There and back again: a dynamical perspective on psychological resilience

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There and back again: a dynamical perspective on psychological resilience

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CONTENT

Chapter 1

Theoretical background

People face challenges and adversity at personal (bereavement, job loss, sickness) and societal (natural disasters, pandemics, terrorist attacks) levels. Adversities are an inevitable part of human life that often cannot be predicted nor prevented; they are a central risk factor for psychopathology and have a detrimental effect on mental health (1–4). Nevertheless, most people face stressful events but do not develop psychopathological symptoms (4–6). The observation of this phenomenon has led to the formulation of the concept of psychological resilience (hereafter referred to as 'resilience') (6–8). Resilience is a collective term for the process and outcome of successful adaptation to adversity, expressed in intact or quickly recovered levels of mental health and well-being (7,9). Because resilience can protect against the detrimental impact of stressors, we can try to understand what makes people resilient and use that information to decrease the effect of adversities on mental health. This idea has inspired decades of resilience research, and it is only growing more popular (10,11), especially in times of major catastrophes such as the current COVID-19 pandemic (12–15).

Over these decades of research, psychological resilience has been extensively studied from many different approaches and positions with various understandings across fields. For example, developmental psychopathology studies people's well-being and mental health trajectories after disasters and adversity (5,16). Positive psychology focuses on post-traumatic growth (increased well-being after adversity compared to before adversity) (17–19). Genetics and molecular biology unravel genetic, epigenetic, and molecular mechanisms underlying resilience, such as genes encoding several neuromediators, hormones, and receptors (20–22). The abundance and variety of approaches to studying resilience have also led to an interest in constructing multidisciplinary theories that combine several approaches. One of the most popular theories is a view on psychological resilience as a common characteristic of a complex dynamic system of mental health (8,23,24).

Unsurprisingly, such variety in resilience-related research questions has led to a considerable heterogeneity of conceptual and methodological approaches. Although all scholars aim to study different aspects of the same concept, there is little consensus on operational definitions of resilience. Whereas some approaches view resilience as maintaining stable health despite adversity (5,16), others see it as a process of bouncing back from adversity (8,25) or even achieving increased well-being after adversity compared to well-being before (17). Moreover, some see resilience as a stable, "trait"-like entity (26–28), while others argue that resilience is dynamic and fluid and depends on a specific combination of factors in the specific context and moment (5,16,19). However, despite this heterogeneity, most authors agree that resilience should be conceptualized at multiple levels, that resilience depends on various factors ranging from biological predisposition to social policies and cultural norms, and that resilience research should

focus on the dynamic process of adaptation to stress and trauma exposure (8,19,23,24). In my dissertation, I follow the same integrative approach and specifically base my understanding on the view proposed by Davydov and colleagues (2010). They define resilience as mental immunity—a complex biopsychosocial system of multifaceted and multilevel interactions facilitating an adaptive reaction to adversity, recovery processes, and mental health improvement or maintenance (29). Like the immune system, resilience does not necessarily mean the absence of symptoms or pathological processes. As a person with chronic illness still can recover from infections, "mental immunity" can facilitate recovery from stressors in people with psychopathology.

Moreover, the immune system may react differently to different pathogens and be effective against some but not others. Likewise, people can be resilient against one stressor and vulnerable to another. The process behind these reactions comprises interactions with stressors that may be stressor-, context- and person-dependent.

The relevance of adopting such an integrative approach may go beyond theoretical research. For clinical practice and public health, there is a great interest in developing interventions that can foster resilience, focusing on individual protective factors (e.g., increasing the level of optimism) or societal contexts (e.g., improving living conditions or creating support groups)(17,30–34). However, although some of the currently existing interventions show promising results (31), the comparability of the interventions is low (31,35–37). An integrative approach to resilience may facilitate the development of similar methods to assess resilience that can be used in different fields. Moreover, such a multidisciplinary framework may highlight the gaps in resilience research and elucidate mechanisms of resilience that are not possible to investigate within one discipline. As such, Davydov and colleagues' "mental immunity" model includes protective factors at individual and societal levels, which are rarely studied together despite their clear interrelations (29,38).

Another example of the relevance of the multidisciplinary framework comes from evidence that stressors at both micro (e.g., minor hassles in daily life) and macro (e.g., divorce, trauma) levels are playing a role in developing psychopathological symptoms (39,40). The effect of these micro- and macro- stressors can be both independent and cumulative. Thus, an integrative approach to resilience may increase our understanding of the topic, facilitate the development of new resilience indicators, and highlight the possibilities for new targets for resilience-enhancing interventions through focusing on different levels of stressors, protective factors, and dynamical interactions between them.

However, many studies of resilience in psychiatry often do not directly assess the interactions between protective factors and adversity. Resilience is often studied by focusing on how certain protective factors lower psychopathological symptoms (41–43). For example, a resilience-related study may have research questions similar to "does the level of optimism influence the severity of symptoms in people with depression?". Such studies help to find resilience factors but do not include stressors per se and thus, do not provide insights into mechanisms underlying resilience. This dissertation aimed to investigate protective factors, stressors, and interactions between the two to unravel these mechanisms.

Furthermore, many studies of mental health resilience have a cross-sectional design, so their results cannot be used to predict the effect of protective factors on future mental health. Therefore, establishing temporal connections between resilience factors and symptoms trajectory is essential. Based on the definition of resilience, protective factors mitigate the effect of adversity, lowering the level of psychopathological symptoms. Assessed simultaneously, however, the direction of causality between protective factors and symptoms is impossible to establish. It is also possible for a higher level of symptoms to lower the level of protective factors and not vice-versa (44). Additionally, to unravel the dynamic process of mitigating adversity, the interactions between protective factors and stressors also need to precede the change in the symptoms. This is why one of the overarching aims of this project was to establish clear temporal connections between the assessed resilience factors and future changes in mental health.

Longitudinal and prospective designs are essential for establishing temporal connections between resilience factors and mental health changes and further studying resilience as a dynamic process (19). A specific type of longitudinal data that is especially promising for unraveling the resilience process is intensive longitudinal data, i.e., data containing repeated assessments in every participant over an extended period of time (45). Such data are usually collected in the flow of daily life and allow one to study how daily life experiences change over time and interact with each other, thereby elucidating the possible dynamics between daily life experiences relevant to resilience functioning. Previous studies have shown that altered dynamics between moment-to-moment affect states are associated with risk factors and mental health outcomes, suggesting that daily life experiences play a role in developing symptoms (46,47,56,48–55). In contrast, some dynamics between daily life experiences may play a role in *mitigating* the development of symptoms. Another advantage of intensive longitudinal data is that it limits the retrospective bias commonly associated with self-report questionnaires (45). Finally, with intensive longitudinal data, it is possible to account for between-individual differences in the dynamics of daily life experiences, which may be substantial (57,58). Considering these differences is essential to understand the resilience mechanisms better and apply

this understanding in clinical practice. However, studies of psychological resilience that assess micro-level or daily life experiences and account for between-individual differences are lacking. Therefore, another aim of this dissertation was to fill this gap.

To find resilience-related patterns in the dynamics of daily life, we applied two (partly overlapping) theoretical frameworks: network theory and complex systems theory. According to network theory, mental disorders may be understood as direct interactions between symptoms, experiences, stressors, and risk and protective factors on different levels, rather than being a result of some (hidden) common cause (59–62). These interactions can be visualized as a network of interconnected elements and analyzed as a whole system. In addition, specific characteristics of these networks can be derived and used as meaningful indicators of a system's functioning (63). In resilience research, the network approach can be used to visualize and analyze interactions between protective factors, stressors, and symptoms to better understand the functioning of protective factors in daily life. Previous studies on resilience have used the network approach to assess the resilience of systems of interacting psychopathological symptoms, as well as systems of interacting protective factors, or combinations of both (23,64–67), and to investigate patterns of micro-level experiences that are associated with known protective factors (e.g., how reward system functions in daily life (66,68). However, most previous studies were conducted with cross-sectional data and investigated associations between symptoms rather than daily life experiences. This project applied network analysis to daily life affect dynamics to find possible resilience-associated patterns.

Furthering the notion of understanding mental health as a complex dynamic system of interconnected elements, we investigated dynamics of daily life experiences using the definition of resilience from complex systems theory. According to this theory, diverse complex systems can undergo substantial changes, such as the climate moving from ice ages to global warmings, ecosystems shifting from a forest state to a swamp state, and the financial market suddenly collapsing (24,60,69). Although such changes result from numerous mechanistic interactions, complex systems theory states that any system's resilience to change can be quantified in one universal characteristic. This overall estimate of resilience is the capacity of the system to recover from minor perturbations. Before the impending change, systems become increasingly slower in their capacity to recover (24). Indicators of this slowing down have been shown to predict future changes in various sorts of complex systems, such as financial markets, oceans, climate, and brain activity (24,70,71). If the same principles work for mental health, we can hypothesize that slower recovery of mental states from minor perturbation reflects reduced resilience and thus an increased risk of future increases in psychopathology (72,73). This recovery can be assessed in daily life by measuring how large the change is in affect levels immediately after experiencing stressors and how quickly these affect levels return to baseline.

Therefore, focusing on the affect recovery in daily life may lead to developing new, dynamics-based indicators of psychological resilience with potentially high predictive validity. However, no studies have looked at recovery from minor stressors directly, and there is a lack of studies on such complex-systems-based resilience indicators as predictors of mental health outcomes.

Taken together, in this dissertation, I aimed to fill several gaps in the extant resilience research in the field of psychiatry and psychopathology, namely the lack of investigations on the interactions between resilience factors and adversity. I applied perspectives from the network and complex systems theories and used prospective longitudinal studies to investigate resilience-related patterns in dynamics of daily life experiences. Such studies may lead to the development of new process-based operationalizations and indicators of psychological resilience. These operationalizations may facilitate consensus in understanding and defining resilience and inform and inspire new diagnostic instruments and resilience-enhancing intervention and prevention strategies for clinical practice.

THIS DISSERTATION

Chapter 2: *Don't worry, be happy: Protective factors to buffer against distress associated with psychotic experiences*. The study described in this chapter investigated interactions between protective factors and adversity in terms of the buffering effect of resilience factors on the level of distress associated with psychotic experiences in the general population.

Chapter 3: *Network dynamics of momentary affect states and future course of psychopathology in adolescents*. This chapter describes a longitudinal prospective study in which network analysis was applied to affect dynamics in daily life to predict mental health trajectories on the group level in a general twin population of adolescents and young adults.

Chapter 4: *Measuring resilience prospectively as the speed of affect recovery in daily life: A complex systems perspective on mental health*. This chapter concerns a longitudinal prospective study of how a complex systems indicator of resilience, i.e., speed of affect recovery from daily stressors, predicts mental health trajectories on the group level in a general twin population of adolescents and young adults.

Chapter 5: *Reflections on psychological resilience: A comparison of three conceptually different operationalizations in predicting mental health*. This chapter describes a longitudinal prospective study comparing three conceptually different indicators of psychological resilience in people with psychotic experiences. The three indicators are a general resilience indicator, which captures self-beliefs on the general ability to overcome adversities; daily resilience, which captures daily experiences of the ability to overcome adversities; and a recovery indicator, which reflects the pattern of negative affect recovery after small adversities in daily life. In this study, resilience indicators were assessed on an individual level and compared in terms of their concurrent associations, stability over time, and predictive potential regarding mental health.

Chapter 6: *General Discussion*. In the General Discussion, findings are summarized and discussed, and future research and clinical practice directions are given.

Chapter 2

Don't worry, be happy: Protective factors to buffer against distress associated with psychotic experiences

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ABSTRACT

Background: Around 6-7% of the general population report psychotic experiences (PEs). Positive PEs (e.g., hearing voices) may increase the risk of developing the psychotic disorder. An important predictor of the transition to a psychotic disorder is secondary distress associated with PEs. We examined the moderating effect of potential protective factors on this secondary distress.

Methods: Data come from 2,870 individuals of the HowNutsAreTheDutch study. PEs were assessed with the Community Assessment of Psychic Experience (CAPE) questionnaire and were divided into three subdomains ("Bizarre experiences," "Delusional ideations," and "Perceptual anomalies"). Protective factors explored were having a partner, having a pet, benevolent types of humor, optimism and the high levels of personality traits emotional stability (reversed neuroticism), extraversion, openness to experience, conscientiousness, and agreeableness. We examined whether these protective factors moderated (lowered) the association between the frequency of PEs and PE-associated distress.

