor.

Die Einteilung der Fragen (Items) in zwei Kategorien (»Faktoren«) legte die Patientin fest. In der weiteren therapeutischen Arbeit sollte sich zeigen, dass die beiden Kategorien bzw. Faktoren genau den beiden für sie dominanten Persönlichkeitszuständen, die sich wiederum aus mehreren Sub-States zusammensetzten, entsprachen – einem »Kind-Zustand« (im Konzept

I Stress und Stressverarbeitung (entspricht dem State-Cluster »Kind«, EPs)
Heute habe ich Stress erlebt …
Heute war es notwendig, mein Kopfkino zu aktivieren …
Heute bin ich weggesaust – dissoziiert …
Heute war es für mich wichtig, alleine zu sein …
Heute wurde ich von der Depression mitgerissen …
Der Impuls zur Selbstverletzung war für mich heute …
Das Gedankenkreisen war für mich heute …
Die Störstimmen waren für mich heute …
Mein Aggressionspegel war heute …
Mein Wutpegel war heute …
Heute fühlte ich mich überfordert …
Mein Bedürfnis nach Abgrenzung war heute …
II Positive Ziele und Identitätsentwicklung (entspricht dem State-Cluster »Erwachsene«, ANP)
Meine Belastbarkeit war heute …
Mein Gefühl der inneren Sicherheit war heute …
Mein Empfinden von Selbstständigkeit war heute …
Das Gefühl für meine innere Identität war heute …
Mein Gefühl der Erleichterung war heute …
Meine Teilnahme am sozialen Leben war heute …

Tab. 1: Die Variablen des idiographischen Systemmodells, überführt in persönliche Fragen.

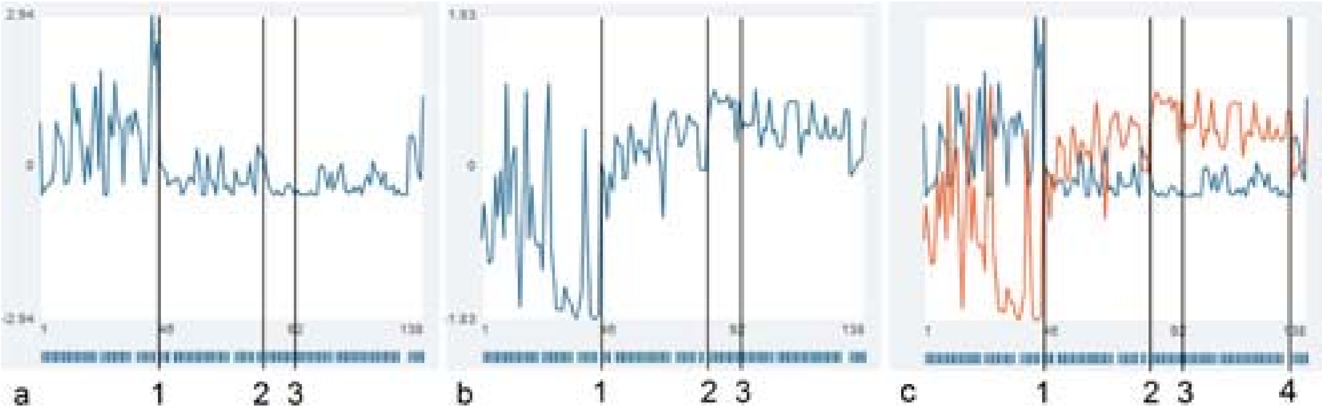


Abb. 3: Entwicklung der beiden übergeordneten Kategorien (»Faktoren«) des persönlichen Fragebogens von Frau A. Die Zeitreihen der Faktoren wurden durch z-Transformation und Mittelung der zu den jeweiligen Faktoren gehörigen Items (Zeitreihen) erzeugt (erfolgt im SNS automatisch). (a) Stress und Stressverarbeitung (entspricht den »Kind«-States), (b) Positive Ziele und Identitätsentwicklung (entspricht den »Erwachsenen«-States), (c) Überlagerung der Zeitreihen (a) und (b). Gut erkennbar sind die alternierenden Spitzen bzw. Intensitätsausprägungen der beiden State-Cluster im ersten Drittel des Therapieverlaufs (bis zu der mit 1 markierten senkrechten Linie). Die kleinen Striche am unteren Rand der Diagramme markieren die Tage mit Kommentareintragungen im SNS. Frau A. hat das SNS fast jeden Tag für Tagebucheintragungen genutzt. Die Ziffern 1 bis 4 an den senkrechten Markierungen beziehen sich auf Ereignisse, die im Text erklärt werden. 1 und 2 sind Ordnungsübergänge in der Dynamik, 3 der Zeitpunkt der Entlassung aus der Tagesklinik, 4 markiert eine Krise im Nachsorgezeitraum.

der strukturellen Dissoziation: emotionale Persönlichkeitsanteile, EPs) und einem »Erwachsenen-Zustand« (anscheinend normaler Persönlichkeitszustand, ANP). Im ersten Drittel der Therapie realisierten diese beiden Faktoren oder States eine recht klare alternierende Dynamik, d. h. sie schlossen sich gegenseitig aus (Abb. 3). Diese Rhythmik zeigte sich in den täglichen Selbsteinschätzungen des Therapiemonitorings, hätte sich vermutlich aber wohl auch auf kürzeren Zeitskalen (z. B. bei stündlichen Einschätzungen) manifestiert. Die alternierende Rhythmik ist vor allem gut erkennbar, wenn man die Verläufe der Faktoren in einem Diagramm übereinander legt (Abb. 3c) oder wenn man sich die zeitlichen Korrelationsmuster der Faktoren und der zu ihnen korrespondierenden Items anschaut (Abb. 4).

Im ersten Drittel der Therapie waren die Items, die jeweils zu einem der beiden Faktoren (States) gehörten, deutlich synchronisiert (positiv korreliert), die Verläufe der Items der beiden unterschiedlichen Faktoren waren anti-synchronisiert (negativ korreliert) (Abb. 4). Das gegenläufige Muster ist auch gut erkennbar, wenn man die Ausprägung der einzelnen Item-Zeitreihen in Farbe aufträgt. Dieses Rohwerte-Resonanzdiagramm (Abb. 5a) überträgt die Werteausprägung der Items in Regenbogenfarben. Bis Markierung 1 alternieren die Farben der Items, die zum jeweils anderen Faktor gehören.

Ordnungsübergänge

Im Verlauf der Therapie ereigneten sich zwei bedeutsame Musterwechsel, die im Sprachgebrauch der Theorie selbstorganisierender Systeme als »Ordnungsübergänge« bezeichnet werden (Haken & Schiepek, 2010). Im ersten Drittel des Erfassungszeitraums war jeder Tag vielleicht nicht ausschließlich, aber doch deutlich von einem der States geprägt – ein Muster, das sich zu einem bestimmten Zeitpunkt (Ziffer 1 in den Abbildungen) fast schlagartig änderte. Direkt davor trat theoriekonform noch einmal eine

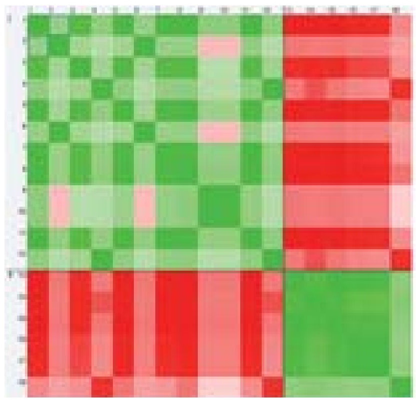


Abb. 4: Charakteristisches Inter-Item-Korrelationsmuster aus dem ersten Drittel des Therapieverlaufs, dargestellt in einer Farbmatrix. Im SNS werden die Items eines Fragebogens, geordnet nach Faktoren, in einem Zeitfenster korreliert, welches über den gesamten Verlauf läuft. Die Breite des Fensters ist frei wählbar, hier wurde eine Fensterbreite von 7 Messpunkten (= Tagen) gewählt. Grün bedeutet positive Korrelation, rot bedeutet negative Korrelation, die Farbsättigung steht für die Ausprägung der Korrelationen. Items, die jeweils zu einem Faktor (State) gehören, sind hier positiv korreliert, während die Korrelationen mit den Items des jeweils anderen Faktors negativ sind.

maximale Fluktuation in Richtung Stresserleben und Identitätskrise auf (Abb. 3). Zu diesem Zeitpunkt hatte die Patientin beschlossen, sich von dem Druck, am ersten Arbeitsmarkt tätig sein zu wollen und wieder in ihren Beruf zurückzukehren, zu verabschieden. Dies war bisher eines ihrer zentralen Themen gewesen und auch im Ressourceninterview noch als wichtige Herausforderung benannt. Der Entscheidungsprozess wurde aktuell eingeleitet von einem attraktiven beruflichen Angebot, das sie von einem Bekannten bekommen hatte. Nach mehreren Tagen der Ambivalenz und der inneren Konflikte entschied sie sich dagegen und erlebte dies als Befreiungsschlag. Es war ihr gelungen, auf ihre innere Stimme und auf ihre Bedürfnisse zu hören, anstatt sich immer wieder in verschiedene Arbeitsprojekte »hineinzupeitschen«. Zugleich hatte sie bis dahin schon intensiv an den hinter den States liegenden Traumatisierungen gearbeitet (z. B. am Zusammenhang zwischen den Störstimmen und den Gewalterfahrungen in ihren früheren Beziehungen) und sich mit den im Systemmodell erarbeiteten psychischen Funktionsmechanismen ihrer State-Dynamik beschäftigt.

Im Tagebucheintrag[3] genau an diesem zentralen Ordnungsübergang bzw. Musterwechsel schrieb sie:

> *… ich habe das Gefühl, wieder ich zu sein … die letzte Zeit war sehr unangenehm und schmerzhaft. (…) Es wurden gemeinsam Entscheidungen getroffen für die Zeit nach der Klinik, die für mich besser sind. Ich will Frieden mit mir schließen, das klappt ja nicht immer, ist aber so wichtig!! Denn so wie es die letzten Jahre war, habe ich mich zwar bemüht und an mir gearbeitet, dass es wieder mit der Arbeit klappt, aber auch immer den Stress und den Druck gespürt (…) und so geht es nicht!! Meine Weichen sind anders gestellt …, um für einen gewissen Zeitraum zur Ruhe zu kommen und Stress loszuwerden und um mir dann Gedanken zu machen, was ich machen will und wie es mit mir beruflich weiter geht. (…) Ich lasse mich nicht in die Knie zwingen, von nichts und niemand!!*

In den Zeitreihen fast aller Aspekte ihres Erlebens bzw. ihrer Systemvariablen war diese Veränderung deutlich erkennbar (Markierung 1). In Abb. 6 sind die Verläufe von vier Items dargestellt: »Belastbarkeit« und »Selbstständigkeit« (Faktor II), »Bedürfnis nach Abgrenzung« und »Stress« (Faktor I). Vor allem die Dynamik der Items von Faktor I weisen extreme, auf den ersten Blick sehr irreguläre Fluktuationen auf (vgl. Abb. 5b), sodass sich hier die Auswertungstools[4] des SNS als sehr nützlich erweisen, um Muster zu identifizieren. Um es der Klientin zu ermöglichen, die Dynamik besser zu verstehen, werden die Items eines Fragebogens zu z-transformierten Faktoren zusammengefasst (Abb. 3a, c: Faktor I: Stress und Stressverarbeitung; Abb. 3b, c: Faktor II: Ziele und Identitätsentwicklung). Das macht die Sache schon erheblich übersichtlicher und erlaubt ihr, die Dynamik ihrer belastenden States und der dazu gehörenden Kognitionen und Emotionen zu verstehen.

Ein zweiter markanter Ordnungsübergang vollzog sich etwa fünf Wochen später (Markierung 2 in den Abb. 3, 5, 6 und 8). Sie hatte für ihre Lebensgefährtin und deren aufwendiges Hobby Geschenke eingekauft und sich dabei finanziell über ihr monatliches Limit begeben, sodass sie ihre Eltern um finanzielle Unterstützung bitten musste. Dies erlebte sie als Rückschritt in ihre Kindheit, und die Kind-bezogenen States aktivierten sich. Allerdings konnte sie diese Krise, die im Vergleich zur Dynamik im ersten Drittel der Therapie »auf hohem Niveau« stattfand, in den therapeutischen Gesprächen nutzen, um ihre Psychodynamik – wiederum auch anhand der Systemmodellierung – zu analysieren und zu verstehen. So ging sie nicht regressiv, sondern progressiv aus der Krise hervor. In vielen Items ist ein Übergang in ein stabileres Muster zu erkennen.

Die Entlassung aus der Tagesklinik fand zehn Tage danach statt, hinterließ aber in den Zeitreihen und offenbar auch in ihrem Erleben keine erkennbaren Spuren (Markierung 3 in den Abbildungen 3 und 6). Stabilisierend wirkte hier, dass sie sich schon vorher entschlossen hatte, die von ihr als unterstützend und ihre Perspektiven erweiternd erlebten täglichen Selbsteinschätzungen mit ihrem persönlichen Fragebogen fortzusetzen, was sie dann auch noch etwa sieben Wochen lang machte. Kurz vor dem einvernehmlichen Ende ihres insgesamt 138 Tage laufenden Therapiemonitorings trat eine Krise auf, die ihre Lebenspartne-

[3] Das SNS bietet die Möglichkeit, ein »elektronisches Tagebuch« zu führen. Entweder am Ende eines Fragebogens oder sogar einem speziellen Item zugeordnet können KlientInnen einen Freitext zu ihrem Erleben, zu den Ereignissen des jeweiligen Tages oder zu einem mit dem Therapeuten erarbeiteten Fokus (z.B. Aktivierung von Ressourcen) schreiben. Diese Tagebucheinträge können (natürlich nur, wenn der Klient/die Klientin das wünscht) gemeinsam mit ihm/ihr besprochen werden und tragen oft wesentlich zum Verständnis der Verlaufsmuster oder spezieller Antwortausprägungen bei. Zudem hat das Schreiben von Therapietagebüchern einen therapeutischen Wert an sich.

[4] Das SNS enthält neben den Funktionen für Klientenverwaltung und für das Anlegen neuer individueller Fragebögen auch verschiedene Möglichkeiten der Visualisierung von Prozessmustern (z.B. in Zeitreihen oder Farbdiagrammen) und der Zeitreihenanalyse. Hierzu gehören die Zusammenfassung von Items zu übergeordneten Kategorien (Faktoren) und deren z-Transformation, die Berechnung und Visualisierung von Inter-Item-Korrelationen (Korrelationsmatrizen und Darstellung paarweiser Inter-Item-Korrelationen), die Darstellung des Verlaufs der dynamischen Komplexität, Komplexitäts-Resonanz-Diagramme, Recurrence Plots und andere. Diese Verfahren sind dafür optimiert, Musterveränderungen (Ordnungsübergänge) auch in vergleichsweise kurzen Zeitreihen von Therapieprozessen erkennbar zu machen.

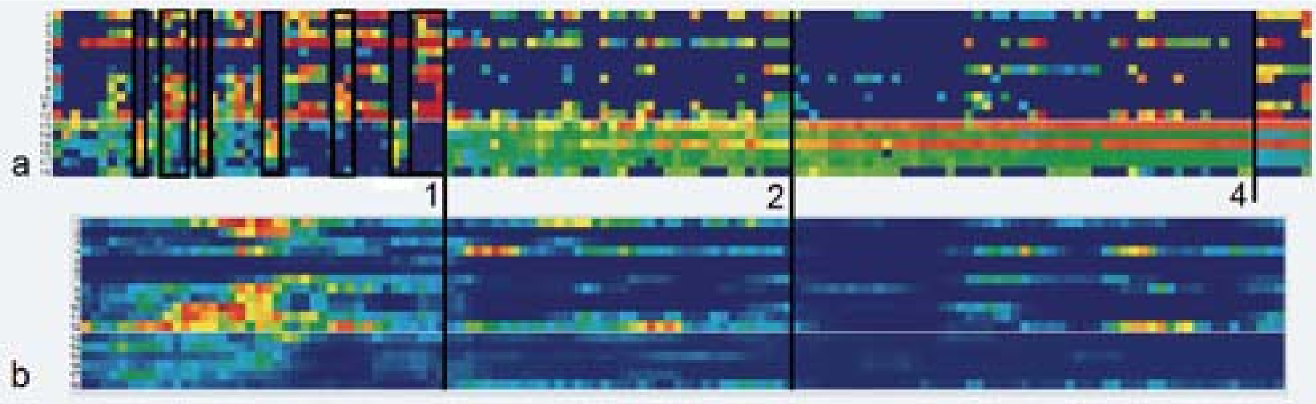


Abb. 5: Resonanzdiagramme. (a) Rohdaten-Resonanzdiagramm. In diesem Diagramm werden die Werteausprägungen der Zeitreihen der Items von Null bis zum Maximum in Regenbogenfarben von Dunkelblau über Türkis, Grün, Gelb bis Rot dargestellt. Die Items liegen in Zeilen übereinander, oben die von Faktor I, unten die von Faktor II (vgl. Tab. 1).
Die eingefügten Rahmungen zeigen Stellen, an denen die gegengetaktete Aktivierung von Faktor I- und Faktor II-Items gut erkennbar ist.
(b) Komplexitäts-Resonanz-Diagramm. Hier liegen ebenfalls die Items in Zeilen übereinander, gezeigt wird jedoch die in überlappenden Gleitfenstern (Fensterbreite = 7 Messpunkte) berechnete dynamische Komplexität (vgl. Haken & Schiepek, 2010). Die Ausprägung der dynamischen Komplexität ist von Null bis zum (im gesamten Diagramm vorkommenden) Maximum ebenfalls in Regenbogenfarben von Dunkelblau über Türkis, Grün, Gelb bis Rot dargestellt. Die Ziffern 1, 2 und 4 an den senkrechten Markierungen beziehen sich auf Ereignisse, die im Text erklärt werden.

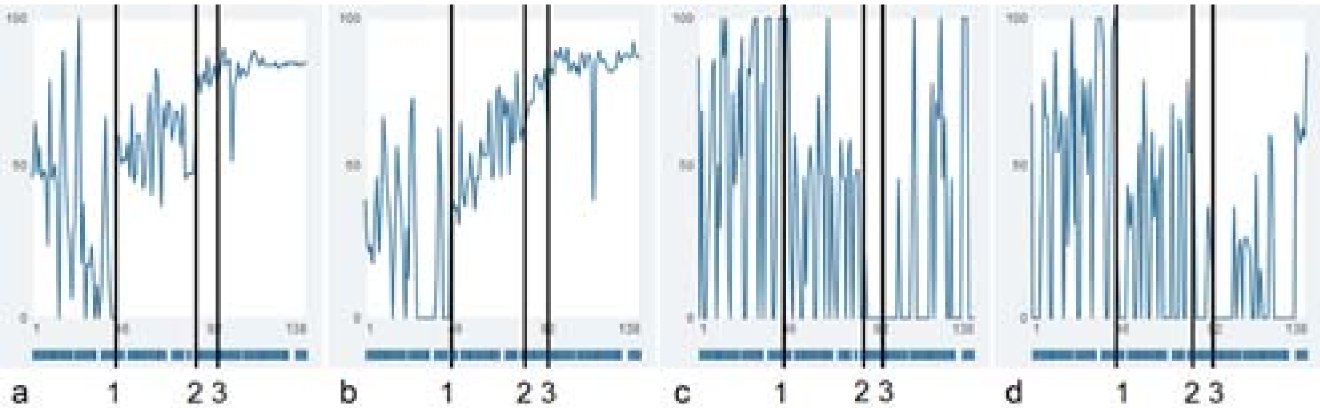


Abb. 6: Zeitreihen der Items (a) »Belastbarkeit«, (b) »Selbstständigkeit« (Faktor II), (c) »Bedürfnis nach Abgrenzung« und (d) »Stress« (Faktor I). Die Ziffern 1 bis 3 an den senkrechten Markierungen beziehen sich auf Ereignisse, die im Text erklärt werden (1 und 2: Ordnungsübergänge, 3: Klinikentlassung). Vor allem in der ersten Phase der Therapie weisen die Items, die die Kind-States der Patientin repräsentieren, extreme und unregelmäßige Schwankungen (0–100) auf, die sich in der zweiten Phase (zwischen den Markierungen 1 und 2) ähnlich, aber mit geringerer Ausprägung verhalten. Eine Besonderheit: Das Item »Belastbarkeit« weist eine Selbstähnlichkeit auf; das Prozessmuster des gesamten Verlaufs hat die gleiche Gestalt wie ein Ausschnitt der Zeitreihe, nämlich der zwischen Markierung 1 und 3.

rin betraf, aber auch sie selbst sehr belastete, weil damit eigene frühere Traumatisierungen und Stresserfahrungen reaktiviert wurden (Markierung 4 in den Abbildungen 3c, 5a, 8c, d). Es gelang ihr, diese Krise zu meistern und ihrer Lebensgefährtin dabei unterstützend zur Seite zu stehen.

Aus Sicht von Frau A. waren die Arbeit mit ihrem persönlichen Fragebogen und die regelmäßigen Therapiegespräche, die konsequent und kompetent auf die Verlaufsmuster und auf ihr Systemmodell Bezug nahmen, sehr hilfreich und motivierend. Im Unterschied zu einem früheren stationären Therapieaufenthalt, bei dem sie einen Standardfragebogen nur sehr unregelmäßig genutzt hatte, hat sie von den 138 Tagen ihres Therapiemonitorings keinen einzigen Tag ausgelassen.