Results: Perceptual anomalies were excluded from analysis due to the low prevalence in the sample. No moderating effects of protective factors on the association between bizarre experiences and distress were observed. Having a partner and high levels of optimism, self-enhancing humor, openness, extraversion, and emotional stability moderated the association between delusional ideations and secondary distress, leading to lower levels of distress.

Conclusions: Several protective factors were found to moderate the association between frequency and secondary distress of delusional ideations, with high levels of the protective factors being associated with lower levels of distress. A focus on protective factors could be relevant for interventions and prevention strategies regarding psychotic phenomena.

INTRODUCTION

Compared to psychotic disorders, mild, subclinical psychotic experiences (PE) are relatively common, with on average around 6-7% of the general population reporting any PE at least once in their life (John J McGrath et al., 2015; Van Os and Reininghaus, 2016), although large differences between cultures have been reported (McGrath et al., 2015; Sun et al., 2017, 2015). Most of these PEs are transient, with 80% of such experiences estimated to occur only once in an individual's lifetime (79). Nevertheless, PEs have been shown to increase the risk of developing clinical psychosis (75,80) and other mental illnesses in the future (81–85). For example, according to the meta-analysis by Linscott and van Os, 7.4% of people with baseline PE will develop a psychotic disorder later in life (79).

Therefore, factors that might affect the development of subclinical PEs into clinical psychotic phenomena have received extensive attention. This development is greatly influenced by the frequency and persistence of PEs and the level of associated or secondary distress (75,79,86–91). Associated distress may be the most crucial factor for future increase in the symptoms and need for care. Individuals who hallucinate and hear "voices" but appraise these experiences as positive tend to report fewer complaints and help-seeking behavior, even when the PEs are persistent and frequent (92,93). Additionally, individuals with a higher need for clinical care tend to appraise induced PEs as more distressing than individuals without a need for care (94). Consequently, some people may experience some PEs as positive and without much distress (93,95–97), and individual differences in such appraisals can underlie variation in the level of secondary distress and clinical outcomes (98,99).

Although the absence of distress and the positive appraisal of PEs have been associated with better outcomes (92,93,95,96,100), little attention has been given to potential protective factors that may *lower* the secondary distress. Some studies showed that non-help-seeking individuals with PE reported lower social and environmental adversity, normal cognitive functioning, high spirituality, and higher psychological and emotional well-being and social support than those with PEs and who need help (101,102). These results are also in line with longitudinal studies on high-risk adolescents suggesting that having a relatively high IQ, a more positive atmosphere at home, and higher levels of social support reduced the prevalence of psychotic symptoms later in life (103–106). However, other protective factors may also buffer against common mental illness but received little attention in the context of secondary distress by PEs. Such factors include having a partner (107), having a pet (108,109), benevolent types of humor (110,111), optimism (112,113), and certain levels of personality trait scores (high emotional stability, high extraversion, high openness to experience, high conscientiousness and high agreeableness)(114–119)

This study aimed to investigate whether the above-mentioned protective factors were associated with lower levels of PE-associated distress in adults from the general population. We hypothesize that protective factors will moderate the association between the frequency of PEs and PE-associated distress so that higher levels of protective factors will be associated with weaker associations between PE frequency and distress. Moreover, previous studies have shown that not all PEs are equally associated with distress (101,120–122). Therefore, we examined our hypotheses separately for three domains of PEs ("Bizarre experiences," "Delusional ideations," and "Perceptual anomalies"), which were recently identified in a meta-analysis of the Community Assessment of Psychic Experience (CAPE) questionnaire (123,124).

METHODS

Study design

Sample

Data came from a large national crowdsourcing study in the Netherlands (*www.HoeGekIs.nl*), an online platform for collecting self-reported data on the general population's mental health in the Netherlands. Participants were included after registration on the project website (launched December 19th, 2013) and could participate in cross-sectional and longitudinal studies(125). In these analyses, only data from the cross-sectional study were used. Measurements for the cross-sectional study were done in modules consisting of one or more questionnaires on a specific domain (e.g., Mood, Well-being, Personality). Participants could choose the modules they wanted to complete but always had to start with a module assessing their socio-demographic profile. This study used data on psychotic experiences from the Community Assessment of Psychic Experiences (CAPE) module and protective factors from the 'Start,' 'Optimism,' 'Humor,' and 'Personality' modules. The data extraction date for the current study was December 31st, 2015. Participants who were 18 years or older and provided informed consent to use their data for the research were included in the study. The study protocol was reviewed and exempted by the Medical Ethical Committee of the University Medical Center Groningen (registration number M13.147422 and M14.160855) (125).

Instruments

Subclinical psychotic experiences

Lifetime subclinical psychotic experiences were assessed with the Community Assessment of Psychic Experiences (CAPE (123)). The CAPE is a 42-item questionnaire with three subscales: positive psychotic experiences (20 items), negative psychotic experiences (14 items), and depressive feelings (8 items; not assessed). Only positive PEs were used for this work, as studies suggest that positive experiences are specifically predictive

for the development of the clinical (psychotic) disorder and need for care (126–129). In contrast, negative/cognitive symptoms seem to be more predictive of poorer psychosocial functioning (130,131). Each item assessed both symptom frequency (CAPE a) on a 4-point scale, ranging from "never" to "nearly always," and associated secondary distress (CAPE b) on a 4-point scale, ranging from "not distressed" to "very distressed." Following a recent meta-analysis on the CAPE (124), the positive psychotic experiences were grouped into three domains: "Bizarre experiences" (7 items), "Delusional ideations" (9 items), and "Perceptual anomalies" (4 items). The domain affiliation of items is presented in Table 1. The frequency scores of all experiences were summed per domain (CAPE a) and the secondary distress scores were summed and dichotomized into no distress (0) and any distress (1) because of the highly skewed distribution. For the analyses, only endorsed items were included, as items can only be experienced as distressing where they are present at all.

Table 1. CAPE Subdomains of positive PEs, from Mark and Toulopoulou, 2016

Bizarre experiences	
CAPE 5	Do you ever feel as if things in magazines or on TV were written especially for you?
CAPE 17	Do you ever feel as if electrical devices such as computers can influence the way you think?
CAPE 24	Do you ever feel as if the thoughts in your head are being taken away from you?
CAPE 26	Do you ever feel as if the thoughts in your head are not your own?
CAPE 28	Have your thoughts ever been so vivid that you were worried other people would hear them?
CAPE 30	Do you ever hear your own thoughts being echoed back to you?
CAPE 31	Do you ever feel as if you are under the control of some force or power other than yourself?
Delusional ideations	
CAPE 2	Do you ever feel as if people seem to drop hints about you or say things with a double meaning?
CAPE 6	Do you ever feel as if some people are not what they seem to be?
CAPE 7	Do you ever feel as if you are being persecuted in some way?
CAPE 10	Do you ever feel as if there is a conspiracy against you?
CAPE 11	Do you ever feel as if you are destined to be someone very important?
CAPE 13	Do you ever feel that you are a very special or unusual person?
CAPE 15	Do you ever think that people can communicate telepathically?
CAPE 20	Do you believe in the power of witchcraft, voodoo or the occult?
CAPE 22	Do you ever feel that people look at you oddly because of your appearance?
Perceptional anomalies	
CAPE 33	Do you ever hear voices when you are alone?
CAPE 34	Do you ever hear voices talking to each other when you are alone?
CAPE 41	Do you ever feel as if a double has taken the place of a family member, friend or acquaintance?
CAPE 42	Do you ever see objects, people or animals that other people cannot see?

Protective factors

Available demographic factors included having a partner (yes/no) and a pet (yes/no). Optimism was assessed with The Life Orientation Test-Revised (LOT-R) (132) using ten items scored on a 5-point Likert scale. The 'optimism' sum score was calculated using optimism-related items and reversed pessimism-related items, and higher scores represent higher optimism levels. Humor styles were assessed with the Humor Style Questionnaire (HSQ) (111) using 32 items scored on a 7-point Likert scale. Separate sum scores for benign styles of humor ('self-enhancing humor' and 'affiliative humor') were calculated, with higher scores indicating higher levels of this type of humor.

Personality traits were assessed with the 60-item NEO Five-Factor Inventory (NEO-FFI-3)(133) or 12 items per domain scored on 5-point Likert scales. Domain scores for the traits 'extraversion', 'openness to experience,' 'agreeableness,' 'conscientiousness,' and 'emotional stability' (the inverse of neuroticism thus low neuroticism) were studied as protective factors, with higher scores representing higher trait levels.

Analysis

For each of the three studied PE domains, we first tested the main effect of the frequency of PEs on the secondary distress of these PEs with binominal logistic regression. Effects are expressed in Odds Ratio (OR). After that, the correlations between PE frequency scores and levels of protective factors were examined. Spearman's rank correlation coefficient was used because of a skewed distribution of the frequency items and potential non-linear association between variables.

Next, potential moderation effects of the protective factors on the association between frequency of PEs and distress caused by these experiences were investigated by entering the interaction between the protective factors and PE frequency scores into the model and testing if this interaction was significant. Multiplicative interactions were tested, as we assumed relationships between the frequency of a PE and associated distress to differ conditionally on the presence and level of protective factors and that this effect was multiplicative (different ORs depending on the presence and level of protective factors). The models were constructed for each subdomain of psychotic experiences and each protective factor separately. All tests were corrected for age and gender (134,135). The False discovery rate (FDR) correction was applied to correct for multiple testing following the Benjamini–Hochberg procedure (136) with an alpha level set at 0.05, thus allowing for 5% of obtained significant results to be false positive.

Significant interactions were visualized; thus, PE frequency*distress was stratified for low and high values of the protective factors to investigate further the size and shape of the moderating effect. For continuous protective factors, the frequency-distress associations were plotted for groups with mean +/- 1 standard deviation (137), and for dichotomous variables, we plotted the associations for the two categories. All analyses were conducted in R, version 3.6.0.

RESULTS

Sample and PEs

From the 12.503 participants who completed one instrument (M_{age} = 45.0 (SD= 15.0), 65.2% female) we selected the subsample of 2870 participants who completed the CAPE (M_{age}=48.73 (SD=13.88), 66.72% female). CAPE-completers were slightly more often female (67% versus 65%, P < 0.05) and older (mean = 48.7 years [SD = 13.9] vs. 44.2 years [SD = 14.7]; P < 0.001) than non-completers. More details can be found in the previous publication on the HowNutsAreTheDutch sample (138). Bizarre experiences were reported by 1127 participants (39.27% of total sample; PE mean= 1.79, SD=1.4) of whom 40% reported secondary distress (n=449). Delusional ideations were reported by 2735 participants (95.30 % of total sample; mean=4.22, SD= 2.61) of whom 71% reported secondary distress (n=1932). Perception Anomalies were reported by 353 participants (12.30% of total sample; mean=1.43, SD=0.89) of whom 28% reported secondary distress (n=99). These three domains showed substantial overlap (Spearman correlations; 'Bizarre experiences'-'Delusional ideations': ρ=0.45, p<.001; 'Bizarre experiences' – 'Perception anomalies': ρ= 0.27, p<.001; 'Delusional ideations–'Perceptional Anomalies': ρ= 0.31, p<.001).

Protective factors

The distributions of the protective factors are presented in Table 2 for the total sample and per PE domain. Because not all participants completed all modules, each model was based on different numbers of people (see Table s1). There were no differences in the distribution of non-responders across these subsamples (see Table s1).

Table 2. Distribution of the protective factors (%, n, mean, and SD) in the total sample and per subsamples of PEs.

Protective factors	Total sample (n = 2870)		Bizarre experiences subsample (n = 1127)		Delusional ideations subsample (n = 2735)		Perceptional anomalies subsample (n = 353)	
	% yes	n yes	% yes	n yes	% yes	n yes	*% yes*	*n yes*
Having a partner	74.11%	2127	72.40%	816	74.22%	2030	70.54%	249
Having a pet	44.29%	1271	44.63%	503	44.46%	1216	49.29%	177
	M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Optimism	13.73	2.58	13.78	2.60	13.73	2.60	13.70	2.64
Affiliative humor style	39.32	9.26	38.72	9.26	39.29	9.06	38.60	8.78
Self-enhancing humor style	36.64	8.65	36.62	8.87	36.62	8.70	37.30	8.66
Extraversion	27.24	7.10	26.69	7.30	27.21	7.12	26.27	7.28
Agreeableness	25.15	5.38	24.65	5.59	25.05	5.39	25.41	5.64
Conscientiousness	26.76	6.20	25.94	6.40	26.71	6.22	25.50	6.98
Openness	23.36	6.32	23.89	6.22	23.45	6.30	26.20	6.12
Emotional stability	28.68	9.32	26.18	9.25	28.45	9.31	26.55	9.83

Associations between protective factors and frequency of PEs

The associations between protective factors and frequency of PEs are presented in Table s2. Most of the protective factors were significantly associated with the frequency of PEs. However, the effect sizes of these associations were very small (rho ~0.07 on average), except for factors openness (rho = 0,23 with the frequency of Delusional Ideations) and emotional stability (rho = -0,23 with the frequency of Bizarre Experiences and rho = -0,25 with the frequency of Delusional ideations)

Associations between frequency of PEs and secondary distress

PE frequency score was positively associated with distress for each domain (Bizarre Experiences: OR=2.62, p<0.001; Delusional Ideations: OR=1.47, p<0.001; Perceptional Anomalies: OR=1.74, p=0.001). Because of the low frequency of Perceptual anomalies, subsequent analyses were only performed for the Bizarre experiences and Delusional ideations domains.

The protective factors showed no significant interaction effects with PE frequency in predicting distress for Bizarre experiences. For Delusional ideations, the protective factors having a partner, optimism, self-enhancing humor, extraversion, openness, and emotional stability showed significant interaction effects on the association between frequency of PEs and PEs distress. More specifically, having a partner, optimism, self-enhancing humor, extraversion, openness, and emotional stability reduced the association between the frequency of PEs and the level of secondary PE distress (Figure 1). The odds ratios (ORs) for the interaction terms of the logistic regression analyses are presented in

Table 3; however, it must be noted that these ORs cannot be directly interpreted as effect sizes. The interpretation of effect sizes presented in Figure as follows: for example, for the trait emotional stability, a person with low emotional stability (-1 SD) and five frequency of Delusional ideations will have ~95% chance to experience distress, and a person with high emotional stability (+1 SD) and also five frequency score will have ~60% chance of experiencing distress.

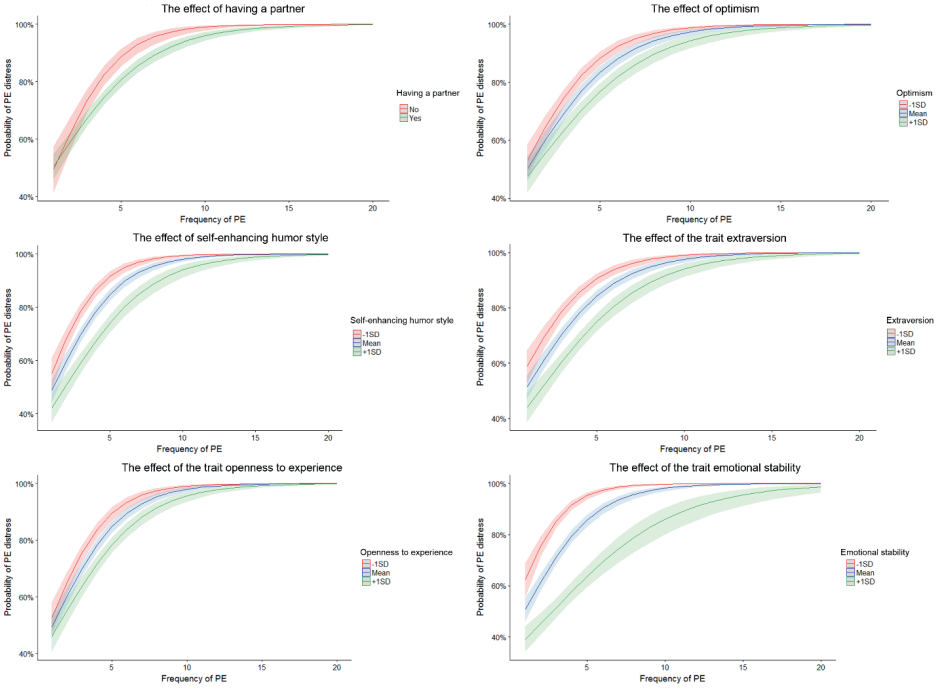
Table 3. ORs for the protective factor * frequency of PEs (CAPE A) interactions, per domains of PEs.

Protective factors	**Bizarre experiences**					**Delusional ideations**				
	OR	*95% CI*		*p*	*Adj.p*	*OR*	*95% CI*		*p*	*Adj.p*
Having a partner	1.04	0.74	1.44	0.80	0.84	0.84 *	0.74	0.96	0.01	0.04
Having a pet	0.85	0.62	1.16	0.30	0.4	0.99	0.9	1.1	0.9	0.9
Optimism	0.96	0.91	1.03	0.28	0.4	0.97 *	0.95	0.99	0.001	0.01
Affiliative humor style	0.99	0.97	1.01	0.18	0.3	1.00	0.99	1.00	0.17	0.3
Self-enhancing humor style	1.00	0.98	1.01	0.63	0.79	0.99 *	0.98	0.99	<0.001	<0.001
Extraversion	0.99	0.96	1.01	0.22	0.34	0.99 *	0.98	1.00	0.01	0.03
Agreeableness	0.99	0.97	1.02	0.68	0.8	1.01	1.00	1.02	0.03	0.07
Conscientiousness	0.98	0.96	1.01	0.12	0.24	0.99	0.98	1.00	0.03	0.07
Openness	1.00	0.97	1.02	0.77	0.84	0.99 *	0.98	1.00	0.003	0.01
Emotional stability	0.99	0.97	1.00	0.12	0.24	0.98 *	0.97	0.99	<0.001	<0.001

* corresponds to the significant interaction effects after the FDR correction. Note that the 95% confidence intervals were not corrected for multiple testing

In these graphs, X-axes correspond to the frequency of PEs (CAPE a sum scores) and y-axes – to the probability of the distress associated with PEs. For the first graph, 'the effect of having a partner,' the red upper line corresponds to the absence of a partner, and the green lower line – to the presence of a partner. For other graphs, the upper red line corresponds to the low level of protective factor (-1 SD), the middle blue line – to the mean level of protective factor, and the lower green line – to the high level of protective factor (+1 SD). The interpretation of the effects is as follows: for example, for emotional stability, a person with low emotional stability (-1 SD) and frequency of five of Delusional ideations will have ~95% chance to experience distress, and a person with high emotional stability (+1 SD) and also five frequency score will have ~60% chance of experiencing distress.

Figure 1. Visualization of the effect sizes: plots of association between frequency of PEs (x-axis) and probability of associated distress (y-axis) per +/- 1 SD and mean values of protective factors (yes/no for 'having a partner').



DISCUSSION

This study aimed to investigate whether several protective factors reduced the level of distress associated with different types of subclinical psychotic experiences (PEs) in adults from the general population. First, higher PE frequency was associated with a higher probability of distress in all three PE domains. This effect was most pronounced for Bizarre Experiences. Second, the protective factors showed different moderating effects on Bizarre Experiences than on Delusional Ideations. For Bizarre Experiences, there were no significant interactions between studied protective factors and PE-associated distress. For Delusional Ideations, the following factors significantly moderated the association between the frequency of PEs and the distress associated with them: having a partner, higher levels of optimism, higher levels of a self-enhancing humor style, higher extraversion, higher openness, and higher emotional stability.

It is difficult to explain why these protective factors only appeared in the context of Delusional Ideation and not for Bizarre Experiences. One possible explanation of the absence of significant results for the domain 'Bizarre experiences' may lie in

the smaller sub-sample size, as 'Delusional ideations' were reported almost twice as often than 'Bizarre experiences.' Moreover, in our sample, Bizarre experiences were associated with a higher level of distress than Delusional ideations. Therefore, it could be speculated that the buffering effect of protective factors is less strong in the case of more intensely distressing experiences. In our sample, 71% reported having any distress by Delusional ideations, whereas for Bizarre experiences any distress reported only 40% of participants. These results may be explained by the intra-item distribution of frequency and distress: in particular, in bizarre experiences, more frequent items were also highly distressing, whereas, in Delusion ideations, more frequent items were generally less distressing. Our observation that Bizarre experiences are more distressing than Delusional ideations is inconsistent with previous findings (120). The discrepancies in PE may explain this inconsistency: because we followed the model of Mark and Toulopoulou (124), we included grandiose and persecutory items in the delusional ideations. However, grandiose items are less distressing (122,139) or even beneficial for mental health (140). Additionally, some delusional items were very frequently endorsed (e.g., "Do you ever feel as if some people are not what they seem to be?"), potentially tapping into more normal experiences and thus being less distressing.

Another speculative explanation for the differential effects of Delusional ideations and Bizarre experiences may lie in the different nature of these domains. Bizarre experiences may be perceived as more genuine and external (i.e., coming from outside) and therefore less controllable and verifiable than Delusional ideations. For example, in our sample, the most distressing Delusional ideations item was "feeling as being persecuted in some way." This feeling may be verified to a certain extent, whereas for the most distressing Bizarre experiences item, "feeling as if the thoughts in your head are being taken away from you," verification is limited. Such reasoning aligns with the recent cognitive model of psychosis, highlighting the importance of the externalizing appraisal of psychotic experiences (141). Therefore, there may be more options for cognitive and emotional reappraisals for Delusional ideations than Bizarre Experiences. Following this argument, it can be imagined that, after a discussion with a partner, the level of distress from "feeling being persecuted in some way" may decrease because a partner can provide some contradictory evidence (or potentially help in case of persecution and awareness of this can reduce distress). Whereas for 'feeling as if the thoughts in your head are being taken away from you,' reality testing and expected help posit challenge.

Within the domain of Delusional ideations, several factors were found to moderate (i.e., lower) the effect of PE frequency on lower secondary distress. Three personality traits had significant effects (high extraversion, openness, and emotional stability), consistent with the literature and our expectations. Higher openness, extraversion, and emotional

stability are associated with more adaptive emotional regulation and beneficial coping strategies (142,143), possibly leading to a more positive reappraisal of psychotic experiences. Similar reasoning may apply to the effects of optimism and self-enhancing humor (144,145). A possible reason for the absence of an effect for affiliative humor may be that this humor style is more connected with relationships with others(111), and therefore may be less relevant for the positive appraisal of subjective PEs.

For socio-demographic protective factors, having a partner was associated with lower distress for Delusional ideations, consistent with findings of a general protective effect of social support (102,107,146,147). Although having a pet has been shown to have some psychological and physical benefits (109), the evidence is somewhat contradictory(148). In addition, the type of pet, which we did not assess, seems important (149). Furthermore, although pets could also be seen as (proxies of) social support (114), as it was discussed earlier, part of the beneficial effect of social support may occur due to the opportunity for reality testing, which is less the case through interactions with animals.

It is also necessary to note that these results may be explained by a mediating rather than a moderating effect of the protective factors. In this case, the association of a higher level of protective factors with a lower probability of distress may be explained by the fact that the protective factors are also associated with the lower *frequency* of PEs, and because of that, also with lower probability of distress. However, this explanation seems unlikely based on the low correlations between frequency and protective factors. Among protective factors with significant interaction effects, only openness and emotional stability were relatively highly associated with PE frequency. Moreover, for openness, this association is positive, meaning that higher levels of openness are associated with the higher frequency of PEs, and so for this factor, a moderation effect may exist despite this association. Therefore, the only factor for which it is impossible to state the absence of mediation is emotional stability.