Das Gesamtmuster des Therapieverlaufs inklusive der 7-wöchigen Nachsorgephase ist in den Abb. 5, 7 und 8 synoptisch dargestellt. Abb. 5 zeigt das Rohwerte- (5a) und das Komplexitäts-Resonanz-Diagramm (5b), in denen die Musterwechsel der Ereignisse 1 und 2 gut erkennbar sind. Im Komplexitäts-Resonanz-Diagramm wird deutlich, dass die Phasen höchs-

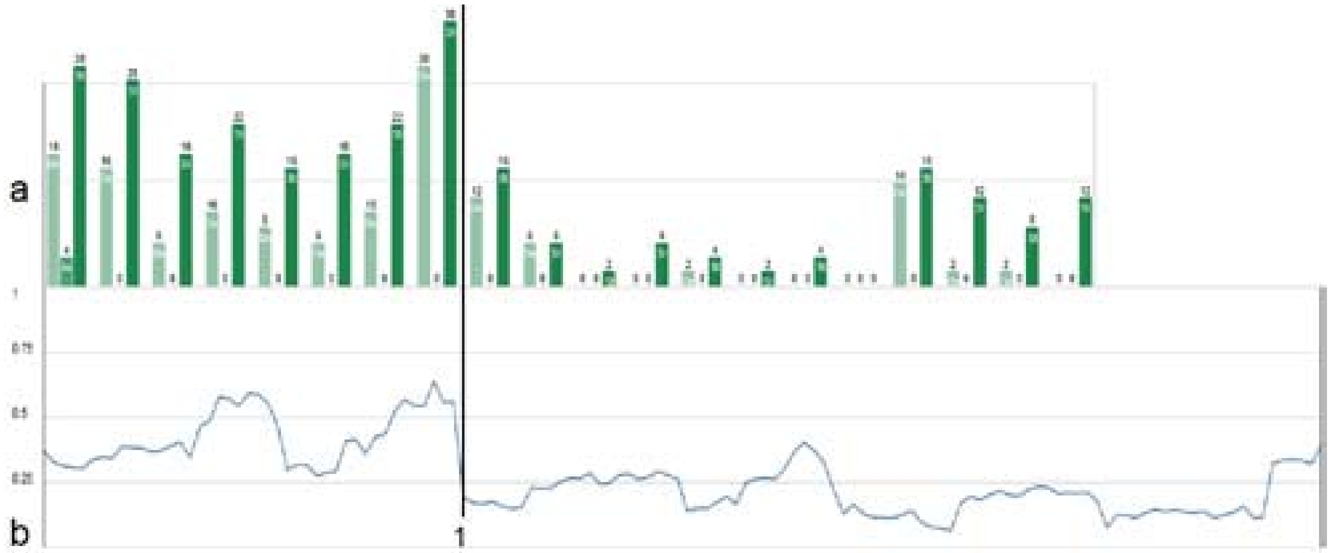


Abb. 7: (a) Depressions- (D), Angst- (A) und Stresswerte (S), resultierend aus den wöchentlichen Einschätzungen im DASS (Lovibond & Lovibond, 1995), die Frau A. im SNS vornahm. Depression und vor allem Stress sind für sie die Hauptbelastungen, Angst tritt bemerkenswerterweise nicht auf. (b) Durchschnittliche Inter-Item-Korrelation über die Absolutwerte der Korrelationen, also ohne Berücksichtigung des Vorzeichens. Der Verlauf zeigt, dass die alternierende (negativ korrelierte) Ordnerdynamik der beiden States das Geschehen im ersten Drittel des Monitoring-Zeitraums deutlich »versklavt«. Die Belastung vor allem durch Stress und diese Versklavung durch die State-Dynamik reduzieren sich exakt zum gleichen Zeitpunkt am ersten Ordnungsübergang der Therapie (Markierung 1). Das Diagramm mit den DASS-Eintragungen ist kürzer, da die Patientin diese Eintragungen mit Klinikentlassung beendet hat, während sie ihren persönlichen Fragebogen, auf dem die durchschnittliche Inter-Item-Korrelation beruht (Diagramm 7b), noch weiterführte.

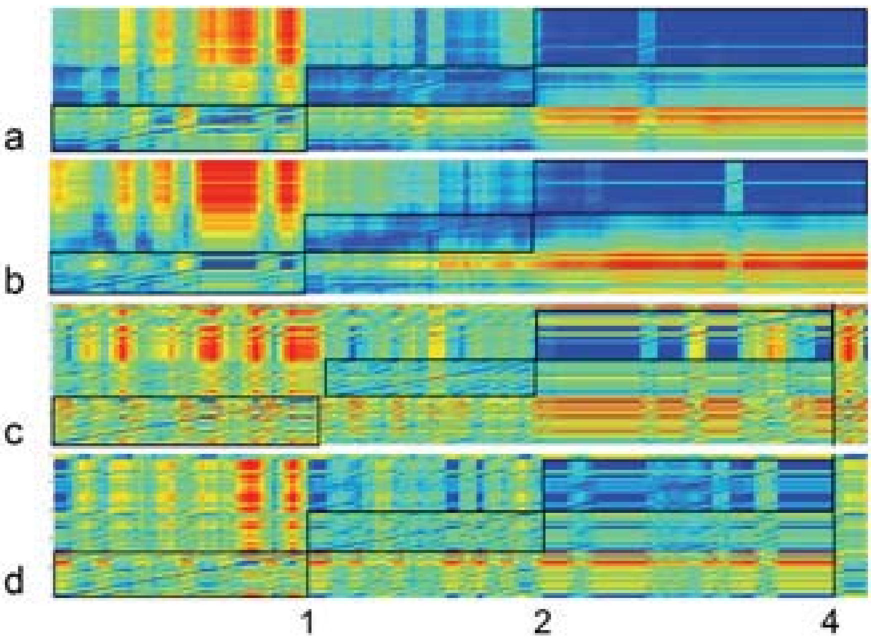


Abb. 8: Farb-Recurrence-Plots der Items (a) »Belastbarkeit«, (b) »Selbstständigkeit« (Faktor II), (c) »Bedürfnis nach Abgrenzung« und (d) »Stress« (Faktor I) (vgl. Abb. 6). Die Ziffern 1 und 2 markieren die beiden wesentlichen Ordnungsübergänge dieser Therapie. Abszisse und Ordinate sind beide als Zeitachsen zu lesen. Wiederkehrende, also ähnliche Kurzabschnitte einer Zeitreihe (recurrent) sind in Richtung von Blauintensitäten, in sich unähnliche Kurzabschnitte (transient) in Richtung Gelb-Rot-Intensitäten markiert. Die einzelnen Blöcke (Zeitabschnitte vor 1, zwischen 1 und 2, nach 2) sind in sich relativ homogen.

ter Komplexität im ersten Drittel der Therapie liegen und sich vorwiegend auf Items des Faktors I beziehen. Vor allem ihre Entscheidung hinsichtlich der beruflichen Perspektive war *der* Ordnungsübergang dieser Therapie (Markierung 1). In der Vorentscheidungsphase intensivierte sich ihr Depressions- und Stresserleben, wie an den Eintragungen erkennbar, die sie wöchentlich in der Depressions-Angst-Stress-Skala (Lovibond & Lovibond, 1995) vornahm (Abb. 7a). Wir sehen hier in den empirischen Messwerten, was wir oft intuitiv spüren, dass nämlich im Vorfeld von persönlichen Entscheidungen und sprunghaften Veränderungen (»sudden gains«, z. B. Hayes et al., 2007) krisenhaftes Erleben stattfindet.

Die alternierende Dynamik der beiden dominanten Persönlichkeitszustände drückte sich auch in einer hohen durchschnittlichen Inter-Item-Korrelation (gemittelt wird hier über die Absolutwerte der Korrelationen, also ohne Berücksichtigung des Vorzeichens) im ersten Drittel des Monitoring-Zeitraums aus (Abb. 7b), mit einem Maximum kurz vor dem Ordnungsübergang (1). Dies entspricht der Beobachtung gesteigerter Synchronisation von Systemkomponenten oder Subsystemen während kritischer Instabilitäten kurz vor einem Phasenübergang (Dakos et al., 2012; Haken & Schiepek, 2010, S. 411 ff.; Scheffer et al., 2009). Die beiden Faktoren »versklaven« – um einen Begriff aus der physikalischen Synergetik zu verwenden – in dieser Zeit als die dominanten Ordner das Erleben, ein Muster, das sich dann zugunsten des Erwachsenen-States (Faktor II) mit seltener erlebten Kind-Anteilen auflöst.[5]

Abb. 8 zeigt die Recurrence Plots der Items »Belastbarkeit«, »Selbstständigkeit«, »Bedürfnis nach Abgrenzung« und »Stress«. Recurrence Plots (Eckmann, Oliffson Kamphorst & Ruelle, 1987; Haken & Schiepek, 2010, S. 395 – 401) illustrieren, wo sich im Prozess bestimmte kurze Abfolgemuster von Werten einer Zeitreihe wiederholen (»recurrent« bedeutet »wiederkehrend«, Blauintensitäten in Abb. 8) oder nicht wiederholen (Gelb-Rot-Intensitäten Abb. 8). Die Musterwechsel bei den Markierungen 1 und 2 sind in allen Diagrammen deutlich erkennbar, obwohl die Zeitreihen der zu Faktor I und zu Faktor II gehörenden Items extrem unterschiedlich aussehen (vgl. Abb. 6). Damit zeigen sich einmal mehr die Vorteile systemischer Analysen, die über eine »Prima vista«-Anschauung hinausgehen.

Für Frau A. erwies sich der systemische Zugang als Rahmung und Orientierung für die traumafokussierte Arbeit als sehr hilfreich. Das bestätigte uns ihr Feedback auch nach Ende ihres tagesklinischen Aufenthalts. Die Arbeit mit dem SNS, ihre aktive Beteiligung an der Therapiesteuerung und die intensive Entwicklungsarbeit eines idiographischen Systemmodells, die von ihr als »Flow-Zustand« erlebt wurde, vertieften auch die therapeutische Beziehung, die sie zu uns und wir zu ihr entwickeln konnten. Frau A. (ebenso wie andere Patienten und Patientinnen) erlebte insbesondere die Entwicklung des idiographischen Systemmodells als »Schlüsselmoment« ihrer Therapie.

Fazit für die Praxis

Das hier vorgestellte Fallbeispiel illustriert das Vorgehen einer systemischen Einzeltherapie. Es folgt einer Definition und Praxiskonzeption systemischer Therapie, die explizit nicht auf Mehrpersonensysteme oder interpersonelle Kommunikation eingeschränkt ist, sondern intrapsychische mit interpersonellen Prozessen verbindet und z. B. auch neuronale Prozesse als Systemprozesse auffasst (in diesem Sinne gibt es auch eine systemische Neurotherapie, wenn sie explizit auf neuronale Selbstorganisation Bezug nimmt, z. B. Tass et al., 2012). Es sei darauf hingewiesen, dass sich das anhand dieses Fallbeispiels illustrierte systemische Verfahren auch in der Paar- und Familientherapie nutzen lässt und auch schon erprobt wurde (idiographische Systemmodellierung, Entwicklung persönlicher Prozesserfassungsbögen, Prozessmonitoring und -feedback, dynamische Analyse interpersoneller Muster).

Aus den Erfahrungen dieser Therapie lassen sich einige Konsequenzen für die Praxis ableiten:

- Das Konzept des synergetischen Prozessmanagements lässt sich auch in der Zusammenarbeit mit Menschen realisieren, deren Erleben von schweren Traumatisierungen und einer komplexen strukturellen Dissoziationen der Persönlichkeit geprägt ist.
- Das Vorgehen unterstützt nicht nur einen expliziten Lernprozess, nämlich das Verständnis von psychischen Systemzusammenhängen und Systemdynamiken (Förderung von Systemkompetenz), sondern auch einen impliziten Lernprozess, der auf den Erfahrungen von Kooperation, Transparenz und Eigeninitiative, also einem partizipativen Prozessmanagement beruht.
- Systemische Praxis im Sinne des synergetischen Prozessmanagements ist ein Metakonzept, innerhalb dessen sich traumatherapeutische und state-bezogene Praxiskonzepte (z. B. Dietrich, 2016; Flatten, 2011; Nijenhuis, 2015, 2016; van der Hart, Nijenhuis & Steele, 2008) umsetzen lassen.
- Alltagsamnesien und State-spezifische Aufmerksamkeitsfokussierung begrenzen den Wahrnehmungs- und Verständnishorizont der betroffenen Personen. Eben darin liegt ja das Problem von Dissoziationen. Die Erarbeitung idiographischer Systemmodelle und ein konsequentes Prozessfeedback erweitern dagegen das Verständnis und eröffnen eine Art »Vogelperspektive« auf die psychische Netzwerkdynamik.
- Betroffene Menschen stehen oft ebenso verwirrt vor den extremen und scheinbar erratischen Emotions- und Befindlichkeitsschwankungen wie der naive Betrachter (vgl. z. B. Abb. 6c, d). Um hier Ordnung ins Chaos zu bringen, erweisen sich die Analysetools des Synergetischen Navigationssystems als sehr hilfreich. Die Systemmodellierung liefert eine inhaltliche, das Prozessmonitoring eine zeitliche Metaperspektive.
- Ansatzpunkte für Veränderung lassen sich über die Variablen eines Systemmodells und die dadurch repräsentierten Teilprozesse von Sta-

[5] Die Analogie zwischen Persönlichkeits-States (vgl. das verwandte Konstrukt der »States of Mind« im Sinne von Horowitz, 1987) und Ordnern im Sinne der Synergetik findet sich an einem empirisch analysierten Fallbeispiel bei Beirle & Schiepek (2002) sowie in Haken & Schiepek (2010, S. 328 – 343).

tes leichter identifizieren als an den States selbst. Sie werden dadurch gewissermaßen griffiger, als die in sich homogenen States es sind. (Wir waren übrigens erstaunt, dass die Einteilung der Variablen im Systemmodell zu den beiden Faktoren genau den beiden dominanten States entsprach, denn weder die Systemmodellierung noch diese Einteilung wurde unter Rückgriff auf das Konzept der dissoziativen Persönlichkeits-States durchgeführt. Wir werten das als eine Validierung des idiographischen Modells.)

- Flatten (z. B. 2011) beschreibt die Fragmentierung von kognitiv-emotionalen Netzwerken mit entsprechender Fragmentierung neuronaler Netze als wesentliches Korrelat von Traumatisierungen. Genau hier setzt die idiographische Systemmodellierung an und schafft zusammen mit dem Prozessmonitoring neue Synthesen im Verständnis und im Erleben (Mentalisierung). Hier würde sich eine weiterreichende Integration der Ansätze anbieten, zumal Flatten sich explizit auf die Synergetik bezieht.
- Auch die Konzepte der strukturellen Dissoziation mit »anscheinend normalen Persönlichkeitsanteilen« (ANPs) und »emotionalen Persönlichkeitsanteilen« (EPs mit sowohl fragilen wie auch kontrollierenden Substrukturen, Nijenhuis, 2016) ließen sich im Systemmodell von Frau A. wiederfinden. Auch hier lassen sich Bezüge herstellen, wobei darauf hingewiesen sei, dass die Systemmodellierung zunächst möglichst konzeptfrei und multiperspektivisch durchgeführt werden sollte. Kriterium ist im Konstruktionsprozess die dialog-konsensuelle Validierung mit der Patientin.
- Die dem generischen Prinzip 2 zuzurechnende systemische Fallkonzeption mit Systemmodellierung und Systemmonitoring unterstützt die Realisierung anderer generischer Prinzipien, z. B. 1, 3, 4, 5 und 6 (Schiepek, Eckert & Kravanja, 2013).
- Die therapeutische Arbeit bereitete die stattgefundenen Ordnungsübergänge vor, aber sie wurden nicht durch gezielte »Interventionen« verursacht. Einmal mehr stellt sich auch in diesem Fall Therapie als ein Prozess dar, der Bedingungen für Selbstorganisationsprozesse schafft.
- Die »Unschärferelation« der Psychotherapie erweist sich nicht als größeres Problem. Diese besteht darin, dass ein Prozessmonitoring einerseits eine valide Messung eines Therapieverlaufs liefern soll, andererseits aber auch den »Messgegenstand«, also die Systemdynamik der Patientin, verändert, indem es therapeutische Effekte realisiert.
- Idiographische Systemmodelle stellen nicht nur einen Ausgangspunkt für die individuelle Therapieplanung und -steuerung dar, sondern auch einen Bezugspunkt für die Zusammenarbeit und die Synergieeffekte von FachtherapeutInnen in klinischen Einrichtungen. Somit sollten sie in fachübergreifenden Teambesprechungen immer präsent sein.

➔ Summary

Systemic Case Formulation and State Dynamics in a Female Patient with Structural Personality Dissociation

The case example describes the synergetic process-management procedure with reference to an instance of psychotherapy in a day-treatment setting. The patient in question had a borderline personality disorder plus a complex dissociative disorder. The patient's development was accompanied and reflected upon by means of process monitoring based on a personal questionnaire completed on a daily basis. The monitoring process plus regular process feedback were initiated via the development of an idiographic system model elaborated with the patient in a work session lasting *ca.* 3 hours. It was essential for the patient to recognise how the various states of her personality were represented in the components of the model and how in psychological terms this helped to understand and explain the transitions between the different states and their respective triggers. With the Synergetic Navigation System (SNS) the patient was able to gain insight into the dynamics and the progress patterns of her personality

WERKZEUGKASTEN

- Ressourceninterview und idiographische Systemmodellierung sind praktikable Methoden der systemischen Fallkonzeption.
- Einen individuellen Prozessfragebogen zu erstellen ist mit dem Fragebogeneditor des SNS leicht machbar.
- Systemische Praxis verfügt über das »Werkzeug« eines hochentwickelten, Internet-basierten Monitoring- und Analysesystems (SNS).
- Alle Schritte des Vorgehens erfolgen in enger Zusammenarbeit (ko-kreativ) mit den PatientInnen. Modellierung und Messung sind somit integrale Bestandteile der Therapie.
- Das systemische Vorgehen ist mit Methoden der Traumatherapie gut kombinierbar.
- Das Vorgehen ist in der Therapie von Borderline- und Dissoziativen Persönlichkeitsstörungen nützlich anwendbar.
- Entsprechende Kompetenzen der Gesprächsführung, der Systemmodellierung und der Technologiehandhabung (inkl. geeigneter Supervision und Intervision) sollten in systemischen Ausbildungscurricula vermittelt werden.

states (established via daily self-assessments). This was the basis for change in the way she reacted to those states. The effects achieved in the sectors »self-related information processing« and »identity development« were remarkable. Idiographic system modelling in combination with SNS enabled both the therapist and the patient to achieve a detailed understanding of the patient's personal psychodynamics and the process patterns displayed by therapy.

Keywords: idiographic system modelling, systemic case conception, therapy feedback, synergetic navigation system, structural personality dissociation, borderline personality disorder

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Systemic Case Formulation, Individualized Process Monitoring, and State Dynamics in a Case of Dissociative Identity Disorder

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Objective: The aim of this case report is to demonstrate the feasibility of a systemic procedure (synergetic process management) including modeling of the idiographic psychological system and continuous high-frequency monitoring of change dynamics in a case of dissociative identity disorder. The psychotherapy was realized in a day treatment center with a female client diagnosed with borderline personality disorder (BPD) and dissociative identity disorder.

Methods: A three hour long co-creative session at the beginning of the treatment period allowed for modeling the systemic network of the client's dynamics of cognitions, emotions, and behavior. The components (variables) of this idiographic system model (ISM) were used to create items for an individualized process questionnaire for the client. The questionnaire was administered daily through an internet-based monitoring tool (Synergetic Navigation System, SNS), to capture the client's individual change process continuously throughout the therapy and after-care period. The resulting time series were reflected by therapist and client in therapeutic feedback sessions.

Results: For the client it was important to see how the personality states dominating her daily life were represented by her idiographic system model and how the transitions between each state could be explained and understood by the activating and inhibiting relations between the cognitive-emotional components of that system. Continuous monitoring of her cognitions, emotions, and behavior via SNS allowed for identification of important triggers, dynamic patterns, and psychological mechanisms behind seemingly erratic state fluctuations. These insights enabled a change in management of the dynamics and an intensified trauma-focused therapy.

Conclusion: By making use of the systemic case formulation technique and subsequent daily online monitoring, client and therapist continuously refer to detailed visualizations of the mental and behavioral network and its dynamics (e.g., order transitions). Effects

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on self-related information processing, on identity development, and toward a more pronounced autonomy in life (instead of feeling helpless against the chaoticity of state dynamics) were evident in the presented case and documented by the monitoring system.

Keywords: idiographic system modeling, systemic case formulation, real-time monitoring, therapy feedback, Synergetic Navigation System (SNS), personality states, borderline personality disorder, dissociative identity disorder

INTRODUCTION

Psychopathologies are marked by cognitive, emotional, and behavioral deviations that form a major burden on the life of clients and simultaneously hinder the cure of these pathologies. Eventually, the tools needed to bring along psychotherapeutic progress are affected by syndromes, making that what is to be cured an integral part of the cure itself. This circularity makes it understandable that patients with severe pathologies, as, e.g., personality disorders, dissociative identity disorder, or schizophrenia, generally remain in treatment for longer and have a poorer projected outcome. It is especially in such severe cases, where therapists face clients with troubled focus when in dialog, impaired memory, or labile emotional conditions which affect therapeutic sessions and render some psychological techniques unfeasible. However, when therapy (i) is marked by a focus on resources rather than pathologies, (ii) makes use of highly individualized techniques, (iii) entails systemic and systematic mapping of the psychological landscape of a client, and (iv) allows for high-resolution monitoring of the ongoing processes therein, one can hypothesize that a client will feel apprehended, better understand seemingly volatile processes and enter a sense of agency. Thereby, one actually turns around the above described problematic circularity and utilizes it for a better psychotherapeutic progress, also in severe cases.

In the present paper we report on a client with dissociative identity disorder and co-morbid borderline personality disorder that followed a therapeutic approach that has earlier been described as synergetic process management (Haken and Schiepek, 2010; Schiepek et al., 2015, 2016). Making use of an online monitoring system (Synergetic Navigation System, SNS) which allows for therapeutic feedback and management, synergetic process management entails

- a resource-focused interview,
- the development of an idiographic system model, covering psycho- and socio-dynamics, from which one derives
- an individual process questionnaire for daily online monitoring,
- regular therapeutic sessions with feedback on basis of the current data-profile (continuous cooperative process control), and
- out-patient aftercare with the Synergetic Navigation System as bridging technology.

The aim of this case study is to present in detail the applied therapeutic procedure and confirm the hypothesis that an individualized, systemic, feedback-driven, monitoring-based therapy approach is not only a viable method for severe psychopathologies, but also an "interscholastic" approach, independent of psychotherapy "schools" and confessions.

METHODS

The Client

The client (Mrs. A.) was a middle-aged German woman with long-term experience as employee of a tax accountant office. After a number of subsequent heterosexual private relationships, in which she was exposed to continuous violence and at times sadistic behavior by her partners, she lived in a lesbian partnership with a same aged woman. When entering the day-treatment program, she had been on sick leave for a longer period and had previously completed an in-patient treatment at the same clinic 1 year before. Despite many traumatizing events since childhood (e.g., mobbing in school, social isolation in puberty, violence in relationships), she managed to uphold 15 years of dedicated office work for the same employer and lead a rather orderly life. The takeover of "her" accountant office by an external firm and the accompanying loss of job, marked the beginning of a crisis for Mrs. A. New foci in her life became automutilation, changing dissociative personality states with mutual amnestic nature, subsequent chronologic disorientation and insecurity about her behavior in these separate states, lack of concentration, and feelings of de-realization (e.g., certain situations with diffused incidence of light possibly carried Mrs. A. back to childhood). At times, amnesias could block memory of entire days. The diagnostic exploration of these experiences through the SKID-D (Gest et al., 2000) suggested a "complex dissociative disorder" (dissociative disorder not otherwise specified, F44.9), while fulfilling the criteria of the DSM-5 diagnoses of a borderline personality disorder (301.83) and other specified dissociative disorders (300.15). According to the nomenclature of Nijenhuis (2016; Nijenhuis and van der Hart, 2011), Mrs. A. could be diagnosed with a "minor dissociative identity disorder," in terms of a tertiary structural dissociation. Besides these formal clinical attributes, she was concerned whether she would be able to have a healthy life again and form an own, congruent identity. She described herself as a "blank sheet of paper," ready for anyone to come along and write on her as he or she pleases—a metaphor for the assaults and abuses she had experienced.