Our study has several other limitations. First, the PEs of different domains were unequally distributed in our sample. In particular, Perceptional Anomalies were not often reported in this general population sample, and their secondary distress was reported even less often, leading us to exclude this domain from interaction analyses. Therefore, the results of our study are not generalizable to populations experiencing Perceptional Anomalies and are not fully comparable to the studies using the full CAPE. Moreover, most of the people who reported Bizarre experiences also reported Delusional Ideations, and therefore they cannot be treated as belonging to separate individual samples. Therefore, no definite statements can be made about moderation effects on Bizarre experiences, as mostly all of these individuals also reported delusional ideations. Second, the distribution of distress was highly skewed. Because other data

transformations and ordinal regression modeling were not possible due to violation of proportional odds assumption, we decided to dichotomize the distress variables, which led to considerable loss of data and potential omission of important information. Third, the exact time between and order of assessments varied largely between participants, and therefore, the time between assessment of PEs and protective factors was often different. However, all measures were assessed within one year. Nevertheless, these differences may potentially lead to discrepant results (e.g., the status of relationships with a partner has changed between the moment of filling in the first module and the CAPE). In line with this, the CAPE asks for lifetime experiences, and the actual PE may have taken place at a different time than the assessed risk factor, which might have added noise to the analysis. Fourth, due to the way the PEs were assessed, frequency scores represent a combination of the presence of PEs and their frequency, some people with identical scores might have had very different combinations of PEs: e.g., frequency score of three might have meant both three different items which are experienced "sometimes," or one which is experiences "nearly always." This discrepancy might have added more noise to the analysis as well. Fifth, the used sample is not representative of the general population because of its crowdsourced nature (125), with people with high education and females being overrepresented. Therefore, generalizing our findings to the general population is not possible. Sixth, as our study is cross-sectional, we cannot establish the direction of the underlying processes; for example, it may still be that PEs influence personality rather than vice versa. This consideration complicated the interpretation of results, which must be considered preliminary until replicated on a longitudinal cohort. Finally, other potential protective factors may explain the low level of distress despite the high frequency of PEs. Among these factors may be sleep quality (150), empathy (151), physical activity (41), green space (152), as well as other, higher-level factors (i.e., family and community dynamics) (41,104,153). Moreover, these protective factors are likely correlated with each other. There may exist meaningful clusters of protective factors, which may differ regarding their buffering effect. Therefore, the next step is to establish such protective processes longitudinally and at the individual level (154); future studies will benefit from including clinical and non-clinical cohorts and data-driving clustering of the protective factors.

It must be noted that our study is closely connected to the concept of resilience. Psychological resilience is defined in different ways and often is understood as an outcome of a dynamic process of successful adaptation to adversity, i.e., good (or stable) mental health despite stressful events and risk factors (8). In this framework of resilience, the protective factors studied in this paper can be seen as resilience-increasing factors that facilitate the process of adaptation in terms of a favorable

outcome despite adversity. Future resilience studies could investigate the process of response responding to psychotic experiences in more detail in people with different levels of these protective factors.

In conclusion, our results indicate that several protective factors may influence the probability of PEs to be distressing and that this protective effect may differ between subdomains of PEs. However, no causal conclusions can be drawn due to the study's cross-sectional nature. In the future, if replicated in longitudinal studies with more generalizable samples and including a more comprehensive selection of protective factors, these findings could be used to help identify individuals at higher risk of poorer outcomes and, potentially, to create tailored intervention and prevention approaches focusing on enhancing individuals' protective factors, such as school-based mental health training (30,155–158). Focusing on distress associated with PEs and on protective factors may enrich our understanding of the nature of PEs and explain why despite having frequent PEs, some people are more resilient to psychopathology (93,95–97)

Chapter 3

Network dynamics of momentary affect states and future course of psychopathology in adolescents

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ABSTRACT

Background: Recent theories argue that an interplay between (i.e., a network of) experiences, thoughts, and affect in daily life may underlie the development of psychopathology.

Objective: To prospectively examine whether network dynamics of everyday affect states are associated with a future course of psychopathology in adolescents at an increased risk of mental disorders.

Methods: 159 adolescents from the East-Flanders Prospective Twin Study cohort participated in the study. Their momentary affect states were assessed using the Experience Sampling Method (ESM) at baseline. The course of psychopathology was operationalized as the Symptom Checklist-90 sum score change after one year. Two groups were defined: one with a stable level (n=81) and one with an increasing level (n=78) of SCL-symptom severity. Group-level network dynamics of momentary positive and negative affect states were compared between groups.

Results: The group with increasing symptoms showed stronger connections between negative affect states and their higher influence on positive states and higher proneness to form 'vicious cycles,' compared to the stable group. Based on permutation tests, these differences were not statistically significant.

Conclusion: Although not statistically significant, some qualitative differences were observed between the networks of the two groups. More studies are needed to determine the value of momentary affect networks for predicting the course of psychopathology.

INTRODUCTION

Mental disorders place a heavy burden on individuals and society (159). First symptoms of psychopathology often emerge during childhood and adolescence (160,161). These symptoms persist and may develop into fully manifested mental disorders later in life for some adolescents. There are various risk factors for future mental illness. Some are genetic (162), whereas others are environmental, such as early life adversities and traumas (163–167). Nevertheless, even among individuals exposed to these risk factors, only a small proportion develops clinical levels of psychopathology, accompanied by impairment and need for care (164). For prevention, it is crucial to understand why some people develop more severe symptoms, and others do not.

A better understanding of the underlying mechanisms of psychopathology may improve the adequate identification of children and adolescents at risk for developing (severe) psychopathology. One approach to uncovering these mechanisms is zooming in to the moment-to-moment patterns of affect, experiences, and thoughts in the flow of daily life. Such dynamical patterns may be effectively assessed with experience sampling (ESM) design, i.e., collecting intensive time-series data on momentary experiences multiple times during the day (45). Previous studies using ESM have shown that changes at the level of daily life experiences are associated with risk factors and the future development of psychopathology. Among the risk factors shown to be associated with the altered dynamics of affect states in daily life are genetic risk (46,47,52), certain personality traits (48), childhood adverse experiences (49–51), and poor sleep quality (168–170). In turn, the altered dynamics of affect states in daily life have been shown to predict the emergence of new symptoms later (53–56). These findings suggest that how momentary experiences interact in daily life, i.e., the dynamics between moment-to-moment affect states, may influence the impact of risk factors on the later manifestation of psychopathology.

Suppose part of the underlying mechanisms of psychopathology can be inferred from the daily life dynamics of affect states. In that case, the critical question arises as to how these dynamics in such short-lived experiences can substantially influence the future development of symptoms. One theory is that the change in a single affect state can set in motion a cascade of changes in other experiences and behaviors (171,172). For example, for some people, feeling lonely may induce states of feeling down and irritated. These affect states, in turn, may re-activate feeling lonely. Such mutual influences, when occurring repeatedly, can lead to 'vicious cycles' of affect states that keep reinforcing each other, trapping a person in a negative flow.

Nevertheless, for others, feeling lonely may pass without activating other negative affect states or may be neutralized by a later positive affect state (e.g., feeling cheerful after seeking social support from peers). Moreover, the ability of positive states to interrupt or downregulate the negative "vicious cycles" may be associated with resilience to psychopathology and may represent an essential part of its mechanism. Thus, the impact of a minor mood perturbation may vary depending on the dynamics of affect states. To investigate these dynamics, we need to assess the whole system of interacting positive and negative affect states.

These ideas align with the network theory of psychopathology (61,63). According to this theory, symptoms of mental disorders may emerge not due to some "hidden" underlying cause but due to direct interaction with each other. For example, insomnia may influence performance at school and peer relationships, increasing rumination and lower self-esteem. These effects can be visualized as a network of interacting symptoms or states and analyzed as a whole system and individual elements. Empirical support for this approach is growing. Several recent studies suggest that negative affect states influence each other more strongly and might have a higher tendency to form 'vicious cycles' in individuals with psychopathology compared to healthy controls (171,173–176), although other studies found mixed results (177,178) or did not find this effect (179,180). However, because most of these studies compared patients or high-risk individuals with healthy controls (or patients with high and low levels of symptoms (180)), it is possible that the observed differences in affect dynamics between these groups are the result of already developed psychopathology, rather than be the cause of it. To determine whether characteristics of the dynamics between momentary affect states are vital factors in the developmental process of symptom formation, we need to examine whether these characteristics are already present in populations at increased risk for psychopathology before more severe symptoms arise. The reasoning behind including individuals at increased risk is that any underlying vulnerability for and resilience against psychopathology can be exposed only when challenged by risk factors. Because (i) adolescence is a sensitive period for the development of psychopathology in which symptoms often emerge for the first time (181,182), and (ii) a low level of happy childhood experiences is a known risk factor for psychopathology (183,184), adolescents with low levels of happy childhood experiences represent a well-suited population for this purpose.

Therefore, we aim in this paper to explore whether the dynamic network structure of affect states differs between adolescents who develop a higher level of symptoms over time and adolescents with a relatively stable level of symptoms. We used a prospective research design in an adolescent population with experience sample (ESM) data collection carried out at baseline and with follow-up assessments to differentiate the course of future psychopathology. We hypothesize that affect state networks of individuals

vulnerable to the development of future psychopathology will show dynamics of affect states prone to the development of vicious cycles. For such individuals, negative affect states will have strong mutually reinforcing connections. Furthermore, we hypothesize that in networks of individuals resilient against psychopathology (i.e., do not develop new or more severe symptoms despite being at an increased risk), positive affect states can potentially interfere with such vicious cycles by down-regulating one or more of these negative affect states. Explicitly stated in terms of network characteristics, we expect that the network of affect states in adolescents with a future increase in the level of symptoms compared to the network of affect states of adolescents with a relatively stable symptom level (i) contains stronger connections between negative affect states, (ii) contains positive affect states that are less influential in the network, and (iii) has a dynamical structure between affect states that predisposes to vicious cycles.

METHODS

Sample and design

Data were obtained from the longitudinal prospective study 'TWINSSCAN' ("http://www.twinsscan.eu"; website only in Dutch), a cohort nested in the East-Flanders Prospective Twin Study (EFPTS), a register of all multiple births in the Province of East Flanders, Belgium, from 1964 onwards (185,186). In 2010 potential participants for the TWINSSCAN cohort were recruited by sending invitation letters to all EFPTS participants between 15 and 18 years. To recruit more twins and their non-twin siblings between the ages of 15 and 34, a general invitation was included in a newsletter from the EFPTS. All participants provided their written informed consent. For those aged below 18 years, their parents or caretakers provided additional written consent. The local ethics committee (KU Leuven, Nr. B32220107766) approved the study.

The TWINSSCAN sample enrolled in the baseline assessment comprised 839 people and involved a broad range of measurements, including clinical interviews, questionnaires, experiments, and an ESM period (187). Additional data-based exclusion criteria were applied for the current work. First, participants needed to score below the median on items assessing their childhood happiness (see Measures for more details), leading to the exclusion of 388 individuals. Second, they needed complete data on the Symptom Check List-90 (SCL-90) (188) at both baseline (T0) and a follow-up wave after one year (T1), leading to the exclusion of another 202 individuals. Third, we excluded ten individuals with more than 30% missing ESM data points. Altogether, this resulted in a sample of 239 participants grouped according to their pattern of SCL-90 symptom change over one year (see details below). This change score was divided into tertiles, representing groups with decreasing, stable and increasing levels of symptoms. The group with decreasing

symptoms was excluded for theoretical reasons (see details below), resulting in a final sample of 159 individuals, categorized into a group with Stable symptom levels (n=81) and a group with Increasing symptom levels (n=78).

Measurements

Quality of childhood experiences.

As our research question can best be examined in a sample at risk for psychopathology, we used four items of the Dutch questionnaire on adverse childhood experiences (JTV) (189) to assess the quality of childhood experiences. Namely, we used items: 'I had a happy childhood,' 'my parents greatly loved each other,' 'I got the attention that I needed,' and 'my privacy was respected.' These four items were over 90% correlated with the overall score of the JTV questionnaire used in a previous twin sample of the EFPTS (see Jacobs et al., 2007 for a description of this sample. In addition, they showed optimal variation in the studied population, as they are phrased positively. Therefore, it was decided to assess only these four items for the subsequent data collection, as it relieves the participants' burden of filling out questionnaires but retains essential information. These items were measured with five points Likert scale ranging from 1 ("Never") to 5 ("Very often"). These four items had good internal consistency (Cronbach alpha for these four items in our sample was 0.83 (Confidence Interval: 0.80 - 0.85)). The sum score of the four items was calculated, and a median split of the sum score of the four items was used to define high-scoring and low-scoring individuals. Participants with a high level of happy childhood experiences were excluded from further analysis (see 'Sample and design').

Subclinical psychopathology

The presence of general psychopathological symptoms was assessed using the Symptom Check List-90 (SCL-90) (188). The items assess the level of distress associated with general and specific psychopathological symptoms with 5 points Likert scale ranging from 1 ("Not At All") to 5 ("Extremely"). Following previous research suggesting that all 90 items measure one common construct of psychopathological problems (191), a sum score of all 90 items was used in the analysis. All participants in the final sample (see Results for detailed description) completed all 90 items.