Resource-Focused Interview

In a resource-focused interview, therapist and client first assessed the major challenges of the client's life, taking into account that topics need to be changeable and goals reachable. Mrs. A. reported that she would like to "be able to distance herself from loud noises and intrusive voices in her direct surrounding" (note that these are real life situations as e.g., in the office and not psychotic hallucinations). Furthermore, she wanted to have "stability in life" and "find a job," the latter she would dismiss throughout therapy as too big a burden. Secondly, therapist and client explored in a dialogical fashion the resources of the client, which were in a third step rated for their current, desired and potential manifestation. As resources, Mrs. A. experienced the felt love for her partner, she enjoyed listening to music (as means to distance herself from unpleasant sounds around her), knitting, liked herself for having a dry and at times satirical humor, being a good listener, a general patience and endurance. Also, she saw herself competent in terms of being a reliable person, having a pool of positive memories (e.g., odors from her childhood) and her "head-cinema"—a technique she invented for herself in which she uses aggressive fantasies featuring the perpetrator of intrusive sounds, in order to channel off her disturbance. Even though some of these resources might appear questionable, the condition of Mrs. A. at the beginning of therapy was such that she truly felt these were capacities and resources that help her in life.

The rationale behind applying a resource-focused interview at the beginning of treatment is manifold. Foremost, it sets a positive antipode to classical psycho-diagnostics, which almost exclusively focus on pathology. Many clients—and so did Mrs. A.—experience the positive tone and direction of such an interview as a relief and a reminder of one's strengths, creating a positive mindset. A second benefit of the rather open and loosely structured resource interview, is its function as a prelude to the idiographic system model, priming the search for psycho-social relevant variables in a client's life.

Idiographic System Model

As the chronological next part of the synergetic process management, one tries to produce a list of important psychological and social variables of the client in a second interview. Starting off with e.g., a general picture of the client's life in the last couple of months, the therapist takes note throughout the interview of important factors such as psychological problems, problem-solving methods, coping strategies, and impact on social life. These notes will form the basic components of the to be developed idiographic system model (Schiepek, 2003; Schiepek et al., 2015). Therefore, virtually any topic of importance to the client can be part of the interview and enter the system. It is advisable to try to capture the actual terms of the client's language, in order for client and therapist to achieve mutual understanding and produce the client's very own individual model. After the interview, all variables are checked for their terminology and content, to make sure that the client can find him or herself therein. It is important that the components are expressed as variables that can change throughout time. In a perfect case, therapist and client manage to capture all important bio-psycho-social aspects of the client's life, incorporating cognitions, emotions, motives, behavior, physiological states and more, yet by using the client's own language and terminology.

Subsequently, the inter-connections of these variables are mapped, creating a personal landscape of relevant aspects of the client's mental functioning—the idiographic system model (ISM).

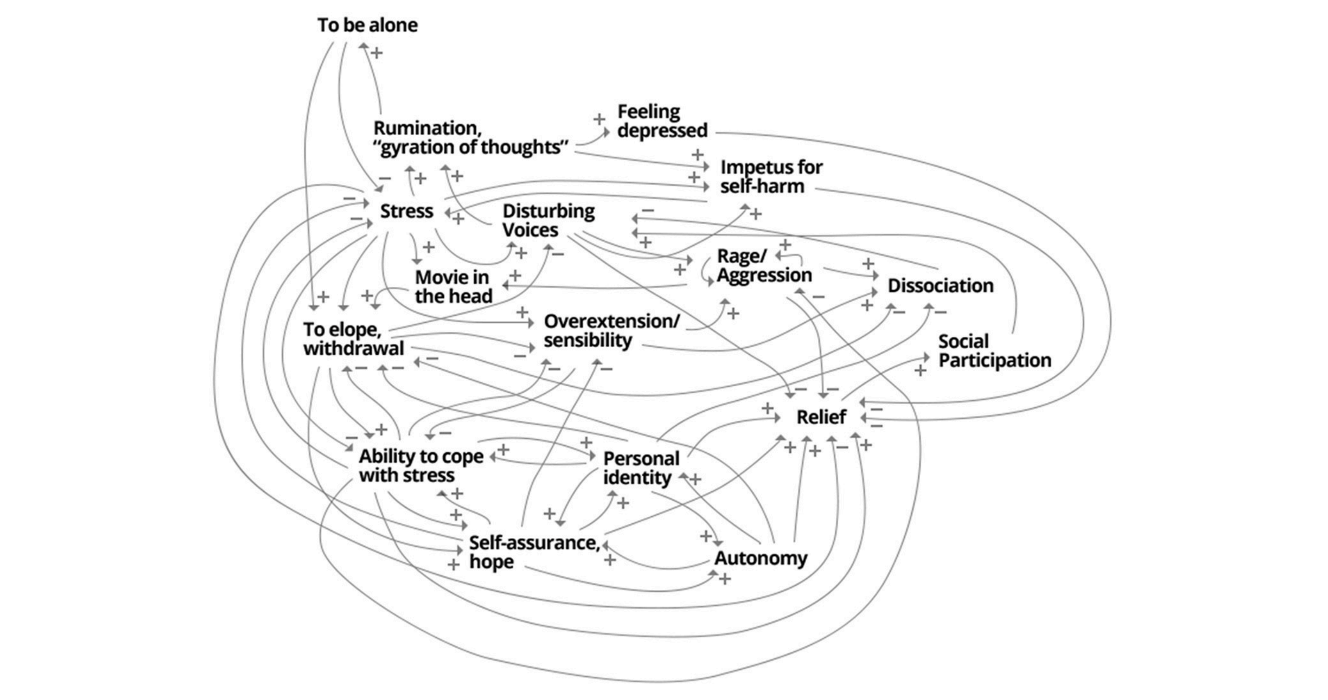

FIGURE 1 | The idiographic system model of Mrs. A. A synopsis of psycho- and socio-dynamical aspects of the patient's experiences.

Using a flipchart, a variable A is written down and the list is checked for other variables that are connected to it. Writing down a second connected variable B, both are linked with an arrow and a + or − symbol, indicating whether there is a positive relation (same-directed: increase in A leads to increase in B and decrease in A leads to decrease in B) or a negative relation (opposite-directed: increase in A leads to decrease in B and decrease in A leads to increase in B). As can be seen in **Figure 1**, Mrs. A. e.g., described that an increase in "dissociation" is accompanied with a decrease of the distraction through "disturbing voices," indicated by a — between the two variables. In contrast and symbolized by a +, the more "rage/aggression" she experiences, the more she needs to switch on her "movie in her head (head-cinema)," and a decrease in aggression makes that coping-mechanism less necessary.

Mrs. A. managed to create her complete ISM in a session of 3 hours, being in a, as she described it, "focused flow" only interrupted by a short break. In contrast to her everyday life experiences of dissociative absences, she managed to keep up her concentration fairly uninterrupted through this intensive session. She reported to find herself very well represented by the model and brought a small copy of the model to almost all therapeutic sessions, referring to it as "the map of my soul". Often, the model helped her to better understand patterns of her own behavior, and how in a systemic fashion, cognitions, emotions and behaviors could trigger each other. In a second step, the client attributed many of the variables to be differentially prominent in separate personality states. That understanding was the basis for seeing patterns, that before had presented themselves as volatile and erratic alternations of these states. In contrast to her everyday life experience, the ISM functioned as a systemic and systematic synopsis of her psychological and social life, making amnestic separations of important aspects visible. Consequently, this understanding allowed trauma-focused therapy and intensive work directed toward the different states (Nijenhuis, 2015, 2016).

Individual Process Questionnaire and Monitoring

After completion of the idiographic system modeling, therapist and client made use of the editor in the Synergetic Navigation System (SNS) and created an individual questionnaire (this happened two sessions after the ISM, because the intermediate session had been marked by lack of concentration of Mrs. A.). **Table 1** shows the items of the personalized questionnaire, based on the variables of the ISM. The client filled in each item on a visual analog slider, ranging from "not at all" to "very much," which is subsequently scored on a scale from 0 to 100.

The actual formulation of the items is thereby dictated by the client, the therapist merely advises and live-edits the questionnaire online. An example of the time series of four items is given in **Figure 2**. Mrs. A. classified the items into two factors, which interestingly turned out to be in accordance with two dominant states (comprised of sets of sub-states); as can be seen in **Figure 3A**, a "child-state" (in terms of the conceptualization of a structural dissociation: emotional personality aspects, EP's) and an "adult state" ("apparently normal personality aspects," ANP's; **Figure 3B**). During the first third of the monitoring process, these two states showed a rather alternating dynamic, excluding the presence of each other (**Figure 3C**, until flag 1). Mrs. A. filled in this personalized questionnaire online daily, not missing a single day.

TABLE 1 | The 18 items of the individual questionnaire of Mrs. A.

I Stress and Coping (state-cluster "child", EP, corresponds to factor I of the individual questionnaire)
1. Today, I experienced stress …
2. Today, I had to activate my "head-cinema" ("movie in the head") …
3. Today, I zoomed out - dissociated …
4. Today, it was important to me to be alone …
5. Today, the depression carried me away …
6. The impulse to hurt myself was today …
7. Today, I ruminated …
8. The intrusive voices were today …
9. My level of aggression was today …
10. My level of anger was today …
11. Today, I felt overwhelmed …
12. My need for distancing myself from others was today …
II Positive goals and development of identity (state-cluster "adult", ANP, corresponds to factor II of the individual questionnaire)
13. Today, I felt resilient and able to cope with stress …
14. My feelings of inner security were today …
15. My feelings of independence were today …
16. The sense of my own inner identity was today …
17. Today I had a sense of relief …
18. Today, I took part in social life …

*Match the 18 variables of her ISM, as shown in **Figure 1**, separated into two factors. The client answered these items daily via the online monitoring system SNS. Each question is scored by a visual analog slider (VAS), ranging from 0 to 100 and extrema of "not at all" to "very much" (where applicable).*

Visualization and Analysis Methods

Raw-Data Resonance Diagrams

In order to grasp the process and therapeutic changes, the time series of each item can be plotted in one diagram each (comp. **Figure 2**). In these diagrams, each item or factor has to be drawn as a single line, making it difficult to get a synoptic overview of the 18 items Mrs. A. filled in daily. In order to get such synopsis, one can use the visualization of raw-data resonance diagrams in the SNS, which allows for visualization of all items in a single diagram. Here, the manifestation of each item is expressed by a color-coded scale. As can be seen in **Figure 4A**, all items are depicted as separate rows, while each column represents a single day. Each cell represents the response of the client on that respective day on a scale ranging from low (blue) via medium (green and yellow) to high scores (red).

Complexity Resonance Diagrams

In order to analyze the changing complexity of each item, a measure called "dynamic complexity" can be calculated in a moving window of freely selectable width (here: 7 days) and displayed as variation in time for each item of a questionnaire.

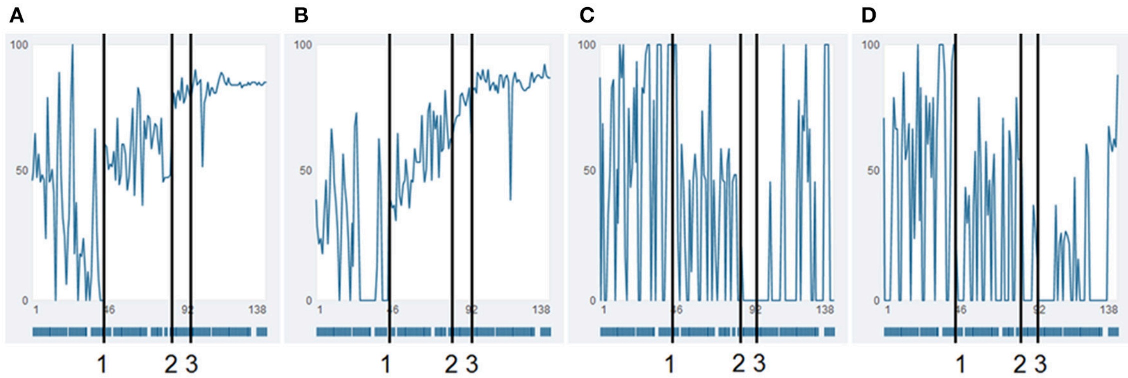

FIGURE 2 | Raw data time series of four items. Time series of the raw data of items “resilience/ability to cope with stress” **(A)**, “autonomy” **(B)** (both factor II), “withdrawal” **(C)**, and “stress” **(D)** (both factor I). Numbers 1 and 2 indicate time points, where not only the absolute values of the time series suddenly shift, but also new dynamic patterns emerge. Such transitions and re-stabilizations are generally denoted in complex systems theory as order transitions. It is noteworthy, that even though the shifts present themselves as sudden tipping points, these are not necessarily caused by a singular event, but can be the result of a continuous underlying process, affecting the complete system of the patient, such as e.g. ongoing psychotherapy. Number 3 is the day of dismissal from the day-treatment clinic. **(A,B)** show extreme, irregular fluctuations at beginning until flag 1. Phase two of these items is marked by similar fluctuations, however with less extreme values. The items in Figures **(A,B)** show a general absolute increase with simultaneously decreasing fluctuations (dynamic complexity), and with specific pattern transitions. The item “resilience” shows the pattern of self-similarity; the whole process has a similar “Gestalt” as a shorter part of the time series, between flag 1 and 3.

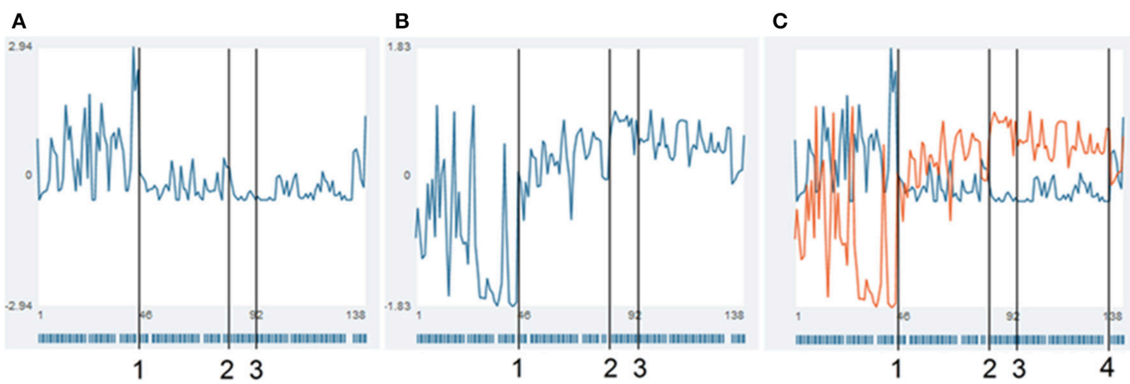

FIGURE 3 | Time series of two factors, combining all items of Mrs. A. Time series of the superordinate factors of Mrs. A. Each time-point represents the standardized mean of the respective items per factor. **(A)** Stress and coping (“child”-states, factor I), **(B)** positive goals and development of identity (“adult”-states, factor II), **(C)** superposition of the time series (blue, factor I and orange, factor II). The bar-code like stripes at the bottom of each diagram depict the days Mrs. A. used the commentary function of the SNS (the diary entries are shown in the SNS when the mouse is moved over a time point). Clearly visible are the alternating extrema of the two state-clusters in the first half of the therapy (until flag 1). Vertical lines (1) and (2) indicate order transitions in the patterns of the time series, flag 3 defines the day of dismissal from the day-treatment clinic, at (4), a personal crisis in the client’s private life occurred.

Dynamic complexity is composed of a fluctuation and a distribution value (Schiepek and Strunk, 2010). Fluctuation is computed for each window, using the number of directional changes of the values and the size of each daily in-/decrease. Distribution is a parameter that increases when the values of a time series within a respective window make use of the complete spectrum of the scale and if the scores are evenly distributed across the scale. The resulting dynamic complexity can be thought of as an own time series per item. In the complexity resonance diagram (CRD), this time series of the dynamic complexity is expressed as rainbow colored pixels, while each pixel corresponds to the amount of complexity within a specific item and within a certain time window (see **Figure 4B**). Ranging from no dynamic complexity (blue) to strong complexity (the maximum of each matrix is depicted as deep red), these CRDs thus allow for identification of periods with strong simultaneous change and also periods of stable scores across the complete underlying questionnaire.

Moving Correlation Matrices

The items of a process questionnaire (here: two factors and their respective items) can be correlated in moving time-windows. In it, all inter-item Pearson’s r correlations are calculated in shifting correlation matrices for a time window of free choice (here: 7 days). Each cell depicts the correlation of a respective item with another item on a graded green (positive) and red (negative) scale, with intensities of green corresponding to positive correlations, white corresponding to 0, and intensities of

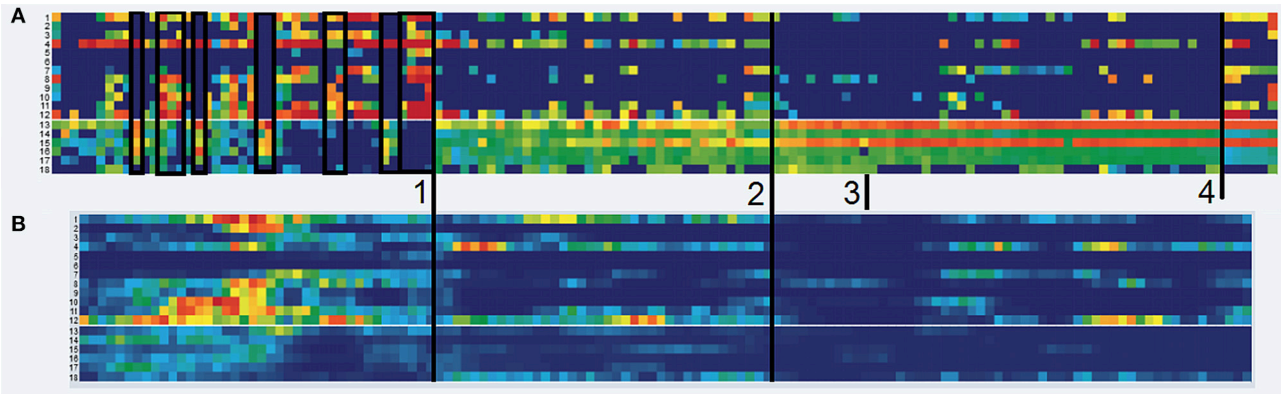

FIGURE 4 | Raw data resonance diagram and complexity resonance diagram. (A) Raw-data Resonance Diagram. Depicted are the manifestations of the time series per item (row). The original scores ranging from 0 to 100 are transformed to a continuous rainbow-like color-scale ranging from blue (0) via turquois, green and yellow (increasing medium scores) to red (100). The slim white demarcation between row 12 and 13 discriminates the factors (see **Table 1**). Black frames underline periods of alternating item scores and manifestation of Mrs A.'s states in the first third of the monitoring period (until flag 1). **(B)** Complexity Resonance Diagram. Depicted is the dynamic complexity in overlapping time windows (window width = 7 days). The maximum score of the dynamic complexity is depicted by a full red pixel, while all other values are graded according to that maximum (red = high, yellow = medium, blue = low complexity). The cluster of high dynamic complexity occurs especially in the items of factor 1 before flag 1, corresponding to the intensely fluctuating and mutually exclusive states.

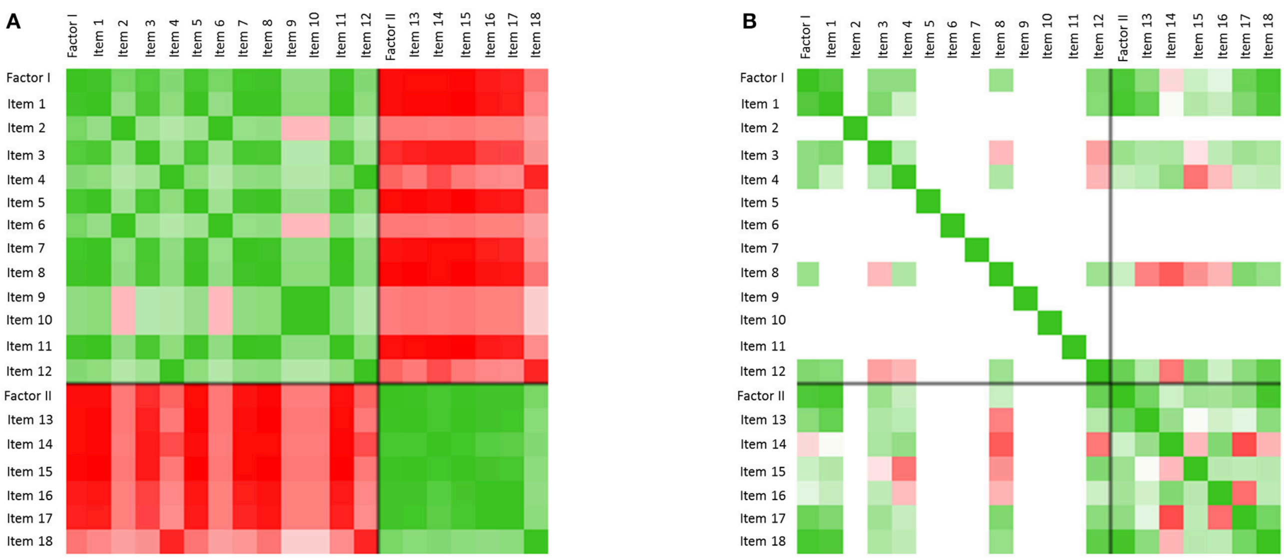

FIGURE 5 | Inter-item correlation matrices. (A) Color-coded inter-item correlation pattern characterizing the first third of the monitoring period (before flag 1). Each cell depicts the correlation of a respective item with another item on a gradual green (positive correlation values, $0 < r < 1$) or red (negative correlation values, $-1 < r < 0$) scale (white cells correspond to a correlation of 0). The black cross in each matrix differentiates items from factor I and factor II. The left matrix ($t = 41–47$) is characterized by high positive within-factor item correlations and negative between-factor item correlations (green and red blocks per factor). **(B)** Only some days later ($t = 49–56$), but after the first order transition of the therapy (occurring at flag 1), this pattern dissolved. The change of correlation patterns concurs with Mrs. A.'s reports of increasing integration of her separate personality states throughout the therapeutic process.

red corresponding to negative correlations. **Figure 5** depicts to this method.

Recurrence Plots

Psychological patterns such as alternating states reoccur over and over in Mrs. A.'s life. One way to visualize the similarity of dynamics in a time series is the method of recurrence plots (Eckmann et al., 1987; Webber and Zbilut, 1994; Haken and Schiepek, 2010, S. 395–401). In these, the values of a time series are transposed to vectors in a phase space defined by time-delay coordinates. Since sequences of measurement points are transformed into time-delay coordinates, it is possible to depict the reoccurrence of the measurement sequences (vector points) and thereby to identify the similarity or dissimilarity of patterns throughout time. The Euclidic distance between vector points is directly transferred to a color scale (blueish colors are "recurrent," and warm colors from yellow to red are "transient"). In **Figure 7**, the dynamics of the items "resilience/ability to cope with stress" (**A**), "autonomy" (**B**) (both factor II), "withdrawal" (**C**), and "stress" (**D**) (both factor I) are analyzed using the method of colored recurrence plots. The advantage of this technique becomes especially evident when looking at the raw value of these four items, as shown in **Figure 2**. The three periods suggested through the recurrence plot would not be as obvious in the time series itself. Identifying such periods might however be important information for therapeutic understanding and intervention, only accessible through a holistic conceptual approach which combines high-resolution monitoring techniques and appropriate analysis techniques.

RESULTS

State Dynamics

During the first third of the complete monitoring period and almost the first half of the therapy, the two states described above (a "child-state," corresponding to factor I, and an "adult state," corresponding to factor II, see **Table 1**) showed rather alternating dynamics, excluding the presence of each other (**Figure 3C**, until flag 1). This pattern of alternating states is visible through the volatile contrasts between items 1 and 12 of factor I and items 13 to 18 of factor II, for the period until mark 1. In the raw data resonance diagrams these contrasts occur in blocks, as is underlined by black frames in **Figure 4A**. In this period, the dynamic complexity of most of the factor I items realizes the most pronounced values (**Figure 4B**), corresponding to the volatility and extremely erratic fluctuations of the components of her cognitive-emotional system (comp. **Figure 2**).

Figure 5A shows this pattern of alternating and mutually exclusive states in terms of inter-item correlations. The correlation matrix refers to inter-item correlations calculated for the therapy days 41–47 (window width = 7 days). The two prominent green blocks of the matrix (upper left green block: factor I, lower right green block: factor II) underline the high correlation of the items within the factors, which is realized during almost the complete first half of the therapy in a similar way. During this period, the correlation of the items with respect to the items of the other factor is highly and consistently negative, as the red blocks in **Figure 5A** show. This asynchrony of the two factors mirrors the exclusive alternation of the respective personality states during the early state of the therapy.

Order Transitions

Before and throughout the first half of the therapy, Mrs. A's case was marked by a pattern of (roughly) daily interchanging personality states. At a certain point during the therapy (marked as time point number 1 in all applicable figures) that alternating pattern disappeared. That is when the client abolished her previous goal to soon enter the first labor market again (see resource-focused interview), which she described as a great relief. An attractive job offer by a friend had triggered days of ambivalent feelings, ambiguity, and inner conflicts (see theory-compliant fluctuations just before flag 1 in **Figure 3**). Instead of her earlier behavior of allowing others to—as she herself put it—"whip her into" new situations, she was capable of allowing herself to turn down the offer. She experienced this decision as big liberation, listening to her inner voice. A process enabled by previous work on traumata and states, in which the creation of the idiographic system model and thereby a better understanding of mechanics of her state dynamics played a major role (e.g., understanding the relation between voices experienced as disturbing and incidences of traumatizing violence in earlier relationships). Mrs. A.'s entry in her SNS-based electronic diary at this order transition said: "...I have the feeling of being myself again (...) the last couple of days were unpleasant and painful. (...) Decisions for the time after the hospital stay have been made, which are better for me. I want to make peace with myself; that does not always work out, but is so important!! Because the last years I always tried and worked on myself to find work again, but always felt so much stress and pressure (...) and that is not how things work!! My switches are set differently (...), in order to have some room for peace and let the stress go and to think about, what I really want to do and what I could work. (...) I will not surrender, to nothing and nobody!!"

This pattern transition can also be seen in the raw-data time series of the items (comp. **Figure 2**: "resilience/ability to cope with stress" (**A**), "autonomy" (**B**), "withdrawal" (**C**), and "stress" (**D**), of which especially the last two show seemingly erratic fluctuations). The integration of all items into the two main standardized factors as shown in **Figure 3**, make the order-transition after almost half of the therapy much more evident. Also the mutual exclusive correlation pattern of the personality states (items of factors I and II, see **Figure 5A**) disappeared almost immediately after the order transition (**Figure 5B**). All this information was integrated into the ongoing therapy, clarifying the change in terms of state dynamics and related cognitions and emotions, both for the therapist, as well as for the client.

This crisis and the resolution thereof was accompanied by an increase of depression- and stress-scores (assessed by the weekly administered DASS-21, Lovibond and Lovibond, 1995), followed by a drop to low scores on these attributes just at the order transition (**Figure 6A**).

A second change of pattern occurred some 5 weeks later (flag 2 in **Figures 2–4**, **7**). Mrs. A. had bought presents for her partner's hobby, spending so much money that she had to ask her parents for financial support. She experienced that as regress to childhood, activating "child"-related states. It triggered a small crisis, which in contrast to the first crisis played out on a "high level." She managed to utilize the crisis by means of the idiographic systems model to yet better understand her psycho-dynamics. In combination with the therapeutic sessions, she progressed from the crisis into a more stable pattern as can be visualized by many items of her questionnaire (see **Figures 2–4**, after flag 2).

Mrs. A. left the day-treatment clinic 10 days after resolving this second crisis. The dismissal as such appeared to not have caused any turbulence (**Figures 2–4**, flag 3). As bridging technology to aftercare, Mrs. A. chose to continue filling in the daily questionnaires. She reported that the routine of filling in helped her as self-referential support and in widening personal

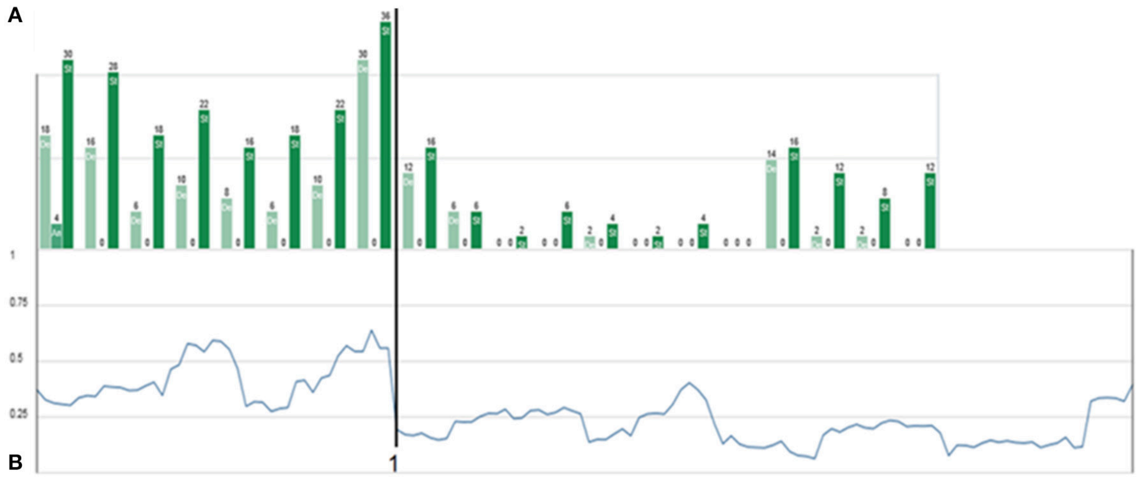

FIGURE 6 | Weekly DASS-21 progress and absolute inter-item correlation. (A) Triplets of depression (light green), anxiety (medium green), and stress scores (full green), resulting from weekly assessment of the DASS-21 (Lovibond and Lovibond, 1995). Depression and stress are expressed strongly, while anxiety scores are surprisingly low. The order transition (flag 1) is characterized by an increase and sudden drop in stress and depression scores. **(B)** Mean absolute inter-item correlation of all possible correlations (averaging without respecting the sign of the correlation values) of the personalized 18 items of Mrs. A.'s individual questionnaire. The order transition is—in accordance with complex systems theory—preceded by a (local) maximum of the inter-item-correlation. The overall higher inter-item-correlation before flag 1 might be interpreted as the presence of an "enslaving" state dynamics, which reduces the degrees of freedom in the patient's life.

perspectives, creating a sense of stability. Just before the projected monitoring end, 7 weeks after dismissal and after 138 days in total, Mrs. A. experienced another crisis. An incidence in her partner's life reactivated own traumata and stressors (flag 4 in **Figures 3C**, **4A**, **7**). However, on her own accord, she managed to handle this crisis and be of help to her girlfriend.

Taken together, Mrs. A. reported that she was constantly motivated and profoundly benefitted from the work with an individualized questionnaire in combination with regular therapeutic sessions, which consequently and competently focused on patterns of her psychological functioning and the linkage of the involved variables as mapped with the idiographic system model. In contrast to an earlier hospital stay at the same clinic, where she filled in a generalized daily questionnaire only sporadically, she did not miss a single day of assessment in the personalized approach.

A complete picture of the therapy process including a 7-week long aftercare period is synoptically shown in **Figures 4**, **6**, **7**. Major order transitions are visualized in terms of the raw data resonance diagram and the complexity resonance diagram (**Figures 4A,B**). The period of strongest perturbation is to be found in the first part of the therapy, mainly expressed in items belonging to the "child"-related factor of stress and coping, as the mosaic-like warm colors of **Figure 4B** exemplify. This mirrors the erratic state dynamics of the period, on the one hand, and, on the other hand, the complexity and instability before her decision to let go her occupational goals (flag 1 in applicable figures). Approaching the solution of this crisis, Mrs. A. showed an intensification of stress- and depression-scores, as the weekly Depression-Anxiety-Stress-Scale (**Figure 6A**) shows. This pattern is often intuitively perceived by therapists as crisis before big decisions or seemingly "sudden gains" (e.g., Tschacher et al., 1998; Stiles et al., 2003; Hayes et al., 2007; Haken and Schiepek, 2010; Lutz et al., 2013; Schiepek et al., 2014).

The alternating dynamic of the two major states of Mrs. A. is also expressed in a high mean inter-item-correlation (the mean of all absolute correlations of the 18 items from the personalized questionnaire) in the first third of the monitoring period and before resolution of the first crisis (**Figure 6B**). The maximum inter-item-correlation appears just before the first order transition (flag 1), a phenomenon in line with observations in complex systems theory of increased synchronization of systems and their components during critical instabilities just before phase transitions occur (Haken, 2004; Scheffer et al., 2009; Haken and Schiepek, 2010, pp. 411ff.; Dakos et al., 2012). The factors or state dynamics might in this light be understood as an enslaving bi-stable attractor, from which Mrs. A.'s alternating behavior hardly escapes (see for a similar dynamics of "states of mind" in another case, analyzed by the method of configuration analysis (Horowitz, 1987; Beirle and Schiepek, 2002; Haken and Schiepek, 2010, pp. 328–343). After solving the first crisis, this pattern dissolves in favor of the desired "adult"-state (factor II) and accordingly a sharp drop in the pathological oversynchronization of the psychic system of Mrs. A. is visible in terms of a sudden decrease of the inter-item correlation (**Figure 6B**, flag 1; **Figure 5B**).

In **Figure 7**, the dynamics of the items "resilience/ability to cope with stress" (**A**), "autonomy" (**B**) (both factor II), "withdrawal" (**C**), and "stress" (**D**) (both factor I) (comp. **Figure 2**) are analyzed by the method of colored recurrence plots. Here the same three periods of recurrent dynamics and pattern transitions (discriminated by flags 1 and 2) can be identified.

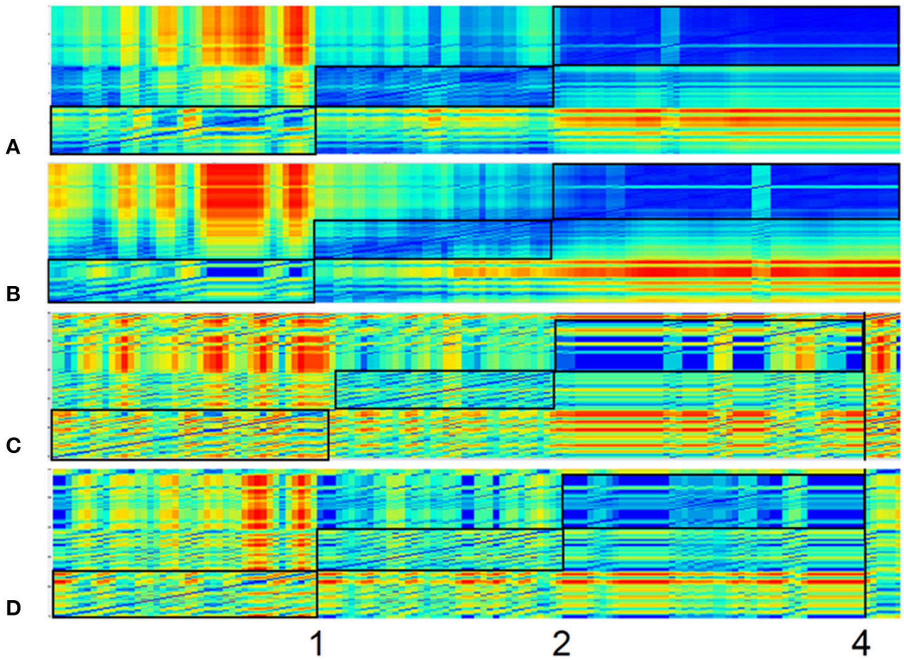

FIGURE 7 | Recurrence plots of four items. Recurrence Plots of the items "resilience/ability to cope with stress" **(A)**, "autonomy" **(B)** (both factor II), "withdrawal" **(C)**, and "stress" **(D)** (both factor I). All plots are based on a 3-dimensional phase space embedding with time-delay $\tau = 1$. Numbers 1 and 2 mark order transitions. Abscissa and ordinate both represent the time dimension, while the color of each pixel depicts the similarity (recurrence) of the item-values of respective time-snippets. This similarity/distance ε between two points of the trajectory in phase space is expressed as pixel with a continuous color scale, ranging from warm colors (yellow/red)—which denote discrepant values (transient)—to colder colors (blueish), which stand for similarity (recurrent) and have less distance between the vector points in the phase space. Framed blocs before marking 1, between 1 and 2, and after 2 can thus be understood as respective homogenous epochs.

DISCUSSION

The concept of synergetic process management, which entails a resource-focused interview, the development of an idiographic system model, an individual process questionnaire for daily online monitoring, regular therapeutic sessions with feedback based on the current data-profile, and ambulant aftercare with the Synergetic Navigation System as bridging technology, is a feasible approach also for patients with complex structural dissociation of personality. As such it enables clients' explicit learning processes, namely comprehending the systemic connections of psychological variables and their dynamics, thereby creating a competency for one's own system. Furthermore, implicit learning is promoted in terms of cooperation with the therapist, the act of making inner processes transparent and fostering own initiative, rendering psychotherapy not a giver-receiver relationship, but a participatory process management on eye level.

The approach of synergetic process management draws on a strong, meta-theoretical background of complex system theory. Hereby, one not only gains theoretical and practical tools, such as time series analysis techniques like recurrence plots or dynamic correlation matrices, but also opens the door for a combination of therapeutic applications. As a meta-theoretical concept it possibly overarches usage of systemic therapy (e.g., idiographic systems model), cognitive behavior therapy (e.g., *in vivo* desensitization interventions timed to critical transitions), trauma- and state-focussed approaches (e.g., Flatten, 2011; Nijenhuis, 2015, 2016), or any other psychotherapeutic tools. A better understanding of a client's psychological variables and processes will be beneficial to any form of psychotherapy, and just as well for patients with amnesias, state-specific attention patterns, or perceptual and cognitive deficits. These fields being impaired and simultaneously necessary for the solution —as is the nature of psychological problems—, makes it even more necessary to individualize the therapeutic approach, and consequently and repeatedly feedback information on processes (continuous cooperative process control). In that way clients are enabled to gain a meta-perspective of their own psychological patterns, increase understanding, and open the door for self-induced change. In cases such as the one presented, where dissociative states create an apparently erratic and confusing alternation of emotional and mental states (see **Figures 2C,D**), clients and their close one's stand dazzled when not supported. The tools of monitoring systems such as the SNS allow for capturing and analyzing ongoing processes, thereby boiling down seemingly irregular behavior to understandable patterns. Creating a client's idiographic system model provides consensual information, while the process-monitoring casts that information into a meta-perspective on dynamic patterns. From there, it is a feasible step to identify the patterns and systemic causes of states, making therapy thereof possible. For Mrs. A. it was, e.g., an astonishing fact that the open modeling work of her idiographic system led to two sets of items, which were rather clearly assignable to her two major personality states. A fact that helped her understanding herself, integrating differential aspects of her life into another and reversely validating her idiographic systems model. Understanding dissociative fragmentation of personality as the trauma-related correlates of fragmented neuronal networks (Flatten, 2011), it becomes evident that any work aimed at synthesizing these fragmented aspects will create understanding and a sense of coherence in affected clients. In order to do so, it seems advisable to allow the client to be the author of his or her own modeling work while entertaining a consensual form of dialog.

The therapeutic work with Mrs. A. utilized naturally occurring crises and transformed these into therapeutically relevant order transitions of emotional and mental processes. It is noteworthy to stress the point that these crises and the accompanying transitions were by no means induced by specific "interventions". Here, therapy can be understood as a process that creates conditions for self-organized change (Schiepek et al., 2015).

One might argue that daily administration of questionnaires yields invalid results, which in fact might change the "object" of the research process (reactive measurement). We fully agree that creating an individualized questionnaire and its daily completion does change the respondent. It is however a change that is therapeutically relevant and intended, when clients improve in comprehending their own mental and behavioral processes. That ultimately will yield the most valid "scores" possible, because it inherits not only the change of psychological variables themselves, but also the change of their interconnectedness. In classical test-theory that might be understood as problematic (e.g., in terms of low test-retest reliability). However, it is therapeutically valid and useable when a client with dissociated states starts to merge these (e.g., as shown with the changing correlation matrices and the course of the averaged inter-item correlation).

Synergetic process management is a concept that sets the client and their needs into the focus of attention, asking for a cooperative, individualized, and meta-theoretical attitude of therapist and client. It then allows for the emergence of synergy effects, creates a basis for interdisciplinary case reviews, offers a bridging technology for changing therapeutic settings (e.g., from in-patient or day-treatment programs to out-patient after-care), and collects vast amounts of valid and reliable data, which will help the individual therapy at hand as well as psychological research in general.

AUTHOR CONTRIBUTIONS

GS: Contributed to all aspects of the article, including concept, data gathering, creating tables and figures, writing and review of text; BS: Contributed to concept, data gathering and review of the text; WA: Contributed to concept and review of text. HS: Contributed to creating tables and figures and review of text; BA: Contributed to concept, creating tables and figures, writing and review of text.

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Integrating the systematic assessment of psychological states in the epilepsy monitoring unit: Concept and compliance

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ABSTRACT

Background: Admission to the epilepsy monitoring unit (EMU) for long-term video-electroencephalography (EEG) monitoring (VEEG) constitutes the gold standard for seizure diagnosis and presurgical evaluation. This study applied the concept of a high-frequency systematic monitoring of psychological states and tested patients' compliance in order to evaluate if its integration in the EMU is feasible and if patients benefit from the graphically underpinned discussion of their EMU stay-related cognitions and emotions.
Methods: The process-monitoring is technically realized by an internet-based device for data collection and data analysis, the Synergetic Navigation System (SNS). A convenient sample was enrolled: All eligible patients who were admitted to the EMU of the Department of Neurology, Christian Doppler Medical Center, Salzburg, Austria, between November 6th 2017 and January 26th 2018 were approached and recruited upon consent. After a short resource-oriented interview, each enrolled patient was provided with a tablet. The daily questionnaire included eight standardized and up to three personalized items. Self-assessments were collected every 5 h prior to meal times (6:30 am, 11:30 am, and 4:30 pm) and at 9:30 pm. The detailed visualizations of the patients' replies were discussed with the participants during a feedback session at the end of the EMU stay.
Results: Twenty-one patients (12 women/9 men, median age 29 years [range 18–74 years]) were consecutively recruited (72% of all eligible patients). Compliance rates were high (median: 82%, range 60%–100%) among the respondents. Mood correlated strongly with hopefulness ($r = 0.71$) and moderately with energy ($r = 0.63$) in all patients. When correlating the intraindividual medians of the process questionnaire time series with the pre-test total scores, energy correlated moderately and negatively with the Perceived Stress Scale (PSS) ($r = -0.45$), while self-efficacy correlated moderately and negatively with the Neurological Disorders Depression Inventory for Epilepsy (NDDI-E) total scores in all patients ($r = -0.5$). Nine patients (43%) reported that they learned something meaningful about themselves after the feedback discussion of their individual time series.
Conclusion: The results support the feasibility of high-frequency monitoring of psychological states and processes in routine EMU settings. Repeated daily collections four times per day of psychological surveys allow for the assessment of highly resolved, equidistant time series data, which gives insight into psychological states and processes during EMU admission.

1. Introduction

1.1. Background

Epilepsies are one of the largest group of serious chronic neurological conditions associated with substantial morbidity including mood disorders and cognitive dysfunction [1–3]. Admission to the Epilepsy Monitoring Unit (EMU) for diagnostic evaluations with long-term inpatient video-EEG (electroencephalography) monitoring (VEEG) constitutes the diagnostic gold standard in epileptology to confirm seizure diagnosis, differentiate epilepsy syndromes, and optimize therapeutic approaches [4]. While it was Hans Berger's original intent to address the mind–body problem, we now know that qualitative EEG analysis has little to add to the investigation of the nature of particular psychological states and processes. Epilepsies have nonetheless repeatedly been referred to as a “window to mind–brain interaction” [5]. If we ever want to come closer to unraveling this biggest mystery of our time, we are in need of frequent and systematic psychological

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assessments yielding time series of psychological dynamics, as well as analysis tools to investigate the nonlinear nature of psychological processes [6–8]. Up to date, only very few studies have integrated systematic psychological assessments into inpatient VEEG monitoring [9].