Group composition

To assess the change in the level of symptoms, we subtracted SCL-90 scores at T0 from SCL-90 scores at T1 for each participant. After that, these change scores were divided into tertiles, resulting in 3 groups defined by a reduction (Decrease group, mean SCL-90 sum score change = -41.48 points, SD =33.09, n = 80;), minimal change (Stable group, mean SCL-90 sum score change = -5.02 points, SD = 4.95, n = 81) and an increase in symptom level (Increase group, mean SCL-90 sum score change = 25.66, SD = 22.5, n = 78) (see also table 1). As the group with a future symptom reduction, the Decrease group (tertile 1)

reported significantly higher scores on the SCL-90 at baseline than the other two groups (see Results for details), we excluded the Decrease group. The reason for exclusion is that when comparing networks of groups of people with different levels of symptoms, we cannot eliminate the possibility that the differences in estimated network paths are explained by differences in variances between the groups in ESM items (192). Therefore, this group could not be used to test the current hypothesis. Hence, we analyzed data from the Stable and the Increase groups only, leaving 159 individuals for the final analysis (for details, see Results section).

The experience sampling method

In this study, participants received a custom-made PsyMate[tm] device developed for the specific purpose of collecting ESM data (https://www.psymate.eu/). For six days, participants completed short questionnaires (around 40 items, with additional items on mornings and evenings) about their current affect states, thoughts, daily life context, and behavior. The devices were programmed to beep ten times a day at semi-random moments between 07:30 am and 10:30 pm, with 90 minutes between beeps on average. Participants were instructed to fill out the diaries immediately after the beep. Only observations with all present ESM items were included in the analysis. Similar to previous studies, we have excluded participants with more than 30% missing observations (46,193). More details regarding the procedure of ESM methodology can be found elsewhere (45,53).

ESM measures

We selected ESM items based on both theoretical and methodological criteria. First, we only selected experiential affect states (not thoughts, behaviors, or context information). Second, of these, we selected at least one item from each quadrant between the axes of "pleasure" and "arousal" as defined in the circumplex model of affect (194,195). Additionally, we added the items "Down" and an item "Energetic," as they reflect common transdiagnostic symptoms (196,197). Third, to avoid a floor effect because of low variance (192), we chose items with a within-person standard deviation (SD) of around 1.0 (see Table 1). Fourth, we chose affect states that were not highly correlated with each other ($r < 0.5$) so that all items captured different aspects of a momentary mental experience. Fifth, to ensure that the differences between group networks originated from differences in the dynamics between affect states, we checked whether the mean levels of the selected items did not differ between the Increase and Stable groups and whether the within-person SDs of the selected items did not differ more than 10-12%. As a result, we included the following six affect states: 'cheerful,' 'relaxed,' 'energetic,' 'irritated,' 'down,' and 'lonely.' The items were formulated as follows: 'At this moment I feel… ('Down', for example)'. The items were assessed with 7 points Likert scales from 1 ('not at all') to 7 ('very much').

Analysis

We sought to investigate the dynamic interrelations between affect states and visualize those interrelations as networks of affect states for each group. The ESM data had a multilevel structure (multiple observations (level 1) within one person (level 2) and multiple persons within a twin pair (level 3)). Therefore, we used autoregressive multilevel linear models to test how each affect state (e.g., 'cheerful') at each time point (t) was predicted by itself and all other affect states at the previous time point (t-1) (see Figure 0 for the regression equation).

Before the modeling, we person-mean centered the selected ESM items to keep only the within-person effects in the models. We chose not to standardize as obvious reasons to standardize did not apply. All the variables were on the same 7-point Likert scale with similar anchors, and we selected items with similar variance (198,199). Hence, b-coefficients from the models can be straightforwardly compared across individuals and ESM variables. Furthermore, beep lags over the night were excluded. All analyses were conducted in R with the 'nlme' package (200); see online supplementary materials for the R script.

The example equation for the model of "Cheerful":

$$Cheerful_{ijk} = (ß_0+e_{ijk}) + (ß_1 + u_{1ijk})* Cheerful_{ijk}^{-lag} + (ß_2 + u_{2ijk})* Relaxed_{ijk}^{-lag} + (ß_3 + u_{3ijk})* Energetic_{ijk}^{-lag} + (ß_4 + u_{4ijk})* Irritated_{ijk}^{-lag} +$$

$$+ (ß_5 + u_{5ijk}) * Down_{ijk}^{-lag} + (ß_6 + u_{6ijk})* Lonely_{ijk}^{-lag} + (ß_7+u_{7ijk}) * Time_{ijk};$$

With $ß_0$ being an intercept, $ß_1$– $ß_7$ being regression coefficients, i corresponds to the level of assessments, j for the person level, k for twin level, u_{1ijk} – U_{7ijk} stands for the random slopes, and e_{ijk} for the error.

The models were fitted separately for the Stable and the Increase group. The resulting b-coefficients were used as values representing the effects of affect states on each other, and those values were used to construct dynamical networks for the two groups.

In the multilevel models, a separate variable representing time (the beep number over the whole ESM period) was added to account for possible trends over time. We added a random intercept for the random effects on both the individual and twin levels. On the level of individuals, we also added random slopes for time and all ESM variables to correct for individual differences in trends in these variables. We used a diagonal structure for the random effects covariance matrix (200). We used a continuous AR(1) correlation structure

(200). Both structures were chosen based on the possibility for the model convergence and the best model fit based on AIC comparison. For all 12 models, the assumptions of normality of the distributions of the residuals were checked with a visual inspection.

Networks of affect states

Each ESM affect state variable was depicted as an individual node in the network, and the b-coefficients of the fixed effects (i.e., the time-lagged effects in the six multilevel models) represented directed connections (edges) in the networks. The networks were visualized using the 'qgraph' R package (201). For a more straightforward visual comparison of the networks, the maximum strength of the connections was set equal in both networks, ensuring the match between the thickness of the edge to the same numeric value for both networks (201).

Comparison of group networks

We used both descriptive assessment and a permutation testing procedure (by W. Viechtbauer (171)) for the statistical comparison of the networks. The idea behind the permutation approach is to randomly combine outcomes with predictors in repeated permutations (here 10000 times) and test the probability of obtaining the same results seen in the actual data (for details, see S3 Text). Permutation tests in dynamic networks have been scarcely applied (68,171,178). Also, the precise power the procedure needs to discriminate effects in dynamic networks is still unknown. One study simulated power for this but only for cross-sectional data networks and not for dynamic ones (202). Therefore, we decided to consider descriptive network outcomes, similar to previous network studies (171,173–176,178), and statistic network outcomes.

Our first aim was to investigate whether the network of affect states of individuals who will develop more symptoms over time (Increase group) contained stronger connections between negative affect states than the network of affect states of individuals with the relatively stable level of symptoms (Stable group). For this aim, we used a permutation test to quantitatively compare the strength of the connections between negative affect states for the Stable and the Increase groups. To this end, we calculated and compared sums of all absolute b-coefficients from the regression models for all the paths between negative nodes. All estimated network paths were chosen based on the common practice in the field to use all available information (176–178). For the second aim, to investigate whether positive affect states are less influential in the networks of affect states in the Increase group than the Stable group, we compared the two groups regarding the influence of the positive affect states. To do that, we used a permutation test to compare quantitatively (i) the relative importance of the positive nodes in the networks, based on their out-strength centrality measures; (ii) the overall effect of the positive states ('cheerful,' 'relaxed,' 'energetic') on the negative states ('irritated,' 'down,' 'lonely') and vice-versa. Out-strength

centrality measure is a network characteristic that equals the sum of all connections going from the node of interest to the other nodes and reflects the overall influence of this node on the other ones. Specifically, the out-strength centrality was calculated by summing the b-coefficients from the regression models for the indicated paths. All of these differences were compared both descriptively and with the permutation test. For the third aim, to investigate whether the network of affect states of the Increase group has a dynamical structure that predisposes more strongly to vicious cycles than of the Stable group, the networks of two groups were qualitatively compared, based on visual inspection (without using a permutation test). Only significant paths ($p < .05$) were visualized and considered for this aim, as visual inspection of all available paths is not informative. Moreover, to ensure the robustness of the visual inspection results, we performed a limited version of multiverse analysis (based on (203)) to test the influence of different group compositions based on different cut-offs for the SCL-90 change score. A detailed explanation of the calculations, the visualization, the assessment, and the limited multiverse analysis can be found in the provided and online Supplementary materials).

RESULTS

Groups

The final sample (n=239) was grouped based on tertiles of change in their psychopathological trajectory over one year. This split led to three groups: a Stable group (n = 81) with a relatively small decrease in symptoms (for details see Table 1), an Increase group (n = 78) with a relatively large increase in symptoms (for details see Table 1), and a Decrease group (n = 80), with a relatively large decrease in symptoms (M_{age}=17.84, age range: 14-33 years, SD = 3.84; 66.25% females). As the latter subgroup had significantly ($p<.0001$) higher SCL-90 scores at baseline (mean level 168.3, corresponding to "high" symptom level in the normal population (204)) than the other two groups, this group was excluded from analyses. The Stable and the Increase group did not differ significantly on the baseline SCL-90 score (mean level of SCL-90 for the Stable group = 126.8, for the Increase group = 130.24, difference = 3.44, p = .48), and their levels correspond to "mean"/"above mean" levels in a normal population (204). At T1, the level of symptoms of the Increase group was equal to 155.90 (corresponding to "high" levels in the normal population (204)) and significantly higher than that of the Stable group (mean level 121.78) with a difference = 34.13, $p<0.001$ which roughly corresponds to an increase of one severity category (204). Trajectories of psychopathology for the two groups are presented in Figure 1.

Table 1. Socio-demographic characteristics, level of happy childhood experiences (JTV), Symptom Check List-90 scores, and mean levels and SDs of ESM variables for the Stable and Increase groups.

Measure		**The Stable group**			**The Increase group**		
Number of people		81			78		
% and n females		69.14% (56)			62.82% (49)		
% and n education	Low education	9.88% (8)			5.13% (4)		
	Middle education	61.73% (50)			70.51% (55)		
	High education	28.40% (23)			21.79% (17)		
	No data	0.00%			2.56% (2)		
Ethnicity	Caucasian	79			77		
	Asian	1			0		
	No data	1			1		
		M	*SD*	*Range*	*M*	*SD*	*Range*
Age		17.86	3.96	14-33	16.92	3.58	15-34
JTV scores*		15.58	1.56	11-17	14.95	2.14	7 - 17
SCL-90 at baseline		126.8	26.1	92 - 214	130.24	34.0	90- 245
SCL-90 change		-5.04	4.95	-13 - +4	+25.7	22.5	+5 - +105
SCL-90 at the follow-up*		121.78	25.8	90 - 212	155.90	42.4	98-305
Number of filled-in ESM observations		43.4	10.5	22-76	41.7	11.2	20 -79
Number of filled-in 2 consecutive ESM observations		32.4	12.1	11-67	31.0	13.6	7 - 76
		M	*SD within-person*		*M*	*SD within-person*	
Cheerful		4.76	1.16		4.53	1.29	
Relaxed		5.03	1.15		4.86	1.26	
Energetic		4.63	1.09		4.34	1.14	
Irritated		2.24	1.20		2.41	1.34	
Down		1.79	.96		1.91	.96	
Lonely		1.69	1.04		1.86	1.09	

Note: * corresponds to a significant difference (<0.05) between the Stable and Increase groups. JTV is four items ('I had a happy childhood,' 'my parents greatly loved each other,' 'I got the attention that I needed,' and 'my privacy was respected') from Dutch questionnaire on adverse childhood experiences, with higher scores reflecting a higher level of happy childhood experiences (Arntz et al., 1996). SCL-90 is from Symptom Check List-90 (SCL-90) questionnaire (Derogatis, 1977), sum score of all items.

The Stable and Increase groups did not significantly differ in socio-demographic characteristics and mean levels of each ESM variable at T0 (Table 1). Ratios of within-person variances for all ESM variables did not differ more than by 10.1% between groups. The Increase group had a significantly lower level of happy childhood experiences (JTV) (difference = 0.63, p = 0.04)

Dynamical affect networks

The networks of affect states for the Stable and Increase groups are presented in Figure 2 (significant paths) and S7 Figure (all paths). S1 Table shows a table of the b-coefficients of the time-lagged effects from multilevel models. For all models, assumptions of normality of the residual's distributions were met.