The potential applications of regularly sampling subjective states in epileptology are manifold: Possible applications for research include, for instance, the investigation of the relationship between interictal stress and mood states, seizure occurrence, and postictal mood changes. In terms of clinical applications and quality control, real-time monitoring of psychological data during hospitalization may help to introduce support systems that aim at rapid identification and alleviation of stressful situations. Considering the heterogeneity of the patient population in EMU settings, clinical applications may also include the development of personalized therapeutic strategies, e.g., for patients whose epilepsy syndromes are associated with specific behavioral seizure risk factors [10] or patients with psychiatric comorbidities including psychogenic nonepileptic seizures (PNES) [11–16].

1.2. Systematic assessment of psychological states and processes: concepts to improve data validity

1.2.1. Paper-based vs. electronic data capture

Paper-based studies may decrease data validity as they may allow patients to record or modify data retrospectively. Electronic data capture has already been used in outpatient settings to provide a more reliable time-stamped data collection method [17]. Modern web-based devices such as tablets, smartphones, or laptops yield easy access to questionnaires for such electronic time-stamped data collection.

1.2.2. Daily vs. high-frequent data capture

Self-report studies in people with epilepsy have been limited by infrequent measurements [17,18]. Irregular and infrequent sampling rates decrease data validity and impede the identification of psychological dynamics and the relationship between psychological and neurological variables [6]. The frequent and systematic (i.e., regular, equidistant) assessment of subjective experiences in close temporal proximity to their actual occurrence may reduce memory biases and distortions by averaging over many events [19–22]. Fig. 1 illustrates how the dynamics of a time series with assessments every 5 h (Fig. 1a) is distorted and the information on the dynamic pattern is lost if measurement points are omitted and information is averaged (Fig. 1b). In addition, only regular and frequent assessments allow for meaningful application of time series analysis methods in the frequency domain (e.g., Fast Fourier Transformations) and particularly in the domain of nonlinear dynamics [6–8,23,24].

1.3. Feasibility and hypotheses

This is a feasibility study aiming at the investigation of compliance, i.e., we specifically aim at reporting on the possibility and difficulties of the frequent 4 times per day daily administration of electronic questionnaires in the EMU setting. The following is of particular interest: how many patients participated in this study, how many measurements patients missed to fill in throughout their stay in the EMU, and reasons for missing measurements. In addition, this is a pilot study of dynamic psychological patterns in the EMU setting. We anticipated that psychological support can be provided based on obtained psychological data. In this pilot study, we aim to describe meaningful observations and derive hypotheses that might be investigated in the future in more specifically designed follow-up studies.

2. Methods

Taking into account the achievements and limitations of previously conducted studies, the study aims at monitoring psychological states (such as self-perceived stress level, mood, and self-efficacy) by integrating partially personalized, high-frequency time-stamped electronic questionnaires into the intensive EMU environment.

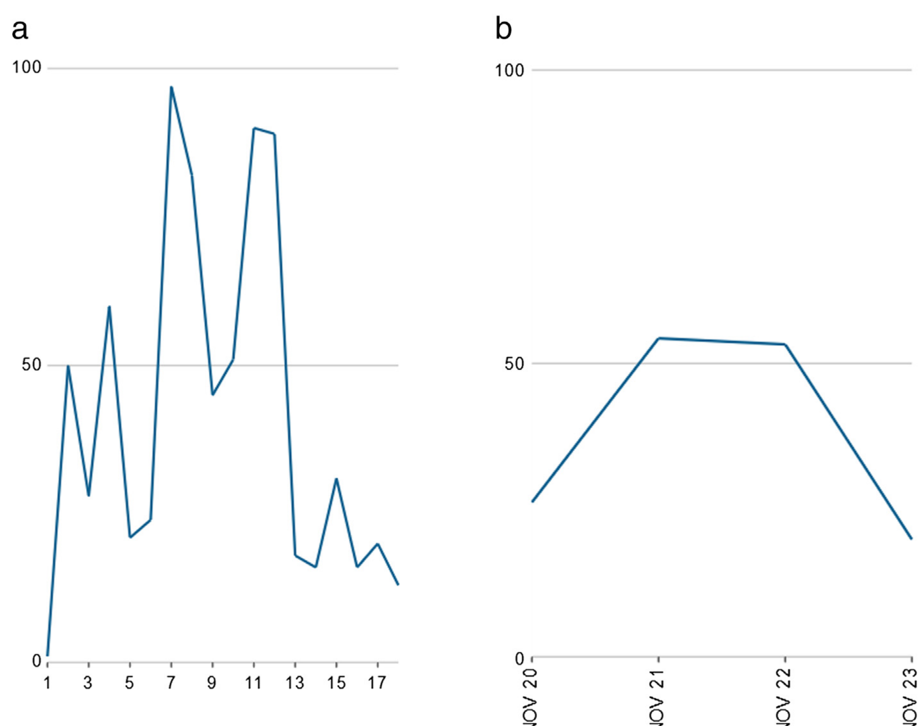

Fig. 1. Ratings of stress every 5 h versus averaged ratings of stress per day. a: Ratings of stress every 5 h by a female patient (42 years) with borderline personality disorder (BPD) and temporal lobe epilepsy (TLE) who was admitted to differentiate if the etiology of postsurgically reoccurring episodes was epileptic or nonepileptic; Y-axis indicates answers on the visual analog scale (0–100), X-axis indicates all consecutive responses. b: Averaged ratings of stress per day; Y-axis indicates averaged answers on the visual analog scale (0–100); X-axis indicates consecutive responses.

2.1. Setting

This pilot study was conducted in the routine care of the intensive EMU of the Department of Neurology, Christian Doppler Medical Center, Salzburg, Austria. In this EMU, admitted patients undergo the usual diagnostic evaluations consisting of long-term VEEG monitoring. These recordings are performed over a mean period of 5 days (Monday to Friday). In order to promote a timely occurrence of seizures during the monitoring period, it is common practice to taper the dosage of antiepileptic drugs (AEDs) and administer sleep deprivation. Informed consent for serious adverse events was completed routinely upon EMU admission.

2.2. Ethical aspects

The study was designed and conducted in accordance with the World Medical Association Declaration of Helsinki and Good Clinical Practice Guidelines. Ethical approval was obtained from the ethics board Salzburg (Paracelsus Medical University, 415-E/2206/9-2017). Written informed consent was obtained from all participants.

2.3. Process questionnaire

The nonvalidated process questionnaire included eight standardized and up to six personalized items. While filling out the questionnaire, patients could add text related to a particular item or the questionnaire as a whole.

2.3.1. Standardized items

The standardized items of the questionnaire were designed in the interdisciplinary team of authors (psychologist (GS), neuropsychologists (ES, MK), neurologists (GK, RM), and psychotherapist (RM)). Although being in an EMU constitutes a stressful situation on its own for some patients, hospitalization may also remove some of the patients' usual stressors. Item development therefore considered briefness (to prevent disruption of routine EMU activities), comprehensibility, and assumed meaningfulness and variability within the EMU setting. Patients were asked to rate the following items on visual analogue scales (VAS):

1. Stress level: “I feel nervous and stressed.” (0 = not at all to 100 = very much).
2. Energy level: “I have energy.” (0 = none at all to 100 = very much).
3. Mood: “My mood is…” (0 = very bad to 100 = very good).
4. Ward atmosphere: “The atmosphere is…” (0 = very bad to 100 = very good).
5. Seizure likelihood: “The likelihood of me having a seizure within the next hours is…” (0 = very low to 100 = very high).
6. Hopefulness/frustration: “I am…” (0 = frustrated to 100 = hopeful).
7. Boredom: “I am bored.” (0 = not at all to 100 = very).
8. Self-efficacy: “I can make use of things that help me to get along with the situation.” (0 = not at all to 100 = very well).

2.3.2. Personalized items

The personalized items included up to two personal seizure-warning signs and one postictal symptom that had been reported during the initial intake interview. These items were only included if patients spontaneously reported known seizure warning signs or postical symptoms.

2.4. Resource-oriented interview

Question number eight (“I can make use of things that help me to get along with the situation.”) probed the use of resources that had been identified during the short resource-oriented interview at admission. During this interview, the interviewer acknowledged the obvious challenges of an EMU stay, including restricted privacy, mobility, and hygiene, and explored potential resources that might support the patient during the EMU stay in a semistructured fashion. The interviewer (RM) documented this interview by taking notes. The notes were reported back to the interviewed patient at the end of the interview to affirm their accuracy.

2.5. Systematic sampling of the process questionnaire

Data collection was realized using the Synergetic Navigation System (SNS); SNS is a web-based generic system that allows for the implementation of various questionnaires at any chosen interval. The response options to the items combine Likert-type scales and VAS. Data can be entered using web-compatible devices, which permits maximal spatial and temporal flexibility for entering data. Data privacy and data security are guaranteed by https-pages, anonymized usernames, and passwords. Its feasibility is supported by various case reports (e.g., [16]) and a compliance study on 151 psychiatric clients treated in an inpatient and a day-treatment clinic [11]. The raw data can be visualized by time series graphs that can be subjected to several time series analysis methods and used for feedback sessions (see Section 2.6) [6,21,25–27].

In this pilot study, SNS was used to collect daytime self-assessments every 5 h, three times daily prior to meal times (6:30 am, 11:30 am, and 4:30 pm) and at 9:30 pm, using the process questionnaire outlined above. Each patient was provided with a tablet. The participating patients were made aware of the measuring times by an alarm set in the tablet and were free to access the questionnaires via internet through a personalized account whose password had to be changed upon first log-in. Each time that the questionnaire was accessed, the items appeared in random order. Participants could enter comments related to single items.

2.6. Feedback session

For the feedback sessions, the time series of each item of a participant's questionnaire was plotted in one diagram each. This resulting time series, i.e., the detailed visualizations of the patients' replies and their dynamics, were discussed with each participant during the feedback sessions at the end of their EMU stay. The interviewer (RM) documented the feedback session. The notes were reported back to the patient at the end of the feedback session to affirm their accuracy. Afterwards, all patients were offered a copy of their personal diagrams and the opportunity to continue outpatient self-assessments one to two times daily following discharge from the EMU including additional feedback sessions, using a personal web-compatible device.

2.7. Pretests

The following validated questionnaires were applied to assess perceived stress, psychiatric comorbidity (depression), and Health Related Quality of Life (HRQOL) at admission:

Perceived Stress Scale (PSS) [28]

This 10-item scale was developed to measure a person's appraisal of nonspecific stress. Patients are requested to indicate how frequently they have experienced certain thoughts or feelings over the past month on a 5-point Likert scale. The PSS scores are obtained by reversing responses to the four positively stated items and then summing across all items, with higher scores corresponding to a higher stress level.

Neurological Disorders Depression Inventory for Epilepsy (NDDI-E) [29]

The NDDI-E is an epilepsy-specific 6-item self-report depression screening measure. Patients are instructed to report how frequently they have experienced six symptoms over the past two weeks on a

4-point Likert scale. The scores are summed to give a total score with a maximum of 24; individual validation studies of the NDDIE have identified different cutoff scores (Italy = 13; France = 15; Germany = 16) for a major depressive episode [30].

Quality of Life in Epilepsy-10 (QOLIE-10) [31]

The QOLIE-10 is a brief version developed from the original QOLIE-89 [32] to assess the quality of life of people with epilepsy. The scale assesses seizure worry, emotional worry, energy/fatigue, cognition, medication effects, social function, and overall quality of life during the past four weeks. Each of the 10 items is rated on a 5-point Likert scale. Responses to each item are summed to yield a total score, with higher scores corresponding to a higher quality of life.

It was hypothesized that these pretests would correlate with the intraindividual medians of the time series of the process questionnaire.

2.8. Recruitment of patients

A consecutive sample was enrolled: All patients who were 18 years and older and who were admitted to the EMU between November 6th 2017 and January 22nd 2018 were approached on the first day of admission. Eligible patients received an introduction to the SNS. Upon willingness to participate, pretest questionnaires (see Section 2.7) were applied via the SNS. Successful completion of pretest questionnaires via SNS was interpreted as an indicator of sufficient literacy and capability to operate the tablet and therefore to participate in the study.

2.9. Data analysis

The patients' clinical characteristics and compliance are summarized using descriptive statistical methods. For interitem correlation as well as for correlating the intraindividual medians of the process questionnaires' items with the pretest questionnaires' total scores, two-sided *t*-tests were performed. The p-values were corrected for false-discovery rates (FDR) [33]. Qualitative content analysis of the interviewer's notes that were recorded during the initial resource-oriented interview and of the feedback-session was conducted.

3. Results

During the 10-week enrollment period, a total number of 40 patients had been referred to the EMU. Eleven patients had not been eligible with the main reasons being a) motor deficits and/or aphasic dysfunctions that severely limited the handling of the tablet and/or comprehension of the survey questions (n = 6), or b) underage (n = 3). Eight patients declined to participate because they a) were already participating in another study (n = 3), b) felt considerable unease with handling a tablet (n = 3), or c) already felt too distressed by the EMU inpatient situation (n = 2). Consequently, the sample included a consecutively recruited cohort of 21 participants (Fig. 2).

3.1. Patient characteristics and characteristics of the EMU stay

The majority of the participating patients were admitted to the EMU within the first year after their first seizure (see Table 1 for sample characteristics). During their stay in the EMU, 15 patients (71%) underwent sleep deprivation at least once. Medication was tapered in 12 patients (57% of all 15 patients who had been taking at least one AED upon admission to the EMU), and at least one epileptic seizure was recorded in four patients (19%).

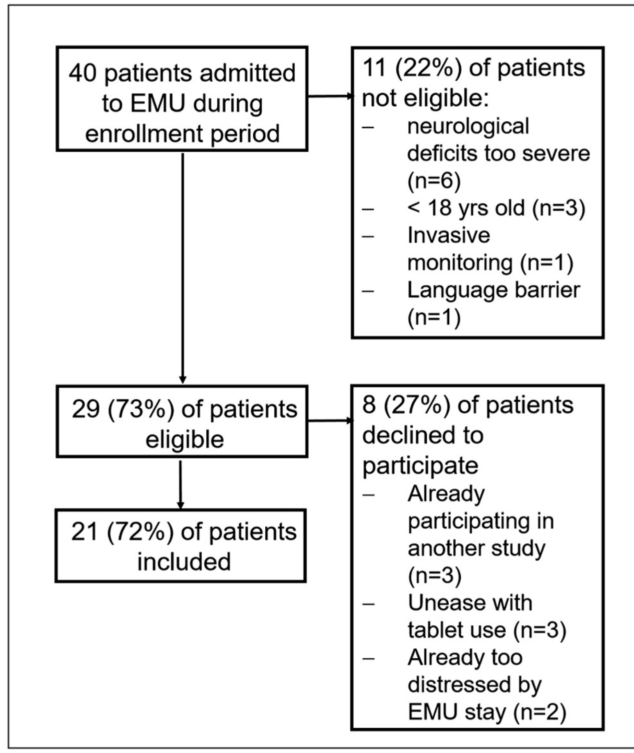

Fig. 2. Recruitment flow chart. EMU: Epilepsy Monitoring Unit, yrs.: years.

3.2. Compliance

During their five-day inpatient hospitalization (including three full and two half days), patients were prompted to fill in the process questionnaire four times a day. Therefore, the usual maximum number of measurement points between admission on the first day and discharge on the fifth day was 15 measurement points (1st day: two measurement points (afternoon and evening), 2nd–4th day: four measurement points each, 5th day: 1 measurement point in the morning). In three cases, this number was reduced because of a national holiday. The median compliance of this sample was 92% (range 60%–100%), i.e., 92% of

Table 1
Patient characteristics.

	Total n = 21	
Age in years median [range]	29	[18–74]
Gender (female) total (%)	12	(57%)
Yrs since 1st event median [range]	0	[0–17]
Reason for admission total (%)		
Classification of epilepsy syndrome	9	(43%)
Investigation of differential diagnosis	6	(29%)
Assessment of seizure frequency	3	(14%)
Optimization of medication	3	(14%)
Diagnosis total (%)		
Structural epilepsy	12	(52%)
IGE	3	(14%)
PNES	3	(14%)
Syncope	2	(10%)
Migraine with aura	1	(5%)
Medication total (%)		
None	6	(29%)
1 AED	14	(71%)
2 AEDs	1	(5%)
> 2 AEDs	0	(0%)

AED: antiepileptic drugs, IGE: idiopathic generalized epilepsy, PNES: psychogenic nonepileptic seizures, yrs.: years.

Table 2
Interitem correlation.

All patients (n = 21)	Stress	Energy	Mood	Ward atmosphere	Seizure likelihood	Hopefulness	Boredom	Self-efficacy
Stress		−0.31**	−0.47**	−0.4**	0.08	−0.42**	0.46**	−0.49**
Energy			0.63**	0.39**	0.03	0.47**	−0.32**	0.19
Mood				0.57**	0.01	0.71**	−0.54**	0.41**
Ward atmosphere					0.06	0.58**	−0.55**	0.56**
Seizure likelihood						0.04	−0.03	−0.02
Hopefulness							−0.48**	0.41**
Boredom								−0.46**
Self-efficacy								

Interitem correlation in all patients, *: p ≤ 0.05, **: p ≤ 0.01, p-values corrected for multiple testing.

all questionnaires were submitted at the required measurement points. The median number of submitted questionnaires was 13 (range 9–15). Seven patients (33%) completed the questionnaires at all measurement points. Altogether, 14% (43 measurement points) of the total number of measurement points were missing for the following reasons in decreasing order: Noncompliance (n = 18 measurement points), technical issues (n = 11 measurement points), difficulties in handling the tablet (n = 6 measurement points), postictal impairment (n = 4 measurement points), and early discharge requested by one patient (n = 4). Four of the included patients (19%) were unfamiliar with the use of a tablet and required initial help with filling out the questionnaires. Delayed submissions of more than 1 h were counted as noncompliance. In a few cases, patients filled out the questionnaire more than once in a row. In such cases, only the first entry was counted toward compliance. It took the participants a median time of 3 min [range: <1 min to 12 min] to fill out the questionnaires.

3.3. Interitem correlation, pretest scores, and correlation of time series with pretest scores

When investigating the interitem correlation in all patients, mood correlated strongly with hopefulness, and moderately with energy (Table 2).

When correlating the intraindividual medians of the process questionnaire time series with the pretest total scores (see Table 3), energy correlated moderately and negatively with the PSS while ward atmosphere and self-efficacy correlated moderately and negatively with the NDDI-E total scores in all patients. In terms of the QOLIE-10, there was a moderate positive correlation with energy (Table 4).

3.4. Reported resources and general feedback

During the initial short resource-oriented interview, three main themes emerged. Some patients stated resilient attitudes toward challenges in life in general, for example *"I do not get upset too easily."* or *"I always attempt to focus on positive thoughts."* Many patients reported specific positive attitudes toward the EMU stay: *"I am glad to have gotten this appointment."*, *"I know why I am here."*, *"This examination is meaningful."*, *"I hope to understand what is going on with me."*, *"I want clarity."* All patients were able to name activities with which they planned to distract themselves during the stay in the EMU (watching TV, listening to music, reading, etc.). Some patients were expecting visits from relatives and friends, while others had explicitly decided against receiving visitors.

Table 3
Pretest total scores.

PSS	NDDI-E	QOLIE-10
16 [4–29]	13 [7–21]	72.5 [47.5–95]

PSS: Perceived Stress Scale, NDDI-E: Neurological Disorders Depression Inventory in Epilepsy, QOLIE-10: Quality of Life in Epilepsy-10.

The majority of patients stated that filling out the questionnaire on the tablet was no inconvenience except for the alarms going off in the morning and noon after the administration of sleep deprivation. Participants appreciated the short questions that could be answered quickly and intuitively *"on a gut level."* However, only a few patients reported spontaneous helpful insights such as *"It was nice to notice that hopefulness was increasing over time. I would not have noticed that without answering the questions."* or *"I enjoyed the* ["self-efficacy"] *question because it made me think of my family."*

3.5. Feedback sessions: personal meaningfulness

Even though only few patients spontaneously reported helpful insights prompted by filling out the questionnaire, nine patients (43%) reported that they learned something meaningful about themselves after the feedback session during which the individual time series had been interpreted by patient and study investigator (RM) together. Six of these patients requested screenshots of their time series to remind them of the knowledge gained during the feedback session. Follow-up sessions were scheduled with two patients, and one patient continued to fill out the SNS questionnaire twice a day in the outpatient setting. The following examples illustrate meaningful aspects from the patients' perspective:

3.5.1. Development of individual psychological illness models

The interpretation of the time series yielded individual models of psychological mechanisms underlying the occurrence of nonepileptic seizures (Fig. 3a and b) and migraine attacks (Fig. 3c). These models reinforced the decision by the two patients with PNES diagnoses to seek inpatient psychiatric or outpatient psychotherapeutic treatment.

3.5.2. Resource-oriented individual investigation of the interrelationship of sleep deprivation, energy, and mood

A number of patients gained insights into the impact of sleep deprivation and resultant decreased energy levels on mood levels. Some patients found out that this relationship was associated with their personal chronotype (i.e., the individual's propensity to sleep and

Table 4
Correlation of process questionnaire with pretests in all patients.

	PSS	NDDIE	QOLIE-10
Stress	0.17	0.30	−0.03
Energy	−0.45*	−0.43	0.36
Mood	−0.35	−0.29	0.07
Ward atmosphere	−0.34	−0.51*	0.05
Seizure likelihood	0.03	0.04	−0.25
Hopefulness	−0.22	0.22	−0.17
Boredom	0.10	−0.16	0.07
Self-efficacy	0.32	−0.5*	−0.11

Correlations between Perceived Stress Scale (PSS), Neurological Disorders Depression Inventory in Epilepsy (NDDI-E), Quality of Life in Epilepsy-10 (QOLIE-10) and intra-individual median process questionnaire time series in patients with epilepsy, *: p ≤ 0.05, **: p ≤ 0.01, p-values corrected for multiple testing.

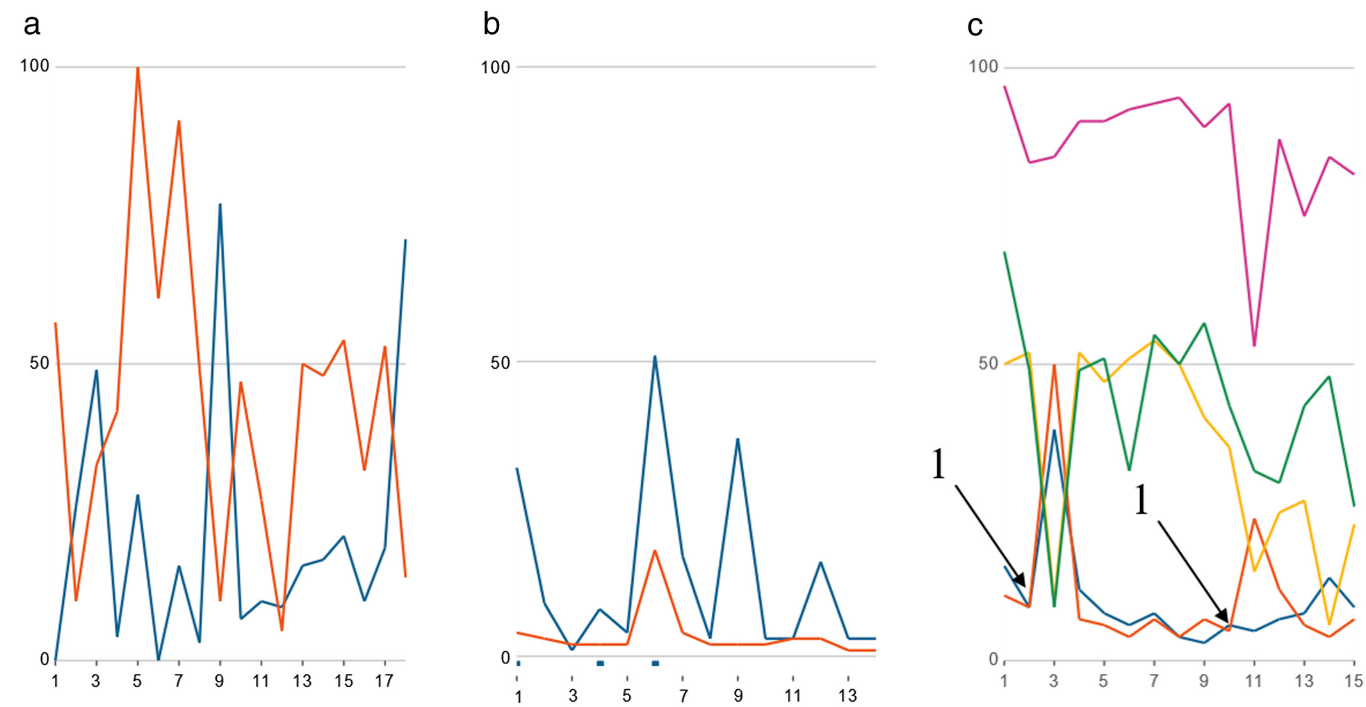

Fig. 3. Development of individual psychological illness models. a: This time series shows the asynchronous ratings every 5 h of a patient's events (blue line: sensation of heat) and her sense of self-efficacy (orange line). During the feedback session, this female patient (42 years) with BPD and TLE was able to formulate the hypothesis that the postsurgical episodes that she experienced were a somatic correlate of her fluctuating sense of helplessness (i.e., lack of self-efficacy). This increased self-awareness reinforced her decision to seek inpatient psychiatric treatment; Y-axis indicates answers on the visual analog scale (0–100); X-axis indicates all consecutive responses. b: This time series demonstrates the discrepancy between this female patient's (25 years) ratings every 5 h of the statements "Since the last measurement I have felt agitated." (blue line) and the statement "At the moment I feel agitated." (orange line). During the feedback session, this patient explained that this discrepancy illustrated "80% of [her] problem". She developed the hypothesis that her capacity to suppress agitation quickly led to an avoidance of addressing the reasons for her agitation and that her episodes might eventually be an outlet for this suppressed agitation; Y-axis indicates answers on the visual analog scale (0–100); X-axis indicates all consecutive responses; the blue rectangles underneath the X-axis indicate that a comment had been submitted with the questionnaire. c: During the feedback session, this female patient (30 years) with a history of migraine with aura observed how her headache (red line) coincided with low energy (yellow line) because of sleep deprivation (1). She developed the hypothesis that low energy was accompanied by a bad mood (green line) and a decreased sense of self-efficacy, which sometimes led to feeling stressed (blue line). Based on this awareness of headache precipitants she decided to focus more on self-care (e.g., sufficient sleep); Y-axis indicates answers on the visual analog scale (0–100); X-axis indicates all consecutive responses. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

wake up at a particular time during a 24-hour period) and that this relationship was mediated especially by social factors (Fig. 4a) and intrinsic factors such as self-efficacy (Fig. 4b). In patients with idiopathic generalized epilepsy (IGE), this visualization of the psychological effects of sleep deprivation provided an opportunity for a resource-oriented cognitive reframing of the common advice to avoid sleep deprivation in order to prevent an increased risk of seizures.

3.5.3. Reflecting challenges during the inpatient monitoring

Some patients were relieved by the opportunity to talk about situations during the inpatient monitoring that they had found specifically challenging and/or distressful such as witnessing seizures by fellow patients (Fig. 5a) or being worried about the administration of sleep deprivation (Fig. 5b).

3.5.4. Outpatient monitoring of AED side effects

One patient continued to fill out the process questionnaire twice a day after discharge to monitor side effects during AED tapering. Daytime dependent fluctuations of the side effect (dizziness) continued while a general decrease of the side effect could be observed (Fig. 6).

3.5.5. Supporting coping with seizures and with comorbidity

The patient who continued outpatient follow-up had also suffered a seizure in the inpatient setting and several seizures during the outpatient follow-up. His resources in terms of coping with the psychosocial discomfort after seizures were discussed based on his individual time series (Fig. 7a and b). One patient had disclosed feeling socially isolated at work and memory difficulties that had not been objectified by neuropsychological testing and were eventually rather seen as symptoms of a moderate depressive episode. Two follow-up consultative appointments were scheduled with him and his spouse to offer prompt support and discuss therapeutic strategies.

4. Discussion

The results of this pilot study illustrate the feasibility of a high-frequency psychological monitoring procedure in the busy setting of an inpatient EMU. A large proportion of the participants revealed high compliance rates, resulting in equidistant time series of high frequency. The application of the questionnaires was accomplished using an internet-based device (SNS) with a process questionnaire.

These results indicate the strong relation between certain psychological variables in regard to patients' mood and their perception of ward atmosphere during EMU admission. As such, some of the variables (e.g., hopefulness, energy, and self-efficacy) highlight the potential impact that conversations with doctors and nurses, sleep deprivation, and proposed activities might have on patients' mood. In addition, the psychological dynamic patterns during EMU admission seemed to be associated with patients' pretest total scores.

While data entry itself only prompted meaningful self-awareness in very few patients, the feedback sessions were regarded as a source of informative insights by more than a third of all patients. The current study design does not allow a differentiation of the various factors that might have influenced this judgment including the visualized time series, the attention by the study investigator, and the content of the conversations. Given the lack of privacy during hospitalization and the busy clinical setting, the additional offer of a personal conversation may have been a rather meaningful influential factor.

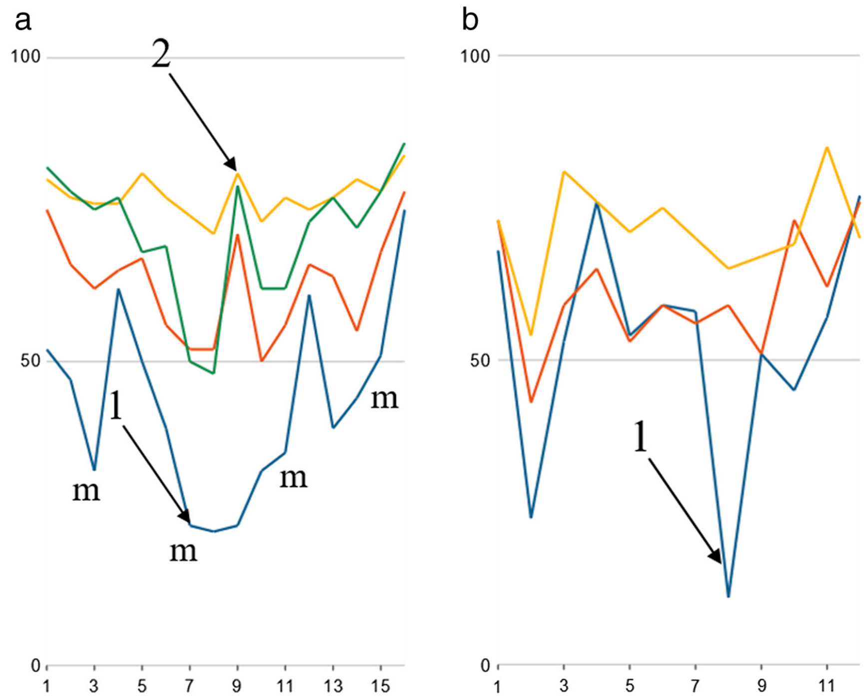

Fig. 4. Resource-oriented individual investigation of the interrelationship of energy and mood. a: This female patient (26 years) with idiopathic generalized epilepsy (IGE) observed low energy levels (blue line) in the mornings (m) and especially after sleep deprivation (1). Low energy was usually accompanied by bad mood (red line) and decreased hopefulness (green line). However, after sleep deprivation, (1) this effect was suspended by her boyfriend's visit (2), indicated by increased ward atmosphere (yellow line) in this time series. During the feedback session, this patient became aware of the important mediating influence of social resources in her life; Y-axis indicates answers on the visual analog scale (0–100); X-axis indicates all consecutive responses. b: This male patient (64 years) with structural epilepsy had reported an accepting attitude toward hardship during the resource-interview. Despite low energy levels (blue line) after sleep deprivation, his mood remained good, which he attributed to his pronounced sense of self-efficacy (yellow line); Y-axis indicates answers on the visual analog scale (0–100); X-axis indicates all consecutive responses. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

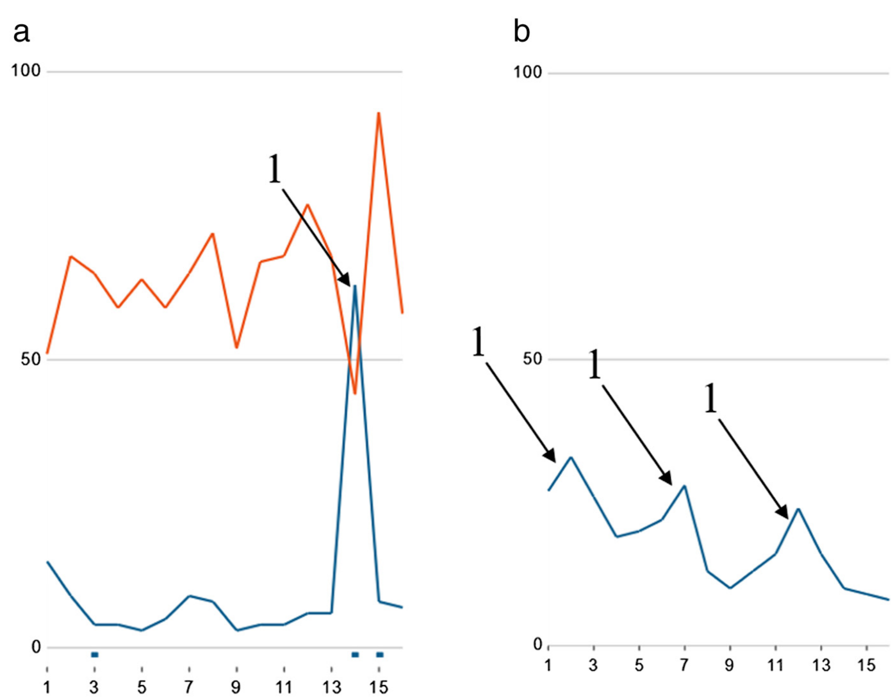

Fig. 5. Reflecting challenges during the inpatient monitoring. a: During the feedback session, this female patient (46 years) felt relieved by the opportunity to share how burdened and helpless she had felt when she witnessed a fellow patients' focal to bilateral tonic–clonic seizure (1) (blue line: stress, red line: mood); Y-axis indicates answers on the visual analog scale (0–100); X-axis indicates all consecutive responses; the blue rectangles underneath the X-axis indicate that a comment had been submitted with the questionnaire. b: During the feedback session, this female patient (26 years) shared that she had been worried (blue line: stress) if the administration of sleep deprivation would be brought up during rounds (1). However, she had avoided to bring up the topic herself. This time-series made her aware of the importance of speaking up to increase clarity concerning worrisome issues; Y-axis indicates answers on the visual analog scale (0–100); X-axis indicates all consecutive responses. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

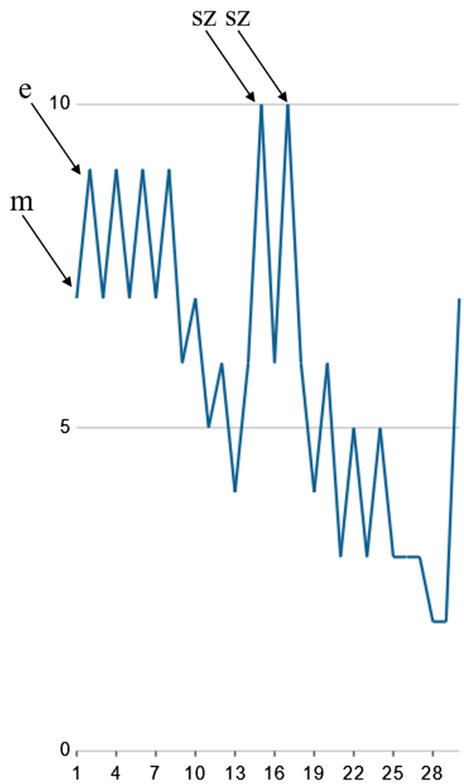

Fig. 6. Outpatients monitoring of AED side effects. In this male patient (26 years) with TLE, daytime dependent fluctuations (m: morning, e: evening) of an AED side effect (dizziness: blue line) continued while a general decrease of the side effect could be observed during AED tapering in the outpatient setting. Seizures (sz) coincided with a rapid increase of dizziness; Measurements were taken twice daily, Y-axis indicates answers on the visual analog scale (0–10); X-axis indicates all consecutive responses. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

The individual examples illustrate a range of potentially useful clinical applications: While VEEG monitoring remains the gold standard for establishing the diagnosis of PNES, this usual diagnostic means can only determine that seizures are nonepileptic. The underlying "psychogenic" model can only be derived explicitly from additional psychological diagnostic means. It has been suggested that the explanation of such an explicit and personalized model may be important to support acceptance of PNES and to increase the likelihood that patients with PNES seek appropriate psychotherapeutic treatment [34]. Data obtained from personalized process questionnaires administered during EMU monitoring may provide an informative basis for the development of such explicit individualized psychological models and the formulation of personalized psychotherapeutic treatment plans (e.g., by the method of idiographic system modeling, [16,35]). This opportunity to develop an understanding of precipitating factors may also apply to other conditions such as primary headache disorders and epilepsy syndromes [36].

Epileptic seizures may be precipitated by the interaction of various clinical factors, but – especially in some idiopathic generalized epilepsy syndromes such as juvenile myoclonic epilepsy – sleep loss stands out as an independent seizure trigger that is used as a diagnostic means to increase the likelihood of seizure occurrence in the EMU setting [37,38]. Little attention has been paid to the potentially mediating role of the psychological effects associated with sleep deprivation, which may also be modified by other factors such as social resources and self-efficacy.

Being in an EMU may constitute a challenging situation for patients [39]. On the one hand, reinforcing the active use of existing resources upon admission such as resilient attitudes, specific positive attitudes toward the purpose of the EMU stay, and/or planned activities to distract themselves may help to promote coping. Providing an opportunity to reflect past challenges at the end of the stay in the EMU, on the other hand, may serve as a relieving outlet.

The side effects of AEDs are rarely monitored systematically in the outpatient setting [40]. As has been shown in the case of one patient whose outpatient follow-up questionnaire included a personalized item to monitor a severely disabling AED side effect, process questionnaires can be used to monitor AED side effects in the outpatient setting and therefore provide a more objective basis for their assessment and inclusion in medical decisions.

Comorbid depression and postictal psychosocial discomfort are common phenomena in people with epilepsy [2,41]. There is moderate evidence that psychotherapeutic interventions may improve health-related quality of life in people with epilepsy, and some of these psychotherapeutic interventions specifically target depressive symptoms and/or coping with uncomfortable postictal states [42,43]. However, psychotherapeutic treatment is not comprehensively integrated into usual care for people with epilepsy. Various barriers have been described: Routine screening for comorbidities is not usually performed despite recommendations by the Association of American Neurology and the availability of cost-free short epilepsy-specific screening instruments. In addition, there are structural barriers (e.g., waiting lists, costs, accessibility, etc.) and barriers related to professional attitude (e.g., discomfort initiating treatment for symptoms related to depression and anxiety) [44]. In this pilot study, the integration of screening procedures and feedback sessions allowed for personalized outpatient follow-up treatment offers to address psychosocial needs.

4.1. Limitations and future studies

In order to realize high-frequency data collection, we limited the number of items asked, i.e., the items of the process questionnaire were well-defined, but the questionnaire is not validated. We deliberately traded this shortcoming for an increased feasibility and compliance in a busy intensive EMU. However, only the combination of the process questionnaire with validated outcome measures would have allowed us to determine if the items in our process questionnaire were sensitive to meaningful change. In addition, the sampling rate of the process questionnaire was chosen for pragmatic reasons, and the optimal sampling rate still needs to be determined in future studies. Ideally, the items of the process questionnaire should be subjected to Rasch analysis and factor analysis in future studies with larger sample sizes.

A major limitation is the restriction of the data to the inpatient setting in which patients were not in contact with their usual everyday stressors and resources. This raises the question of generalizability of our results. This concern can be addressed by implementing the procedure in an outpatient monitoring setting. A future application and improvement of these monitoring procedures could include a broader personalized item selection (e.g., by integrating personal topics, problems, and goals of a patient into a questionnaire), which has already been demonstrated in psychiatric patients [11,16].

The small sample size in this pilot study constitutes the biggest limitation to interpret our findings. Given the small number of patients in the respective subgroups, specific psychological (i.e., cognitive–emotional) differences between patients with different seizure disorders could not be determined based on the presented data. Optimal follow-up studies with more specific designs would include sufficient numbers of patients in all subgroups. The narrative result section presenting qualitative data constitutes a merely anecdotal evidence level. In addition, qualitative content analysis was performed based on notes and not transcripts. However, we believe that we did not overstate our evidence but simply portrayed opportunities for potential clinical application and hypotheses that will need further investigation in the future. Furthermore, neither validated outcome measures nor follow-up data

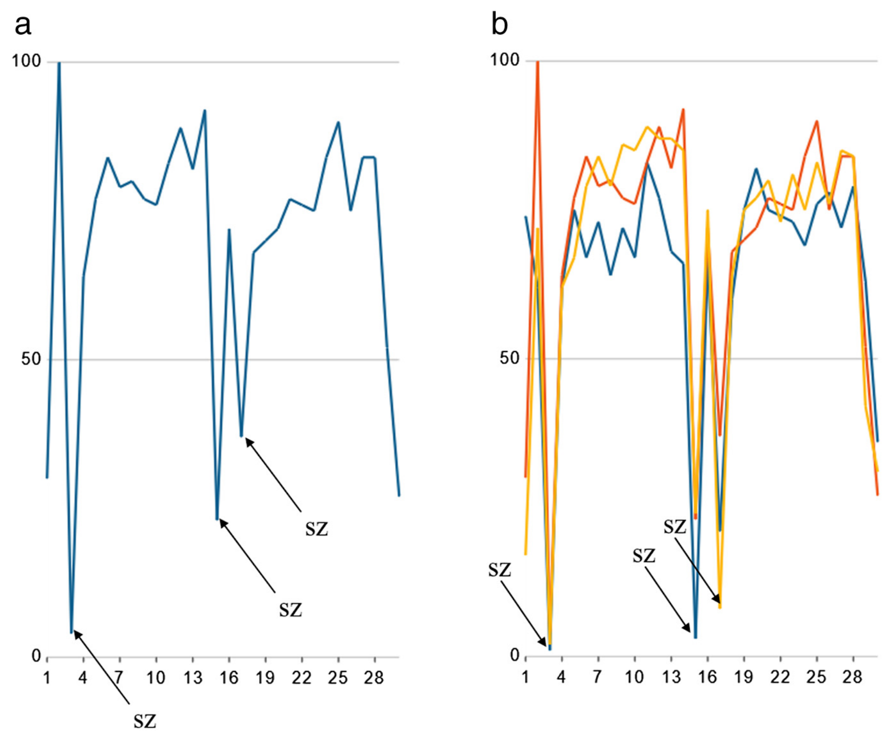

Fig. 7. Supporting coping with seizures. a: Outpatient monitoring continued with measurements twice daily in this male patient (26 years) with TLE and revealed the detrimental impact of seizures (sz) on the atmosphere at home due to parental worries (blue line); Y-axis indicates answers on the visual analog scale (0–100); X-axis indicates all consecutive responses. b: This time series in the same patient as in Fig. 7a (and Fig. 6) revealed how meaningful resources in terms of coping with the psychosocial discomfort after seizures (red line) led to the recovery of mood (yellow line), hopefulness (green line), and energy (blue line) shortly after a seizure (sz); Measurements were taken twice daily, Y-axis indicates answers on the visual analog scale (0–100); X-axis indicates all consecutive responses. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

were collected, and therefore, we have no means to determine if the insights that patients reported during feedback sessions translated into functional improvements.

Potential selection bias was introduced by the five patients who declined to participate because they felt considerable unease with handling a tablet or already felt too distressed by the EMU inpatient situation. This study failed to investigate factors that could have made participation acceptable or even attractive for these patients. The motivation of these patients will need special attention in future studies, esp. when the potential application of SNS as a support system is under investigation.

The SNS provides an opportunity to investigate the correlation between neural and mental (cognitive/affective) states by correlating process questionnaires with quantitative EEG analysis in future studies [45, 46].

5. Conclusions

This pilot study demonstrated the feasibility of integrating high-frequency monitoring of psychological states and processes in the busy setting of an EMU with good compliance. In addition, the study suggested that individual feedback and feedback-related interviewing sessions were meaningful for the participants.

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Conflicts of interest

The authors have no conflicts of interest to declare.

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Individual OCD-provoking stimuli activate disorder-related and self-related neuronal networks in fMRI

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ABSTRACT

For patients with Obsessive-Compulsive Disorder (OCD), whose triggers are highly idiosyncratic, individual stimulus material has been used in several fMRI studies. This study aims at comparing individual to standardized picture sets and at investigating a possible overlap of the former with the self-referential neuronal network. During fMRI-scanning, 17 inpatients with OCD and 17 healthy controls were exposed to pictures of their personal triggers, photographed in their domestic environments, to standardized pictures designed to provoke OCD symptoms, and to neutral pictures. Whole-brain analyses were calculated and the pictures were rated by both patients and controls with respect to valence, arousal, and coping. Patients rated the individualized stimuli lower in valence and coping and higher in arousal compared to controls, and also compared to standardized OCD- and neutral stimuli. The individual stimuli elicited neuronal activity in the cingulate cortex, hippocampus, insula, middle frontal/precentral gyrus, superior/inferior parietal lobe, and precuneus, while no group difference was detected by the standardized OCD-stimuli. In conclusion, individual picture sets facilitate the detection of neuronal activity, but the results might be confounded due to the overlap with the network of self-referential processing and memory retrieval. The use of individual symptom-provoking and individual neutral stimuli would therefore be optimal.