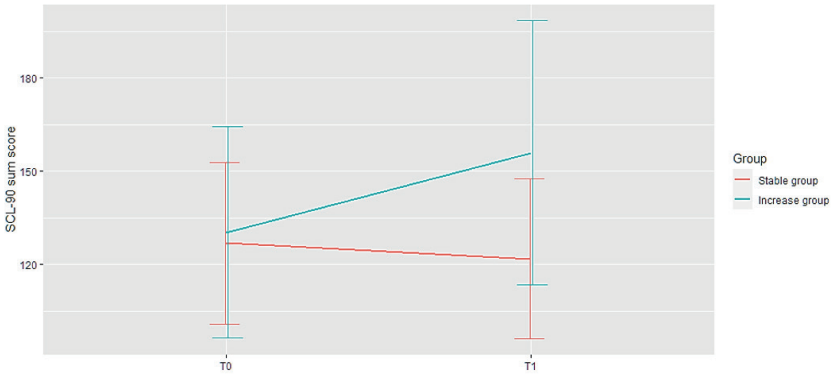
Comparison of the group networks

For the first aim, we compared the total strength of the network connections between negative affect states (negative connectivity) for the Stable and the Increase groups. The network of the Increase group had a more than twice as high level of connections between negative affect states (0.29) than the network of the Stable group (0.13). This difference (0.17; 229%) was not confirmed statistically (S2 table).

We compared the influence of positive affect states in the networks between the Stable and the Increase group for the second aim. First, we compared the relative importance of the positive nodes in the networks based on their out-strength centrality measures. The most considerable difference was found for the node 'cheerful,' with a higher value in the Stable group (0.28 in the Stable group, 0.18 in the Increase group, difference = 0.10, 158%). For 'energetic,' the relative importance of this node was higher in the Increase group (0.24 in the Stable group, 0.36 in the Increase group, difference = 0.12, 148%), and for 'relaxed,' values were almost similar for the two groups (0.12 in the Stable group, 0.10 in the Increase group, difference = 0.02, 124%). None of these differences were significant (table S2).

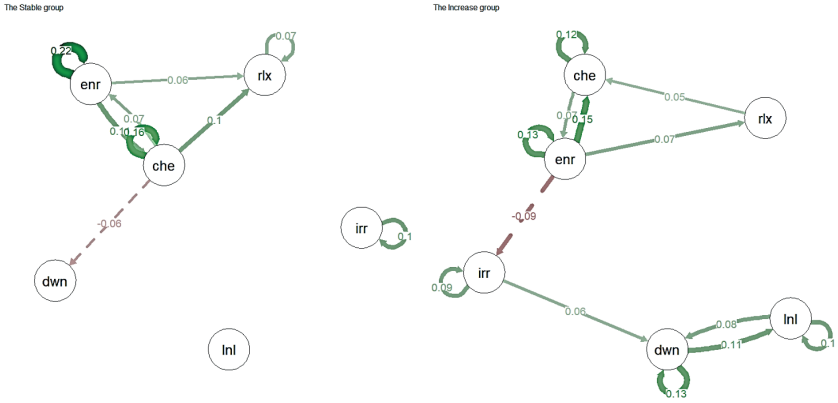
Second, we compared the overall effect of the positive states ('cheerful,' 'relaxed,' 'energetic') on the negative states ('irritated,' 'down,' 'lonely') and vice-versa (figure 3). We found that the positive affect states were more strongly associated with lower subsequent levels of negative ones in the Stable group than in the Increase group (For the Stable Group = 0.21, for the Increase group = 0.16, difference = 0.06, 136%). Negative affect states were more strongly associated with lower subsequent levels of positive affect states in the Increase group (For the Stable Group = 0.13, for the Increase group = 0.21, difference = 0.09, 166%). However, these differences were again not significant according to the permutation test (table S2).

Figure 1. The change in SCL-90 mean sum score for the Stable and the Increase groups



In this figure, the y-axis represents the total sum score of the SCL-90 items; x-axis represents the baseline (T0) and one year (T1) assessments. The lines represent the change in the mean number of symptoms for the Stable group (lower red line) and for the Increase group (upper blue line). Vertical lines represent the standard deviations of the mean SCL-90 scores for the Stable group (a red line slightly to the left) and the Increase group (a blue line slightly to the right) on T0 and T1. The Stable and the Increasing group did not differ significantly on the SCL-90 score (difference = 3.44, p = .48) at T0. At T1, the level of symptoms of the Increase group was significantly higher than of the Stable group with difference = 34.13 (p<0.001), which roughly corresponds to the differences in severity categories between «above middle» and «high» (Arrindell et al., 2003)).

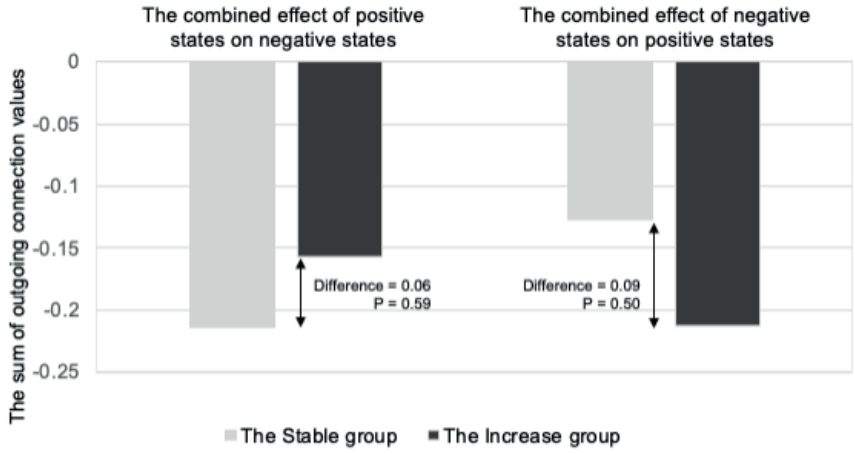
Figure 2. Networks of affect states: significant paths



In this figure, affect states networks are visualized for the Stable and the Increase groups. Only significant paths (p<0.05) are presented. Presented are temporal networks, meaning that the connections represent the effect of the variable at time point t-1 on the variable at the time point t. Solid green edges represent positive connections from one node to the other, meaning that the increase in one node variable at time point t-1 is associated with increase in the other variable at

time t. Dashed red edges represent negative connections, meaning that the decrease in one node variable at time point t-1 is associated with decrease in the other variable at time t. Circular edges represent autocorrelations, i.e. the effect of the variable at time point t-1 on itself at t. 'Che' - 'cheerful', 'rlx' -'relaxed', 'enr' -'energetic', 'dwn' -'down', 'irr' -'irritated', 'lnl' - 'lonely'.

Figure 3. The combined effect of the positive states on the negative states and vice-versa for the Stable and the Increase groups.



In this figure, the y-axis represents the summed value of all outgoing connections from the positive affect stated towards negative ones, and vice-versa. The light-grey bar represents the effect for the Stable group, and the black bar the Increase group. Depicted differences between groups are not significant according to the permutation test.

Lastly, for the third aim, we compared the networks of the affect states for the Stable and the Increase groups descriptively for the presence of dynamical structures that can predispose to vicious cycles. Visual inspection of the networks revealed qualitative similarities and differences in the structure of the networks between the groups (see fig 2). In the networks of both groups, we observed similar positive (covering nodes 'cheerful', 'relaxed,' 'energetic') clusters of interconnected nodes. Furthermore, in both groups, the positive cluster had a connection associated with a subsequent reduction in the negative nodes, namely to node 'Down' in the Stable group and node 'Irritated' in the Increase group. However, the Increase group had an additional cluster of interconnected negative nodes (covering nodes 'down', 'lonely,' and 'irritated'), with bidirectional paths between 'Down' and 'Lonely.' The negative nodes in the Stable group, however, were not connected and could therefore not form a vicious cycle. These networks differences were robust to the changes in group allocations based on the limited multiverse analysis (see S4 text and S5 Table for details).

DISCUSSION

The purpose of this study was to investigate whether the presence of differences in the dynamic networks of momentary affect states precedes the development of more severe psychopathological symptoms in adolescents at an increased risk. In this study, we examined, both statistically and descriptively, whether differences in the dynamical networks of affect states at baseline can be found between groups of adolescents with increasing and relatively stable levels of psychopathological symptoms over one year. For aims one and two of the study, although all differences were consistent with the hypothesized expectations, the observed quantitative differences were not confirmed by statistical tests. For the third aim of the study that was assessed descriptively, results cautiously suggest that, compared to adolescents who appeared resilient against psychopathology, the dynamic structure of affect states in adolescents who developed more severe psychopathology over time had a dynamical structure between affect states that could predispose to vicious cycles.

Comparison to previous studies

The null results for the quantitative aims in our study are partly inconsistent with several previous studies that suggest the existence of both quantitative and qualitative differences between networks of people with and without psychopathology or risk of it (46,173–175,178,205). There are several explanations for this discrepancy. First, most of the previous studies compared the networks of individuals based on *current* levels of psychopathology and did not focus on the development of future psychopathology. Some other studies comparing groups based on the follow-up measures also did not find any differences (180) or found mixed results (178). In addition, none of these studies can be directly compared to the current one, as they either compared patients with healthy controls (171,173–175) or followed patients with MDD through the course of recovery and treatment (178,180). However, our study assessed the dynamics of affect states a year before the new symptoms arose. Hence, the observed quantitative differences at this stage might be too small to be detected by permutation testing, as the differences in effects were quite large (~160% on average), and almost all effects were in the expected direction. These numbers suggest that there may be quantitative differences but that the permutation tests were too power-hungry to detect them.

Moreover, regarding these effect sizes and their relevance, it is yet unknown how large differences in network dynamics need to be to have the potential to influence the future course of symptoms. A well-known characteristic of complex systems is that even the slightest perturbation may lead to dramatic differences over time (206). Therefore, observed effects may be enough to become relevant over time, even though they are not statistically significant at the moment of assessment.

Other, more methodological, explanations of the null findings in this study (opposed to most previous studies) may relate to the fact that some of the previous studies did not use any statistical tests and showed different mean levels of ESM affect states, which can lead to different variances between groups because of floor and ceiling effects. Therefore, previous studies' contrasting levels of means and variances of ESM items may have contributed to artificial differences in connection strengths (192), leading to disparate networks and unrealistically large effect sizes. In the current study, we tackled this problem by using groups of individuals with similar levels of means and variances of ESM variables.

The qualitative findings aligned with the theoretical expectations and previous research (171,172). The main advantage of the network approach is the possibility of investigating network pathways, i.e., which variables are connected to which ones, in which directions, and how. No statistical test currently exists to compare such pathways within networks, yet these pathways may contain essential information about the mechanisms of psychopathology. Therefore, we argue that even in the absence of quantitative differences between networks, the qualitative differences (based on the visual assessment) may be essential to consider.

Qualitative results: negative cluster and possibilities for 'vicious cycles'

Based on visual assessment, the most striking visual difference between groups was the absence of the negative affect cluster in the network of the Stable group because the negative items were not connected to each other in this group. In the Increase group, on the contrary, the negative items were interconnected, and there was a loop of reinforcing connections ('vicious cycle') between the items "Down" and "Lonely." If negative affect states can easily trigger other negative states, then a vicious cycle may ensue that may contribute to the development of symptoms by accumulating these minor effects. The current results show that a network structure that could facilitate the emergence of such 'vicious cycles' between affect states was present only in the Increase group. Thus, these findings partly align with the theory suggesting that "vicious cycles" and high clustering between negative states may be present in psychopathology (172,207,208).

Furthermore, these findings further support previous results on differences in network structures between depressed and healthy people, which also showed more connectivity between negative affect states in the depressed groups than in the healthy groups (173,174). In the current study, however, in contrast to the previous studies, we can be sure that differences in the network's structure were not the result of baseline differences in symptom levels. Thereby, this study adds important information to this field.

Methodological issues

There are several limitations to our study. First, the sample used had several features that limit the generalizability of the findings: (I) the data came from a twin sample, and the dynamics of affect states may have a shared hereditary component. However, we could only use those participants who also had follow-up measurements, leading to a sample size that was too small to address this. (II) The sample consisted almost exclusively of Caucasian participants, limiting the generalizability of the finding to other populations, and (III) although most participants were adolescents (mean age = 17.46), emerging adults were also included in the TWINSSCAN cohort. We decided to keep their data in the analysis because we were interested in the sensitive period for the development of psychopathology, which is broader than adolescence per se (181,209). Moreover, keeping these participants slightly increased the power of our study and its consistency with other studies using the same dataset.