1. Introduction

1.1. Importance of stimuli for fMRI

Choosing the right stimulus material is highly relevant in fMRI research in order to answer the hypotheses under investigation. In studies aimed at examining neuronal correlates for psychiatric disorders, patients are usually confronted with disorder-specific triggers in the imaging environment, e.g., by passively viewing pictures designed to evoke symptom-related emotions and cognitions. The BOLD-signal of the fMRI scan, however, is composed of a baseline neuronal activity (comparable to resting-state activity), plus the activity due to visual processes when viewing pictures of any kind, plus the activity representing the neuropathological mechanisms of a disorder. Therefore, most analyses use contrasts of two conditions by subtracting the measured signal when viewing the symptom provoking pictures (condition 1) from the measured signal when viewing neutral pictures (condition 2). The difference (contrast) can then be interpreted as the neuronal activity evoked by specific aspects of condition 2 in comparison to condition 1 (e.g., disgust-provoking stimuli). The same procedure is conducted for all participants, and the averages for each group (patients and controls) are calculated. The difference between patients and controls can then be determined by subtracting the mean contrast of the controls from the mean contrast of the patients. The remaining signal can be interpreted as the pathological activity. Considering this procedure of analysis, it becomes clear that the choice of stimulus

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material is not to be underestimated and could alter the results considerably.

1.2. Obsessive-Compulsive Disorder (OCD)

Individuals with Obsessive-Compulsive Disorder (OCD) experience a persistent intrusion of unwanted thoughts or images (obsessions) and/or the urge for repetitive, ritualistic behaviors or mental acts (compulsions) that need to be neutralized in order to reduce anxiety or distress (American Psychiatric Association, 2013). With a prevalence of 2–3%, OCD is one of the most common psychiatric diseases and has a serious impact on the quality of life (Crino et al., 2005). The illness is very heterogeneous, i.e. patients experience a wide range of different situations, objects and/or thoughts as triggering. Four general subtypes have been identified: symmetry/ordering, hoarding, washing/cleaning and checking (Mataix-Cols et al., 2004). Still, even within the subtypes, the exact nature of the symptom provoking stimuli can differ immensely.

1.3. Possible stimulus material for OCD

Choosing stimuli for the scanning environment that appropriately address the disorder's heterogeneity is a challenge. Researchers have therefore addressed the cognitive aspects of the illness (for a review see Del Casale et al., 2015), or its emotional side (e.g., Thorsen et al., 2018). Others have adressed the problem by focusing on specific subtypes of OCD, e.g., showing disgusting pictures to a sample of patients with fear of contamination (washing subtype, e.g., Shapira et al., 2003). After Mataix-Cols and his co-workers published their standardized Maudsley Obsessive-Compulsive Stimulus Set (MOCSS), many researchers have used the 50 pictures for each subtype category for their studies (Mataix-Cols et al., 2004). Even though the standardization can be seen as a clear advantage to science in terms of reproducibility and validation, the stimulus set was able to provoke mild to moderate OCD symptoms only (Simon et al., 2012). In consequence, many paradigms used some kind of individualization in order to reflect each subject's primary OCD triggers, e.g., individual words related to the symptoms like “door/key/switch” for a patient from the controlling/checking subtype, or – most commonly – individual pictures (e.g., Schienle et al., 2005; Schiepek et al., 2009, 2013; Simon et al., 2012).

1.4. Self-related processing

While individual stimulus sets clearly account for the diversity of OCD phenomenology and the idiosyncrasy of obsessions (Baioui et al., 2013a), one has to take into account that these are classical stimuli used to investigate self-relatedness (Northoff, 2014). In an activation-likelihood-estimation (ALE) meta-analysis, Hu et al. (2016) found several areas to be consistently active in self-related processing, including the cortical midline structure (bilateral anterior cingulate cortex (ACC)/medial frontal gyrus, left precuneus), left middle frontal gyrus, inferior parietal lobule and bilateral superior temporal gyrus.

Some of these regions, especially the ACC and the prefrontal cortex, has also been revealed to be significantly altered in OCD. Despite this obvious possible confound, a direct comparison between the neuronal activation for individual versus standardized stimulus sets has hardly been considered by researchers. Baioui et al. (2013b) used both conditions, but did not conduct a whole-brain analysis and instead used a mask with regions known to be part of the cortico-striatal network model of OCD.

1.5. Hypotheses

In our study, we did not limit the analysis to predefined regions but were hypothesizing that hyperactivation of some of the regions often reported in OCD patients with individual stimuli are due to an overlap with a network for self-referential processes activated by recognition (cortical midline structures including the cingulate cortex and the precuneus, see Cavanna and Trimble, (2006) and Northoff et al., (2006)). This could be a confound in studies using individual compared to neutral pictures only and might explain some of the diverging results in neuronal correlates found for OCD. We also assumed that the two approaches provoked partly different OCD relevant processes and therefore different regional activity as suggested by Baioui et al. (2013a). Furthermore, in comparison to standardized OCD pictures, we expected the individual stimuli to evoke higher neuronal responses in regions central to the OCD etiology, i.e., the cortico-striato-thalamo-cortical circuit including cingulate, insular, and parts of the frontal and parietal cortices (e.g., Schiepek et al., 2011; Del Casale et al., 2015).

2. Methods

2.1. Participants

The sample of this study consisted of 17 inpatients (6 men and 11 women, mean age 43.5 years (SD = 10.7)) from the Christian-Doppler University Hospital, Salzburg, Austria, as well as 17 healthy controls (HC) matched by age and gender. Patients were eligible to participate in the study if obsessive-compulsive disorder was the main illness by clinical judgement based on ICD-10 and DSM-IV criteria and on the Structured Clinical Interview for DSM-IV Axis I disorders (SCID-I, First, Spitzer, Miriam, and Williams, 2002). Exclusion criteria consisted of neurological impairment and/or neurological diseases, acute psychosis, substance abuse, and/or suicidality. As commonly found in OCD patients, comorbidities of the sample included depression (8 patients), social phobia (2 patients, in addition to depression) and one each from the schizophrenic spectrum, alcohol and substance abuse (currently abstinent), and posttraumatic stress disorder (PTSD). For results of the psychological assessment see Section 3.1. All but one patient took some kind of antidepressant (mostly SSRI), 7 of them in addition neuroleptics, 3 anticonvulsants, 2 benzodiazepine and 1 lithium. One patient also had to be medicated for high blood pressure, thyroid dysfunction and incontinence. The study was approved by the Ethics Commission Salzburg (Ethikkommission Land Salzburg, No. 415-E/1203/5-2012).

OCD subtypes were determined by their total score on their MOCSS picture rating (see 3.2 *picture rating*). As expected, all patients scored in all categories, confirming prior findings in the literature on the overlap of subtypes (for a review see Rowsell and Francis, 2015). Out of the 17 participants, 11 scored highest in the category *washing*, 3 in *symmetry/ordering*, 1 in *hoarding* and 2 in *checking*.

2.2. Study procedures

As preparation, detailed information on the study was provided and written informed consent was obtained from all participants according to the Declaration of Helsinki. After the acquisition of individual stimulus pictures, a picture rating of the individual and standard MOCSS stimulus pictures was obtained in order to determine the most relevant pictures for each individual that were then shown during the fMRI scan. The scans were realized within the first week of hospitalization and were followed by another picture rating. In addition, all participants filled in the Symptom Checklist-90-R (SCL-90-R, Derogatis et al., 1977; German Version: Gloeckner-Rist and Stieglitz, 2011) and the Beck Depression Inventory II (BDI-II, Beck et al., 1996; German Version: Hautzinger et al., 2009).

The study is part of a larger multi-level longitudinal project with 4-5 fMRI scans during inpatient treatment, accompanied by venipunctures for assessment of several immune and endocrinological parameters, and real-time monitoring of the psychotherapeutic process, aiming at investigating the changes during psychotherapy. Please note that the results reported here focus on the above mentioned hypotheses only and are based on the data acquired at admission to the hospital.

Fig. 1. Exemplary pictures of individual stimulus pictures of OCD patients.

2.3. Stimuli

As mentioned before, our approach to individualize the stimulus pictures goes beyond the selection of individually triggering material, but includes taking photos from the patients' domestic environment. Two members of the study group accompanied each patient to their homes and took pictures of symptom-provoking situations presented by the patient. Exemplary pictures are shown in Fig. 1. Compliance was very high, since the patients themselves confirmed our assumption that the most problematic situations occur at home. The visit was often perceived as part of the therapy.

The standard pictures were taken from the Maudsley Obsessive-Compulsive Stimulus Set (MOCCS, Mataix-Cols et al., 2009), a validated picture set targeting the 4 subgroups of OCD (for examples see Fig. 2). It should be noted that the picture set is based on a dimensional approach, i.e. especially the washing subgroup evokes responses also in healthy controls, but on a lower level (Mataix-Cols et al., 2003).

For creating contrasts, neutral pictures from the International Affective Pictures Set (IAPS, Lang et al., 2008) were used (for examples see Fig. 3). In addition, participants were exposed to pictures from the IAPS-category 'disgust'.

2.4. Picture rating

The procedure of the picture ratings consisted of two parts. The first one aimed at choosing the 40 most triggering pictures for stimulation in the scanner, the second part aimed at collecting psychological data. Ratings were conducted computer-based with the E-Prime 2.0 presentation software (http://www.pstnet.com). First, the concepts of valence and arousal were explained to the patients, followed by a short introduction and training on the software. Then, all photos taken at the domestic settings were displayed on the computer screen and patients rated each picture on a Likert-scale from 1-9 with respect to the dimensions arousal and valence. The same was repeated for the pictures from the MOC stimulus set and the neutral pictures from the IAPS. The inverse value for valence and the value for arousal were added for each picture to obtain a total score and create a ranking, one for individual and one for standardized photos (over all subcategories). The top 40 pictures of each list, i.e. the most triggering ones, were chosen to be shown during the fMRI scan. For the healthy controls, the pictures of their respective patients were used.

In the post-scan ratings, only the pictures shown in the scanner (i.e., the top 40 of each list) were rated again, with a supplementary question on "coping", i.e. how well the participants felt that they could handle the situation shown. 2-sided *t*-tests and ANOVA were calculated for differences in groups and categories; all *p*-values were corrected for false-discovery rates (FDR, Radua and Albajes-Eizagirre, 2010).

2.5. fMRI Data Acquisition

Images were acquired with a 3T Siemens TIM TRIO whole-body scanner (Siemens Symphony, Erlangen, Germany) with a 32-channel head coil. First, a high-resolution scan was acquired for anatomical referencing using a T1-weighted MPRAGE sequence (FoV = : 256 mm, slice thickness = 1.0 mm, TR = 2300 ms, flip angle = 9°, resolution = 1x1x1 mm). Functional images were obtained in two sessions with a

Fig. 2. Examples of standardized pictures from the MOCSS (Mataix-Cols et al., 2004).

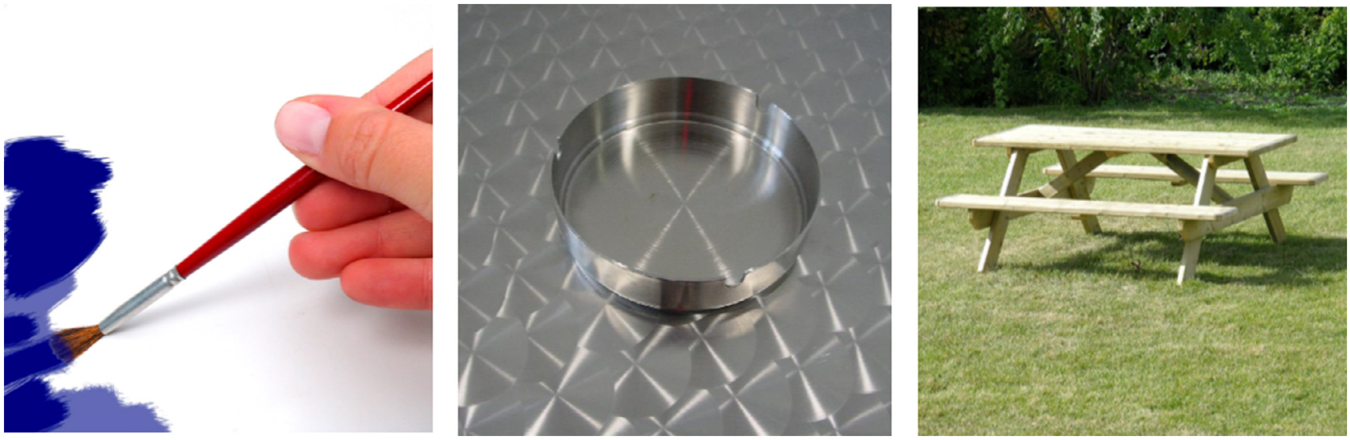

Fig. 3. Examples of neutral pictures from the IAPS (Lang et al., 2008).

short pause in between. A total of 552 volumes were acquired using a T2*-weighted gradient echo EPI with 36 slices (slice thickness = 3 mm, descending slice order, TR = 2250 ms, TE = 30 ms, flip angle = 70°, FoV = 192 mm). The first 6 volumes of each functional session were discarded due to saturation effects (Sarty, 2007), leaving a total of 540 volumes. The 40 most triggering pictures from the categories, as determined by the pre-scan picture rating (see 2.4), plus 40 neutral pictures were presented with the E-Prime 2.0 presentation software (http://www.pstnet.com) as an event-related design in a pseudo-randomized order in 2 sessions (20 pictures of each category in each session). The pictures were shown for 4 seconds each, separated by a fixation cross; the inter-stimulus interval was 2 seconds. The resulting DICOM files were converted to 4D-NIfTI-files with the tools *MRIConvert* (University of Oregon, 2016) and *dcm2nii* (Rorden, 2010).

2.6. Preprocessing

Preprocessing and statistical analyses were performed using the Statistical Parametric Mapping software package SPM12 (Wellcome Department of Cognitive Neurology, London) implemented in Matlab (Mathworks, Inc., Natick, MA, USA, release 13a). Functional images were realigned to the first image, de-spiked with the AFNI 3d-despike function (https://afni.nimh.nih.gov), unwarped, corrected for geometric distortions using the fieldmap of each participant, and slice time corrected.

The high resolution structural T1-weighted image of each participant was processed and normalized with the CAT12 toolbox (http://dbm.neuro.uni-jena.de/cat) using default settings. Each structural image was segmented into gray matter, white matter and CSF, and denoised, then warped into MNI space by registration to the DARTEL template provided by the CAT12 toolbox via the high-dimensional DARTEL registration algorithm (Ashburner, 2007). Based on these steps, a skull stripped version of each image in native space was created. To normalize functional images into MNI space, the functional images were coregistered to the skull stripped structural image and the parameters from the DARTEL registration were used to warp the functional images, which were resampled to 3x3x3 mm voxels and smoothed with a 6 mm FWHM Gaussian kernel. The quality of the preprocessing was checked using the tools *BXH* (Duke University, 2014) and *tsdiffana* (University of Cambridge, 2009).

2.7. Model specifications

Since SPM uses a mass-univariate approach, the effect of the conditions were modeled for each voxel with the general linear model (Kiebel and Holmes, 2008). The movement parameters gained from the realignment procedure during preprocessing were used as regressors. Corresponding to the 4 categories of pictures shown during scanning, the four conditions “Individual OCD pictures (OCD_Ind)”, “Standard OCD pictures (OCD_MOCSS)”, “Disgust (Disgust)” and “Neutral (Neutral) were modeled. The effects of the OCD pictures were investigated by calculating the *t*-contrasts “OCD_Ind > Neutral”, “OCD_MOCSS > Neutral” and “OCD_Ind > OCD_MOCSS” for each participant. These contrasts were then used to calculate two-sample *t*-tests on the group level.

In order to illustrate the differences in activation of the 7 most relevant regions (i.e., with voxels that survived FWE-correction on peak-level, see Table 5) between groups, the eigenvariates were calculated separately for each participant for both individual and neutral pictures. The eigenvariates were extracted using SPM's inbuilt functionality by specifying a sphere with r = 6 mm around the peak voxels and adjusting for effects of interest.

3. Results

3.1. Psychological Assessment

The psychological assessment of patients and controls confirms the clinically relevant symptoms of the patients and the mental health of the controls (Table 1). The mean of 26.7 (*SD* = 8.8) on the Yale-Brown Obsessive-Compulsive Scale (Y-BOCS, Goodman et al., 1989; German version: Hand and Buettner-Westphal, 1991) ranks the sample in the

Table 1
Arithmetic means (standard deviation) and *p*-values confirm significant differences in the psychological assessments of patients and controls. Ranges: Y-BOCS: 0–40; Beck Depression Inventory (BDI-II): 0–63; Symptom Checklist (SCL-90-R), scaled values: 0–4.

Psychological assessment			
Questionnaire	Patients	Controls	*p*
Y-BOCS			
Total	26.7 (8.8)	n.a.	
BDI-II			
Total	29 (9.4)	1.2 (1.5)	< 0.001
SCL-90-R			
Somatization	1.1 (0.7)	0.2 (0.3)	< 0.001
Obsessive-Compulsive	2.4 (0.8)	0.1 (0.2)	< 0.001
Interpersonal sensitivity	1.9 (0.9)	0.1 (0.1)	< 0.001
Depression	2.1 (0.6)	0.1 (0.1)	< 0.001
Anxiety	1.5 (0.8)	0.1 (0.2)	< 0.001
Hostility	0.9 (0.8)	0.1 (0.2)	0.001
Phobic anxiety	1.2 (0.8)	0.0 (0.0)	< 0.001
Paranoid ideation	1.4 (0.7)	0.1 (0.1)	< 0.001
Psychoticism	1.0 (0.7)	0.0 (0.1)	< 0.001
Additional items	1.6 (0.9)	0.1 (0.1)	< 0.001

Table 2
Arithmetic mean values of the picture rating for all stimulus categories for valence, arousal and ability to cope. In brackets: *SD*. *p*: *p*-values (FDR-corrected) of 2-sided *t*-test with H_0: mean (patients) = mean (controls).

Post-scan picture ratings: significance between groups

Stimulus	Patients	Controls	*p*
Individual OCD			
Valence	2.50 (1.04)	5.30 (1.03)	< 0.0001*
Arousal	6.96 (1.80)	2.14 (1.39)	< 0.0001*
Coping	3.32 (1.96)	8.17 (1.34)	< 0.0001*
MOCSS OCD			
Valence	2.94 (.86)	4.87 (.85)	< 0.0001*
Arousal	6.21 (1.88)	2.53 (1.59)	< 0.0001*
Coping	4.5 (2.14)	7.88 (1.56)	< 0.0001*
Disgust			
Valence	3.08 (1.69)	3.51 (1.18)	0.48
Arousal	5.92 (2.09)	3.71 (2.47)	0.03*
Coping	4.63 (2.34)	6.85 (2.44)	0.03*
Neutral			
Valence	6.72 (1.33)	6.59 (1.05)	0.75
Arousal	2.38 (1.11)	1.65 (.84)	0.08
Coping	8.15 (.83)	8.57 (.67)	0.17

middle to upper range of OCD symptom severity. Patients rated their strains significantly higher than controls on the BDI-II and on all subscales of the SCL-90-R. Next to the obsessive-compulsive subscale, depression was rated highest by the patients.

3.2. Picture Ratings

3.2.1. Comparison between groups

The pictures that were finally chosen and used during the scanning procedure were rated again after the scan including the question “ability to cope”. As expected, individual and OCD-pictures were perceived significantly different by patients and controls in all dimensions (i.e. valence, arousal and coping, see Table 2). Neutral pictures were perceived comparably.

3.2.2. Post-scan ratings: comparison between categories

Furthermore, we tested for significant differences between the categories within each group. For patients, Table 3 shows that neutral pictures are perceived clearly different to all other categories in all dimensions. Perception of individual OCD-pictures was also significantly different in all dimensions compared to the standardized pictures, but not to the disgusting pictures. Also, the difference between standardized and disgusting pictures was not significant.

The ratings of the controls were significantly different between all categories for all dimensions apart from the ability to cope, which was

Table 3
Significant differences between the categories (*p*-values, FDR-corrected) for paired *t*-test (2-sided).

Post-scan picture ratings: Significance between categories

	I-M	I-D	I-N	M-D	M-N	D-N
Patients						
Valence	0.03*	0.39	0.00*	0.84	<0.01*	<0.01*
Arousal	0.01*	0.18	0.00*	0.73	<0.01*	<0.01*
Coping	0.01*	0.15	0.00*	0.85	<0.01*	<0.01*
Controls						
Valence	< 0.01*	< 0.01*	< 0.01*	< 0.01*	< 0.01*	< 0.01*
Arousal	0.01*	< 0.01*	0.03*	< 0.01*	< 0.01*	< 0.01*
Coping	0.01*	< 0.01*	0.07	< 0.01*	0.01*	< 0.01*

I: individual OCD-pictures, M: MOCSS OCD pictures, D: disgusting pictures, N: neutral pictures.
* $p < 0.05$.

Table 4
Results of the ANOVA for the picture rating for the three dimensions.

	F	*df*	*p*	η_p^2
Valence	35.38	7	< 0.001	0.66
Group	40.10	1	< 0.001	0.24
Category	57.71	3	< 0.001	0.58
Group*category	11.49	3	< 0.001	0.21
Arousal	25.68	7	< 0.001	0.58
Group	94.27	1	< 0.001	0.42
Category	19.35	3	< 0.001	0.31
Group*category	9.14	3	< 0.001	0.18
Coping	22.62	7	< 0.001	0.55
Group	79.41	1	< 0.001	0.38
Category	16.90	3	< 0.001	0.28
Group*category	9.41	3	< 0.001	0.18

rated comparable for individual and neutral pictures (Table 3).

A univariate ANOVA with the factors “group” and “category” confirmed the significance of the differences (Table 4; see Nieuwenhuis et al., 2011).

All factors and the interaction between group and category were significant.

3.2.3. Variability within groups

In Fig. 4, the results are displayed in boxplots in order to show the variability within the groups. Arousal and coping reveals the most specific reactions (within the negative stimuli) for the individualized stimuli for both patients and controls, while valence was most specific for the standardized pictures in both groups.

3.3. Brain imaging data

The anatomical regions were determined by the Anatomy Toolbox implemented in SPM (Eickhoff et al., 2005).

3.3.1. OCD-stimuli vs. neutral pictures

First, we were interested in the differences between both OCD-stimuli sets compared to neutral pictures. The individual pictures revealed a group difference in several clusters, including the cingulate cortex, insula, hippocampus, middle/precentral gyrus, and superior/inferior parietal lobe (Fig. 5 and Table 5). Concerning the expected activation of the cortico-striato-thalamic network of OCD, no group difference was found for the thalamus or the striatum. For the standard OCD stimulus set (MOCSS), no group difference was found. Since this was unexpected and contradicting the results from the literature, we lowered the threshold to $p < 0.001$ without correction for false-positive results. At this level, group differences were found in the left inferior parietal and the right superior frontal gyrus (note that these regions were also significant for the individual pictures at the respective level of significance, i.e., the standard pictures did not activate any additional regions). Only when lowering the threshold even further to $p < 0.005$ uncorrected, activation was found for the MOCSS for the left hippocampus, bilateral middle frontal gyrus, bilateral precuneus, and left superior parietal cortex. However, no group difference was found with this stimulus set for the cluster including the anterior and posterior cingulate cortex/supplementary motor cortex, and the insula. It should be noted again that these results have to be interpreted with great caution due to the missing correction for false-positives. When checking for controls > patients, no significant activation was found for neither the individual pictures nor for the standardized pictures for $p < 0.05$ (FWE).

The contrast “OCD_Ind. vs. Neutral” is illustrated in Fig. 6 by the eigenvariates (interpretable as the height of the neuronal activation) for both groups and both conditions.

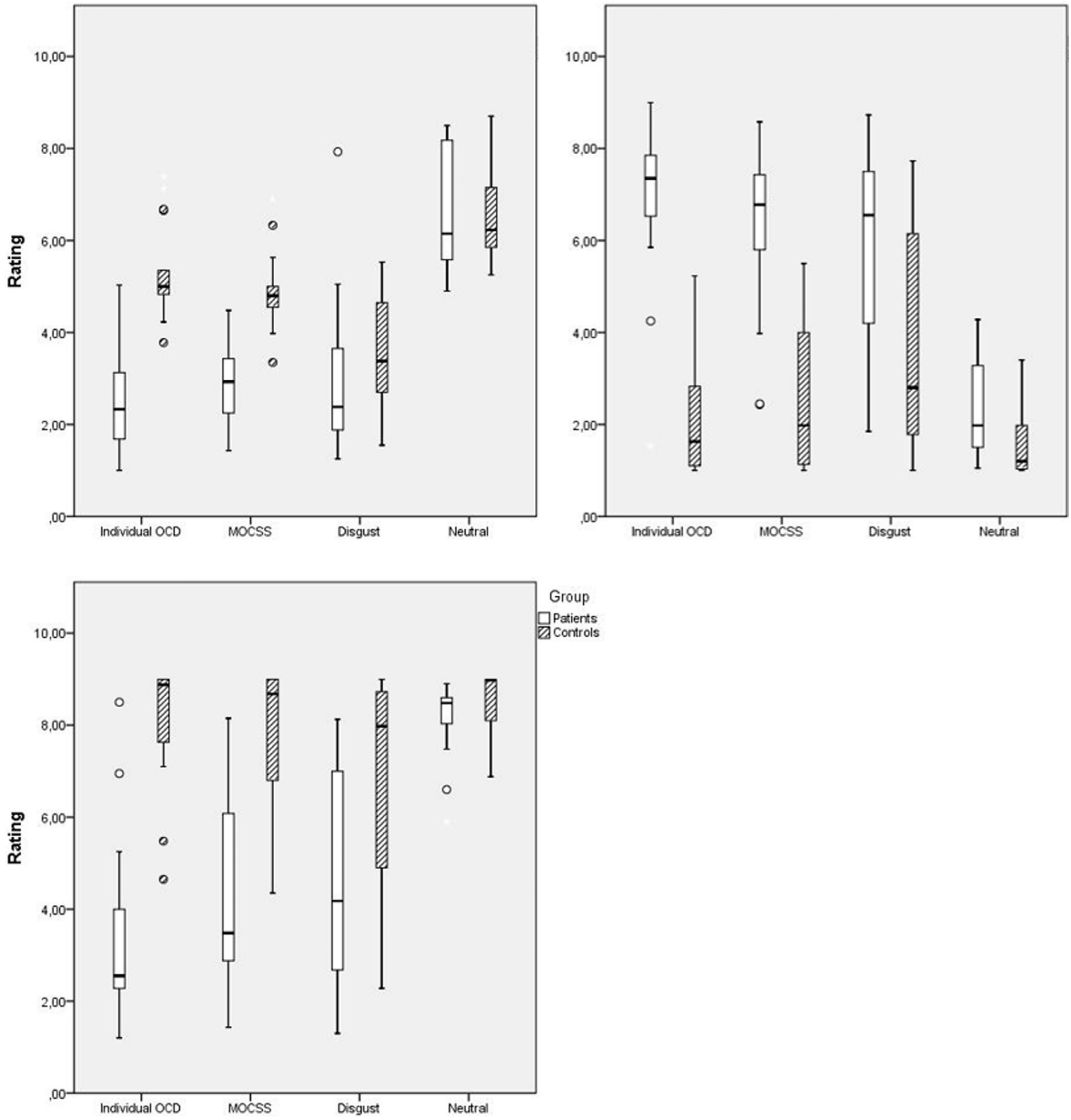

Fig. 4. Boxplots of the picture rating. The pictures were rated for valence (top left), arousal (top right) and coping (bottom). 50% of the answers are within the boxes, with the median marked as a horizontal line. The upper and lower 25% are indicated by the whiskers.

3.3.2. Individual vs. standardized OCD-stimuli

While Table 5 shows a listed comparison of the two conditions, the statistically significant difference between individual and standardized pictures was calculated using the contrast “OCD_Ind > OCD_MOCSS”. The result for patients > controls reveals the precuneus (left and right) as the region with highest alteration in neuronal activity (Table 6). For $p < 0.001$ (uncorr.), also the other regions with high differences in significance from Table 5 become significant, especially regions of the cortical midline-structures like the ACC, MCC and the supplementary motor cortex (SMC). Both contrasts are depicted in Fig. 7.

For controls > patients, no significant activation was found for $p < 0.05$ (FWE) on peak- or cluster level.

It should be mentioned that considerable activation was detected in voxels assigned to white matter (corpus callosum). This phenomenon has been reported before (Mazerolle et al., 2010) and is still an open research question.

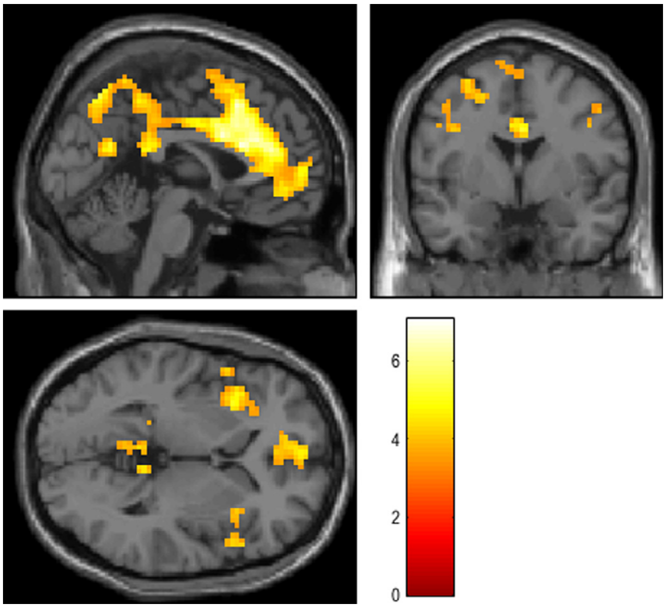

Fig. 5. Heightened activation for "OCD_Ind > Neutral" for patients > controls ($p < 0.001$ on peak-level with FWE cluster correction of $p < 0.05$).

Table 5
Brain regions (clusters) with increased activations for patients > controls for contrast "OCD_Ind > Neutral".

Brain region(s)	L/R	*x*	*y*	*z*	*T*	k
ACC/SMC	L	−3	17	37	6.56**	132
	-	0	17	46	6.56**	
	R	6	26	25	7.06**	
Hippocampus	L	−30	−34	−8	4.96*	52
Insula	L	−39	14	−5	6.65**	19
	R	33	17	−11	6.36**	6
MFG/PrG	L	−45	5	37	4.48*	69
	R	45	8	43	4.96*	58
PCC	L	−3	−46	10	6.16**	3
Precuneus	L	−12	−61	16	6.17**	4
SPL/IPL	L	−36	−55	49	6.17**	7
	R	51	−34	49	4.05*	65

k: number of significant voxels within the cluster for the respective threshold. ACC: anterior cingulate cortex, IPL: inferior parietal lobe, MFG: middle frontal gyrus, PCC: posterior cingulate cortex, PrG: precentral gyrus, SMC: supplementary motor cortex, SPL: superior parietal lobe.
* $p < 0.001$ on peak-level with $p < 0.05$ FWE-corrected on cluster-level,
** $p < 0.05$ FWE corrected on peak-level.

4. Discussion

4.1. Individual pictures are rated most relevant for OCD patients

As expected, the differences between groups in the picture ratings were very clear for the individual and standardized OCD-specific pictures in all three dimensions (Table 2). The significant difference between the categories "individual" and "standardized" OCD-pictures (Table 3) confirm prior findings on the enhanced psychological reactivity of OCD patients to individually tailored pictures (e.g., Schienle et al., 2005; Baioui et al., 2013b; Schiepek et al., 2013). The fact that the neutral pictures are indeed rated as neutral by the OCD patients (Tables 2 and 3) is an important prerequisite for creating meaningful contrasts, since OCD triggers are usually objects considered as "normal" by healthy controls.

The evaluation of the specificity of the categories (Table 3) for the patients showed clear differences for all categories compared to neutral pictures, and to a lesser extend also for the contrast "individual versus standardized" pictures, but neither between individual and disgusting nor between standardized and disgusting pictures. At first glance, one could conclude that disgusting pictures are just as suitable as stimuli as individual pictures. When interested in group differences, however, this does not hold true for the valence, as shown in Table 2. The only result not expected is the significant difference between individual and neutral pictures for valence and arousal for the controls. This might be because of the patients' choice of pictures with toilets, dirt etc., which of course are less pleasant than neutral pictures for healthy individuals, too.

4.2. Enhanced neuronal activity for individual stimuli

The aim of this study was to investigate differences in the activation of an individual compared to a standardized stimulus set. While the individual pictures were able to reveal neuronal activation in regions commonly reported in fMRI-studies of OCD patients (e.g., Schiepek et al., 2011; Del Casale et al., 2015), this was not the case for the standardized Maudsley Obsessive-Compulsive Stimulus Set. It seems like – in accordance with the picture rating – the enhanced psychological reaction is reflected by a heightened neuronal activity in the individual pictures. Concerning the missing difference in activation when corrected for false-positives for the standardized pictures between groups, one has to keep in mind that the MOCSS was designed on a dimensional scale, i.e., especially the pictures for the washing subset are also provocative for healthy controls (Mataix-Cols et al., 2004), as confirmed by our picture ratings (Table 3). In contrast, the individual pictures of our sample did not provoke any different neuronal response than the neutral pictures in the control group (not reported), i.e., they were well suited to elicit group differences between patients and controls. The missing activation for the standardized pictures could therefore be due to the fact that the difference between groups is not as strong as in the individual picture set.

4.3. Regions concerned with self-related processes and memory

Another hypothesis concerned the interpretation of Baioui et al. (2013a), who proposed that the two OCD-stimulus sets will elicit responses in different aspects of the pathology. Our results, however, suggest another approach. As reported in the results section, the standardized pictures did not reveal group differences in any additional regions, even when the correction for multiple comparisons was disregarded. Although Baioui et al. do not discuss this possibility, their reported results for the standardized pictures at the level of $p < 0.05$ with FWE correction are limited to one region only (nucleus caudatus), while the individual set detected pathological activation also in additional regions (nucleus accumbens, pallidum). Instead of interpreting the difference in activation as some kind of functional difference, it could well be a matter of effect size.

In contrast, some of the regions found for the individual pictures were not significant for the standard set even at the very loose uncorrected threshold of $p < 0.005$. It therefore seems unlikely that the activation of ACC/PCC/SMC and insula with the individual stimuli only is due to different aspects of OCD symptoms. A more plausible explanation might be that they are active because of effects of recognition. The direct comparison of the two stimuli sets revealed the precuneus as the region with the biggest difference. The precuneus belongs to the associative cortices with numerous connections to other cortical and subcortical regions, thus permits the brain to integrate both external and internal information (Cavanna and Trimble, 2006; Northoff, 2014). In a review study, Cavanna and Trimble categorized the functional correlates of the precuneus found in fMRI and PET studies into the three domains "visuo-spatial imagery", "episodic memory retrieval" and "self-processing". Similar roles can be found for the cingulate cortex (ACC/SMC and PCC), which is known to be part of the cortical midline region responsible for self-referential processes (Northoff, 2014). Also,

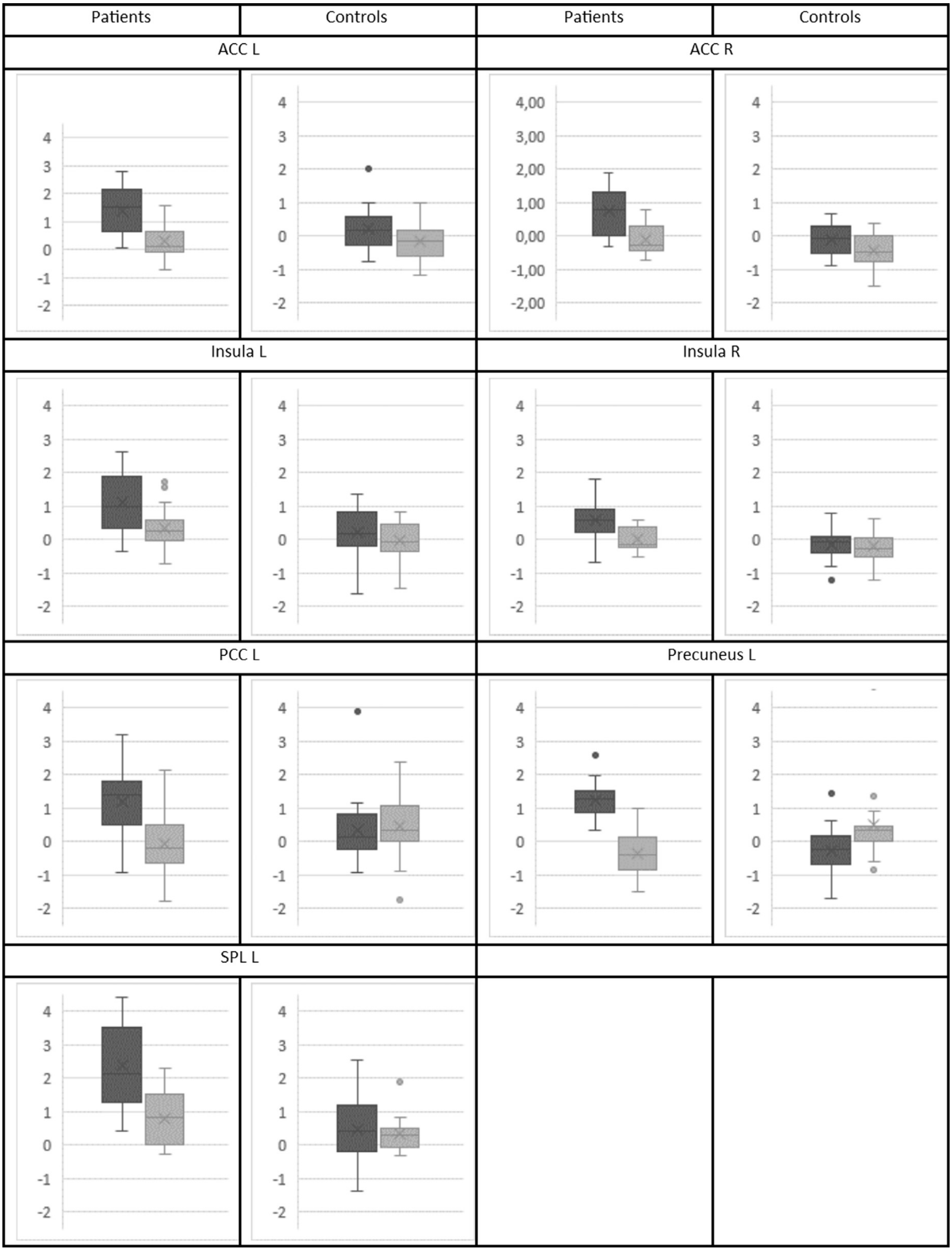

Fig. 6. Eigenvariates for patients and controls for the 7 most relevant brain regions for both individual OCD pictures (dark grey) and neutral pictures (light grey).

the left insula has recently been shown to play an important role in autobiographic memory retrieval (Parlar et al., 2018) and might be additionally activated through its connectivity to the ACC (Chang, 2012). Still, it should be noted that these regions could per se be altered in psychiatric disorders, reflecting an abnormal processing of self-related information and memory retrieval, as shown for depression (Northoff, 2014; Parlar et al., 2018). The paradigm presented here, however, was not aimed at and does not allow differentiating between "normal" and "abnormal" self-processing.

4.4. Limitations

Some limitations have to be taken into consideration with regard to this study. First, a sample size of 17 patients and 17 controls is assumed

Table 6
Contrast "OCD_Ind >. OCD_MOCSS" for patients > controls.

Brain region	L/R	*x*	*y*	*z*	*T*	k
ACC	R	9	17	22	6.70*	291
MCC/SMC	R	3	11	31	6.59*	119
		0	17	49	4.99*	
MFG/PrG	R	48	8	46	5.03*	49
		54	5	40	4.87*	
N. Caudatus/Thalamus	L	−9	8	1	5.72*	53
		−12	−4	1	4.95*	
Precuneus	L	−12	−61	19	9.09**	18
	R	9	−61	25	8.01**	7
Precuneus/MTG/SOG	L	−36	−76	34	6.48*	102
		−42	−76	22	5.36*	
		−30	−82	28	4.43*	
	R	36	−76	34	4.74*	99
		42	−79	16	4.69*	
		42	−67	16	4.56*	
SPL/IPL	R	39	−58	55	4.51*	171
		39	−40	43	5.37*	

k: number of significant voxels within the cluster for the respective threshold. ACC: anterior cingulate cortex, IPL: inferior parietal lobe, MCC: middle cingulate cortex, MFG: middle frontal gyrus, MTG: middle temporal gyrus, PrG: precentral gyrus, SMC: supplementary motor cortex, SOG: superior occipital gyrus, SPL: superior parietal lobe.

* $p < 0.001$ on peak-level with $p < 0.05$ FWE-corrected on cluster-level,

** $p < 0.05$ FWE corrected on peak-level.

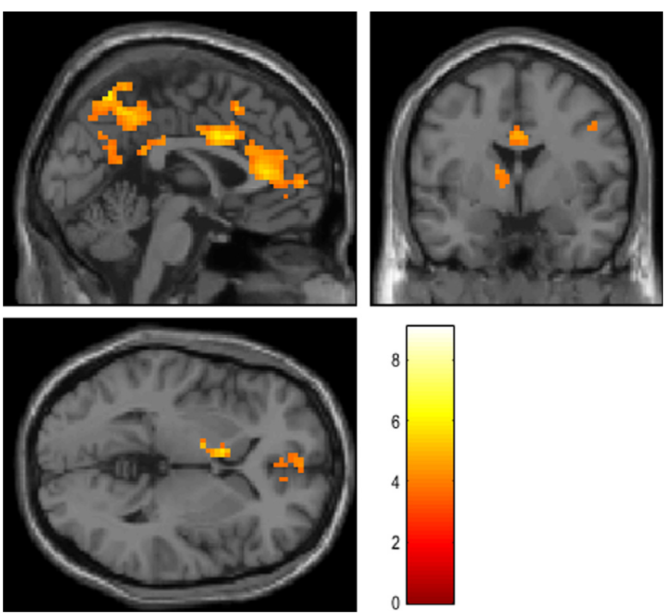

Fig. 7. The contrast "OCD_Ind > OCD_MOCSS" for patients > controls reveals highest activation in the left and right precuneus ($p < 0.001$ on peak-level with FWE cluster correction of $p < 0.05$).

to detect large effects only (Carp, 2012). However, the same author found the median in his review of 234 fMRI studies to be 14.75 for two-group analyses. Although this should not be an excuse for limited statistical power, bigger sample sizes hardly seem to be practically feasible (note that the results presented here are part of a longitudinal study with four to five measurements per participant). Second, the patients were not medication-naïve. Even though psychotropic drugs are specifically designed to alter neuronal activity, it can be assumed that – if the patient still meets the criteria for OCD – the drug was not able to change the disease-specific activation to an extend that normalized the brain function. Third, comorbidities, especially with major depressive disorder, are common in OCD (Schiepek et al., 2011). In consequence, it cannot be excluded that some of the pictures – though specifically designed to provoke OCD symptoms – also provoked altered neuronal activation due to a comorbidity in depression.

To conclude, the study confirms the enhanced psychological and neuronal reactivity of OCD pictures when confronted with individual stimuli compared to standardized stimuli and thereby stresses and confirms the advantages of individually tailored symptom provocation in fMRI. Only when choosing stimuli that appropriately address the unique patterns of symptom manifestation in patients, brain regions were significant with family-wise error correction applied.

When using individual stimuli in fMRI, one yet has to take into account that validity might be affected when using these stimuli only, since the aspect of recognition cannot be subtracted by contrasts if the patients' stimuli are used for the control as well, for whom they are unknown. As a result, parts of the self-referential network were significant, too, and could easily be misinterpreted as neuronal correlate of the illness under consideration.

4.5. Future research

An idiographic, individualized approach should also be considered for other studies, especially with a clinical questions at hand, to account for the considerable intra-individual variation in neuronal activity. Using such stimuli would be an important step towards replicability and validity of fMRI results, as they are able to detect effects that would have been discarded when using the standard stimulus set only. However, it is important to use individual pictures in the neutral condition, too, so that the overlap with processes of recognition and self-reference will be eliminated. Another approach to enhanced effects while avoiding this confound might be given by a standardized set of stimuli that can be individualized by choosing the most triggering images, as proposed by Simon et al. (2012).

Author's Contributions

KV analyzed the data and wrote the manuscript. BA and AK took the individual pictures with the patients at their homes, conducted the psychological tests and interviews and realized the picture ratings. MK set up the fMRI procedure and helped analyzing the data. HS advised on the statistical analysis of the picture ratings. EMR realized the fMRI scans. SSY and LK prepared the scripts for fMRI analyses. BKS and BSS recruited the participants and gave information about the study. WA supervised the study. GS designed and supervised the study.

Declaration of competing interests

All authors declare no competing interests.

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„Einer allein kann kein Dach tragen“

Aus Afrika

München, Salzburg und Mondsee, Oktober 2018

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