Second, we made several methodological decisions that may have impacted the results. (I) the sample was created by selecting the 50% of people with the lowest level of happy childhood experiences, and the SCL-90 change scores were split into tertiles. Although these decisions are, to a certain extent, arbitrary, they were based on theoretical (e.g., interest in those at highest risk) and methodological (e.g., optimizing subgroup size) reasons. In addition, the results were robust to changes in group allocations, supporting our confidence in the choices made. The limited multiverse analysis that we ran to investigate the potential effect of our subgroup selection strengthens us in our assumption that our choice was solid (see S4 text and S5 Table). (II) Due to the rigorous selection of the ESM items, other affective experiences playing an important role in the network may have been included. To minimize this possibility, we included affect states out of all four quadrants of the affect grid from the model of Barrett & Russell (1998) (194). (III) we used the total score of the SCL-90 as an indicator of general psychopathological severity; this could also have led to averaging any changes in specific areas (e.g., depression). However, the use of a general index aligns with current views of psychopathology as a broad, transdiagnostic, or even one general factor (210,211). In addition, because this sample is at risk but not diagnosed for any particular psychiatric disorder), we feel that using a general index is most suitable. (IV) A threshold of an (around) 10% difference in within-person standard deviations of ESM variables between groups was conservative but arbitrary. Therefore, we cannot completely rule out that the differences between groups are partly explained by the items' variances remaining differences. However, as this threshold is conservative and we chose items with a considerable variation, it is unlikely that floor effects were present in the data that could have biased the findings. (V) The diagonal matrixes were used for the random effects covariance structure, as models with more complex structures did not converge. Therefore, although we modeled random

slopes for all affect variables, thus capturing individual differences in the changes of these affect variables through time, the correlations between these differences were not considered.

Third, several study design features could also have influenced the results. The course of psychopathology was assessed only at two time points, at baseline and one year after, and therefore only a part of the entire developmental trajectory is captured. Finally, this study was conducted at the group level, as we examined average differences in the structures of group dynamic networks, so it is impossible to estimate the effects for individual cases directly. Such individual estimations will be an essential next step. Identifying dynamical patterns at the individual level and connecting those to future changes in symptoms will add new evidence on the relevance of the network approach to affect dynamics and may yield promising targets for future personalized diagnostic, prevention, and treatment strategies (212–214).

Taken together, our findings cautiously suggest that some differences in dynamical networks of affect states of adolescents with different mental health trajectories may exist already one year before new symptoms develop. However, these differences may be subtle and not yet statistically detectable by the permutation testing approach. Hence, more studies examining these qualitative indicators at an early stage are needed to give a more definite answer as to whether these emotion dynamics can be detected reliably, and if so, how they may be used to create new methods of treatment and prevention of psychopathology.

Chapter 4

Measuring resilience prospectively as the speed of affect recovery in daily life: A complex systems perspective on mental health

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ABSTRACT

Introduction: There is growing evidence that mental disorders behave like complex dynamic systems. Complex dynamic systems theory states that a slower recovery from small perturbations indicates the loss of resilience. This study is the first to test whether the speed of recovery of affect states from small daily life perturbations predicts changes in psychopathological symptoms over one year in a group of adolescents at increased risk for mental disorders.

Methods: We used data from 157 adolescents from the TWINSSCAN study. The course of psychopathology was operationalized as the 1-year change in the Symptom Checklist-90 sum score. Two groups were defined: one with stable and one with increasing symptom levels. Time-series data on momentary daily affect and daily unpleasant events were collected ten times a day for five days at baseline.

We modeled the time-lagged effect of daily unpleasant events on negative and positive affect after each experienced unpleasant event to examine at which time point the impact of the events is no longer detectable.

Results: There was a borderline significant ($p=0.05$) difference between groups in the effect of unpleasant events on negative affect 90 minutes after the events were reported. Stratified by group, in the Increase group, the effect of unpleasant events on both negative ($B=0.05$, $p<0.01$) and positive affect ($B=-0.08$, $p<0.01$) was still detectable 90 minutes after the events, whereas in the Stable group this was not the case.

Conclusion: Findings cautiously suggest that adolescents who develop more symptoms in the following year may display a slower affect recovery from daily perturbations at baseline. This supports the notion that mental health may behave according to the laws of a complex dynamic system. Future research needs to examine whether these dynamic indicators of systems resilience may prove valuable for personalized risk assessment in this field.

BACKGROUND

Mental disorders are directly and indirectly associated with a large part of overall morbidity and mortality worldwide (215). Once developed, many mental disorders become chronic or recur(216). Hence, the prevention of these disorders is crucial.

Still, our current understanding of the development of psychopathology is limited due to a substantial number of different factors involved in this process (such as variations in individual differences and environmental factors) and complex, non-linear interactions between these factors. Such complexity behind psychopathological processes hampers accurate identification of people at risk. However, embracing this complexity may be the way forward. Complex systems theory may suggest a promising approach to obtaining accurate risk estimations. A characteristic of a complex system is the tendency to move from one stable state to another suddenly. An example of such a transition is the well-known change ecosystems can make from a forest state to a swamp state or a financial market collapse (3,4). Rather than trying to understand all mechanistic interactions at play, complex systems theory states that the stability of a system, i.e., the tendency to remain in its current state, can be quantified in one characteristic: an index of resilience. This overall estimate of the system's resilience (synonymous with 'stability' in this context) can be assessed by its capacity to recover from minor perturbations that occur. The longer it takes for the system to get back to the original state - the closer it is to transition. This phenomenon is called "critical slowing down" and refers to the process whereby the system becomes increasingly slower in its capacity to recover (24,70). This principle has been proved valid for various complex systems, whether financial markets, oceans, climate, or brain activity (24,69). If it works for psychopathology, these principles will allow for an individual estimation of stability or resilience without detailed knowledge of the exact mechanisms causing the system's current state. Therefore, applying this approach to mental health may help improve personalized assessment of risk and resilience before new symptoms have arisen.

We hypothesize that a similar process of critical slowing down may occur in anticipation of relevant symptom transitions in psychopathology (217–220). If that would be the case, then we expect that when the speed of recovery from small perturbations becomes slower over time, this will signal lower stability of people's current mental health state and, therefore, a higher likelihood that they are approaching a transition in the level of symptoms.

Supporting this line of reasoning, some previous studies examined indirect indicators of the process of critical slowing down, such as rising temporal autocorrelation and variance (24), in the micro-dynamics of affect states. These studies showed that temporal autocorrelations and variances are increased in people with higher levels of

psychopathological symptoms compared to people with lower levels of symptoms or healthy controls (45,172,221–223). Moreover, a study by Wichers and Groot has shown on the individual level how a change in these indicators directly preceded a transition to a more psychopathological state (224). Thus, initial empirical support suggests that mental health may behave as a complex dynamic system based on indirect measures of critical slowing down (172,220,225).

However, hardly any studies in psychopathology have examined the phenomenon of critical slowing down using direct measures of this process, i.e., direct measurements of the speed of recovery from minor perturbations in the system. A design that allows for prospective and detailed assessment of the impact of minor daily life perturbations on mental states is needed. To our knowledge, only one recent study, by Vaessen and colleagues (226), examined in this way the speed of the affect recovery from daily stressors in groups with various levels of psychopathology. They found that speed of affect recovery was slower in people at early stages of psychosis than in healthy volunteers and people with already developed psychosis. Although this study was not written explicitly from a complex systems perspective, results seem to support the predictions from that theory. As healthy controls and people with established psychosis are likely to be in more stable states than those at early stages of psychosis, these results align with the idea that speed of recovery is associated with system instability and thus with a higher likelihood for sudden symptom transitions. Therefore, as a next step, it is crucial to test the hypothesis that speed of recovery, as an indicator of the process of critical slowing down, indeed predicts the future development of psychopathology. The current study, therefore, for the first time, used 'speed of recovery from minor perturbations to the system' as a direct dynamic indicator of the process of critical slowing down to examine whether this measure predicts future change in levels of psychopathology.

In order to examine this question, we used the TWINSSCAN data set, which includes baseline experience sampling measures (ESM) combined with baseline and follow-up assessments of psychopathology in a large sample of adolescents. Using a similar approach to measure the concept of the "speed of recovery" as Vaessen and colleagues (226), we used negatively appraised small events that happened throughout the day (e.g., spilled coffee, traffic jams) as minor perturbations to the system in terms of the affect dynamics. The system's recovery rate was estimated as a duration of the influences of these small negatively appraised events on the level of negative and positive affect, with less duration indicating faster recovery and higher system resilience.

In sum, this study aimed to examine whether the speed of recovery from small perturbations in daily life differs between adolescents with different future trajectories of psychopathology. We expected the speed of affect recovery from daily life unpleasant events to be slower in adolescents who will develop more psychopathological symptoms over one year than in adolescents who remain on similar levels of symptoms over one year.

METHODS

Sample and design

Data came from the TWINSSCAN cohort (187), which comprises a subsample of 460 adolescents from the East-Flanders Prospective Twin Study (EFPTS), a register of all multiple births in the Province of East Flanders, Belgium from 1964 (185,186). All twins from the registry between 15 and 18 were invited to participate in the TWINSSCAN study. This study consisted of baseline assessments and annual follow-ups (46). Data from questionnaires and experience sampling methodology (ESM) at baseline (T0) were used, as well as questionnaire data at one-year follow-up (T1). Following our previous study with the same sample (227), we used the data from subjects with an above-average psychopathology risk. Within this subsample, we identified two groups with similar baseline levels of symptoms, but different symptom trajectories over the following year (see below), resulting in the subsample of 159 individuals.

All participants provided written informed consent. For those aged below 18 years, their parents/caretakers signed additional written consent. The local ethics committee (KU Leuven, Nr. B32220107766) approved the study.

Instruments

Selection of individuals at increased risk

Risk for psychopathology was operationalized as an above-average level of childhood adverse experiences, as these are associated with psychopathology later in life (183). The level of adverse childhood experiences was assessed at T0 with four items from the Dutch questionnaire on adverse childhood experiences (JTV) (189). Included items were: 'I had a happy childhood,' 'my parents greatly loved each other,' 'I got the attention that I needed,' and 'my privacy was respected.' These items assess general adverse experiences with a wide distribution in the population, are 90% correlated with the full JTV, and lower the participants' burden of filling out questionnaires. Therefore, these items were used instead of the full JTV (227). Above-average risk for psychopathology was defined as having below-average scores on the four items of the JTV, and selection of this group was made using a median split.

Psychopathology trajectories

The number of general psychopathological symptoms was assessed at T0 and T1 with the Symptom Check List-90 (SCL-90) questionnaire (188) as a sum score of all 90 items. The trajectory of psychopathology was defined based on the tertiles of the change in SCL-90 sum score between T0 and T1, and the resulting groups were labeled "Stable," "Decrease," or" Increase." Only individuals from the Stable (n=78) and Increase groups (n=80) were included in this study. Because the Decrease group reported significantly higher symptom levels at T0 than the other groups, adding this group would not help to answer the research question as we would not be able to make valid comparisons between this group and the other groups; A detailed description of the cohort and the construction of the groups can be found elsewhere (227).

Experience sampling procedure

Time-series data on affect states and daily unpleasant events were collected using experience sampling methodology (45,53). Participants filled in short questionnaires on a PsyMate^{tm}, a custom-made electronic gadget (https://www.psymate.eu/), for six days, ten times a day at semi-random moments between 07:30 am and 10:30 pm. More details about the ESM procedure in the TWINSSCAN cohort can be found elsewhere (227).

ESM measures

Positive and negative affect

We constructed negative and positive affect scores based on the mean item scores of all available assessed affect items. For the negative affect score, the mean score of all available negative affect items ("insecure", "lonely", "anxious", "irritated", "listless", "suspicious", "down", and "guilty") was used. For the positive affect score, the mean score of all available positive items ("cheerful," "relaxed," "satisfied," and "enthusiastic") was used. All items were formulated as follows: 'At this moment I feel… ('lonely,' etc.)' and assessed with 7-point Likert scales from 1 ('not at all') to 7 ('very much').

Daily unpleasant events

Daily events were recorded at every beep with a question about the most important event since the last beep and how pleasant/unpleasant this event was. Participants were asked to rate an event (if any) on a 7-point Likert scale ranging from -3 as "very unpleasant" and 3 as "very pleasant." For our study, we only used events that were appraised as unpleasant or neutral (reference category).

Speed of affect recovery

We operationalized the recovery speed as the amount of time it takes until the effect of unpleasant events on negative/positive affect is no longer significantly different from the person-specific mean of negative/positive affect.

Analysis

Differences between groups in the speed of affect recovery from daily unpleasant events

Separate models were fitted for negative and positive affect, starting from the contemporaneous association (including affect as an outcome and unpleasantness of the event at the same time point (t) as predictor). Following the contemporaneous association, the second model assessed the lag-1 effect (affect at a time (t) as an outcome and the lagged unpleasantness of the event at the previous time point (t-1) as a predictor, approximately 90 minutes earlier), and so on, for five time points (t, t-1, …, t-4) in total. The reason to choose only five time points was the reduction of the number of observations due to restriction of the assessments within the same day (associations from one day to the next were omitted because of the large gap during the night).

Since ESM data have a multilevel structure (multiple observations (level 1) within one person (level 2), and multiple persons within a twin pair (level 3)), we used vector-autoregressive multilevel models. The general (shortened) model equation is presented below (I):

$$Affect_{ijk} = (B_0 + e_{ijk}) + (B_1 + u_{1jk}) * Event_{ijk}^{-lag} + (B_2 + u_{2jk}) * Time_{ijk}; \quad \text{(I)}$$

With ß$_0$ being an intercept, B_1 – B_2 being regression coefficients, i corresponds to the level of assessments, j for the person level, k for twin level, u_{ijk} stands for the random slope, and e_{ijk} for the error.

Before the analysis, negative and positive affect scores were person-mean centered to keep only the within-person changes in the models. A random intercept was added on the individual (second) and twin (second) levels. Random slopes for events and time were modeled only on the individual (second) level. For the random effects covariance matrix, we used a diagonal positive-definite matrix, and for the residuals, an autocorrelation structure of order 1 (continuous AR(1)), with a continuous time covariate (200). All models were corrected for age and gender. All analyses were conducted in R version 3.6.0 with the 'nlme' package (200). In addition, we checked whether the mean levels of the variables used did not significantly differ between the two groups to ensure valid comparisons in the speed of recovery.

To assess the speed of recovery per group and group differences, we examined at which time point after an unpleasant event the level of negative and positive affect returns to the person-specific mean. Models (model (I)) were fitted separately for the Stable and the Increase groups for five consecutive time points. After that, we investigated whether this

effect differed between the Increase and Stable groups at every time point. For that, we added an interaction effect of group*event to equation (I) that led to equation (II) and fitted these models to the whole sample.

$$Affect_{ijk} = (B_0+e_{ijk}) + (B_1 + u_{ijk})* Event_{ijk}^{-lag} + B_2 * Group_{ijk} + B_3 * Group_{ijk} * Event_{ijk}^{-lag} + (B_4+u_{ijk}) * Time_{ijk}; \quad (II)$$

With ß$_0$ being an intercept, B_1 – B_4 being regression coefficients, i corresponds to the level of assessments, j for the person level, k for twin level, u_{ijk} stands for the random slope, and e_{ijk} for the error.

Speed of affect recovery from daily unpleasant events as a predictor of individual symptom trajectories

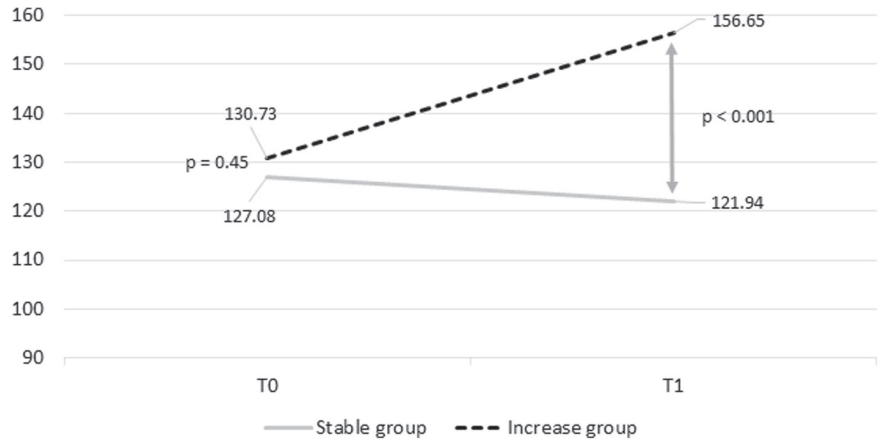
After estimating the group differences in speed of affect recovery, we performed a reversed analysis and investigated whether the estimates of the speed of recovery predict future individual symptoms trajectories. The additional benefits of this approach were i) the creation of one indicator that reflected recovery over several time points; ii) a possibility to test the predictive value of this indicator on the individual level, and iii) a possibility to obtain potentially clinically relevant estimations of effect sizes (i.e., how differences in the speed of recovery were associated with the change in SCL-90 scores). However, this approach led to a substantial reduction of power because of the loss of the multilevel structure of the data. To create this personal indicator, we derived an individual estimation of the effect of daily unpleasant events on affect from the multilevel models (I) (fitted for the whole sample) from the random effects of the slope of the variable 'negatively appraised events' (also sometimes called Best Linear Unbiased Predictors; BLUPS). These BLUPS were extracted from models for the contemporaneous association, the lag-1 effect, etc. The number of lags included was based on the main (group-based) analysis results and was equal to the time lag at which affect was no longer significantly different from the person-specific mean of affect for both groups. Based on these BLUPS from these subsequent lags, we calculated individual areas under the curve with respect to baseline (AUCb) using the formula proposed by Pruessner and colleagues (228) to arrive at one measure for affect recovery. After that, we tested whether these individual AUCbs were associated with the SCL-90 scores at T1, corrected for scores at T0, belonging to twin pair (as a random intercept), age, gender, and the number of adverse life events from T0 to T1. The outcome and predictor variables were standardized using a grand mean score for the effect size estimation.

RESULTS

Sample characteristics

Data on SCL-90 questionnaires were available for 460 individuals, from whom we selected the subsample with the above-median level of adverse childhood experiences based on JTV scores (n = 245). Six participants were excluded as they provided less than 30% of ESM data, and two reported no unpleasant events during the ESM period. Grouping was based on the change in SCL-90 scores from T0 to T1. The Stable group consisted of 77 participants[2] with an average change in symptoms of - 5.48 points, see Table 1). The Increase group consisted of 80 participants with an average change in symptoms of +24.57 points. The Stable and the Increase groups had similar level of SCL-90 at T0 (difference = 4.08, p = 0.2) and different at T1 (difference = 34.73, p<0.01). The trajectories of psychopathology for the two groups are presented in Figure 1.

Figure 1. The one-year change in the mean SCL-90 sum score for the Stable and Increase groups.



The SCL-90 mean sum score changes for the Stable and the Increase groups. In this figure, the *y*-axis represents the total sum score of the SCL-90 items; the *x*-axis represents the baseline (T0) and 1-year (T1) assessments. The lines represent the change in the number of symptoms for the Stable group (solid light-gray line) and the Increase group (dashed dark-gray line). *P* values correspond to the results of the tests of the differences of SCL-90 sum-scores between the Stable ($n = 80$) and the Increase ($n = 77$) groups at T0 and T1. The Stable and the Increase group did not differ significantly on the SCL-90 score (difference = 3.65, $p = 0.45$) at T0. At T1, the level of symptoms of the Increase group was significantly higher than of the Stable group (difference = 34.72, $p < 0.001$), which roughly corresponds to an increase of one severity category (204).

2 Please note that although the sample and grouping strategy is similar to Chapter 3, the Stable group in this Chapter contained one individual less due to the additional exclusion criterion of reporting at least one unpleasant event. Therefore, some group characteristics differ between chapters.

Table 1. Demographic and ESM variables for the Stable and Increase groups.

Variable	Stable group			Increase group		
Number of people	77			80		
% of females	70.13			62.50		
	M	*SD*	*Range*	*M*	*SD*	*Range*
Age	17.87	4.05	14-33	16.96	3.5	15-34
Trauma scores	15.56	1.57	11-17	15.00	2.14	7-17
SCL-90 sum score at T0	126.78	26.38	92-214	130.86	33.44	90-245
SCL-90 sum score at T1 *	121.23	25.98	90-212	155.96	41.65	105 – 305
Negative life events reported at T0	3.03	1.67	1-8	3.275	1.82	1-9
ESM Variable	M		SD_{within}	M		SD_{within}
Negative affect	1.69		0.51	1.89		0.61
Positive affect	4.90		0.78	4.71		0.91
Unpleasantness of daily events	0.92		0.87	0.87		0.85

* corresponds to the presence of significant difference between groups

Differences between groups in the speed of affect recovery from daily unpleasant events

At the contemporaneous time point (lag 0), the effect of unpleasant events was present for both groups, both on negative and positive affect (see table 2 and Figure 2). There was no significant difference between the groups.

At the next time point (average 90 minutes after the event, lag 1), the effect remained significant for the Increase group's negative and positive affect, but not for the Stable group. The difference between groups was borderline significant for negative but not positive affect (see table 2 and Figure 2).

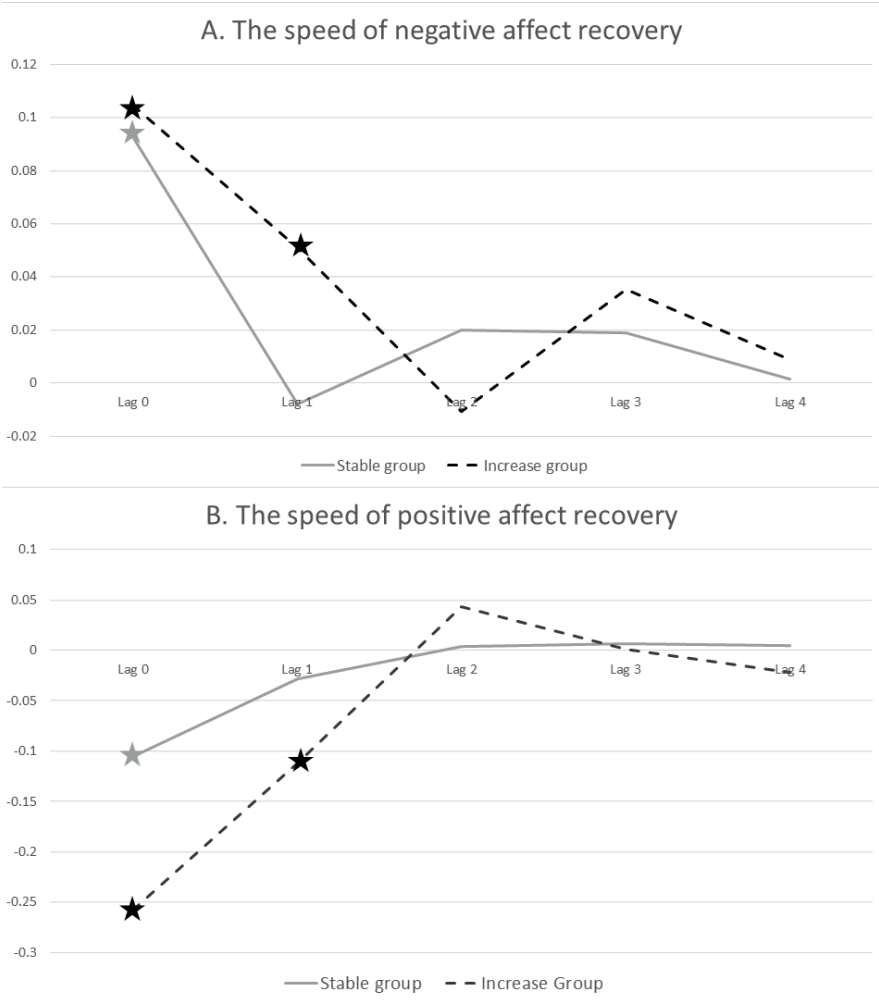
Table 2. The speed of affect recovery per group and group*unpleasant event interaction.

	The Stable group				The Increase group				Interaction effect			
	Negative affect		Positive affect		Negative affect		Positive affect		Negative affect		Positive affect	
	B	p	B	p	B	P	B	p	B	p	B	p
Lag 0	0.09*	<0.01	-0.11*	<0.01	0.11*	<0.01	-0.15*	<0.01	0.02	0.34	-0.05	0.23
Lag 1	-0.01	0.77	-0.03	0.28	0.05*	<0.01	-0.08*	<0.01	0.05*	0.05$	-0.05	0.20
Lag 2	0.02	0.22	0.00	0.96	-0.01	0.59	0.04	0.14	-0.03	0.32	0.04	0.28
Lag 3	0.02	0.38	0.01	0.86	0.04	0.16	-0.01	0.86	0.02	0.57	-0.01	0.75
Lag 4	-0.00	0.97	-0.00	0.90	0.01	0.55	-0.02	0.57	0.02	0.45	-0.02	0.70

* indicates significant values
$ Non-rounded value is 0.0505

At the following time points (lags 2, 3, and 4), the effect was no longer significant for neither negative nor positive affect, and there were no differences between groups (see table 2).

Figure 2. The speed of negative and positive affect recovery for Increase and Stable groups

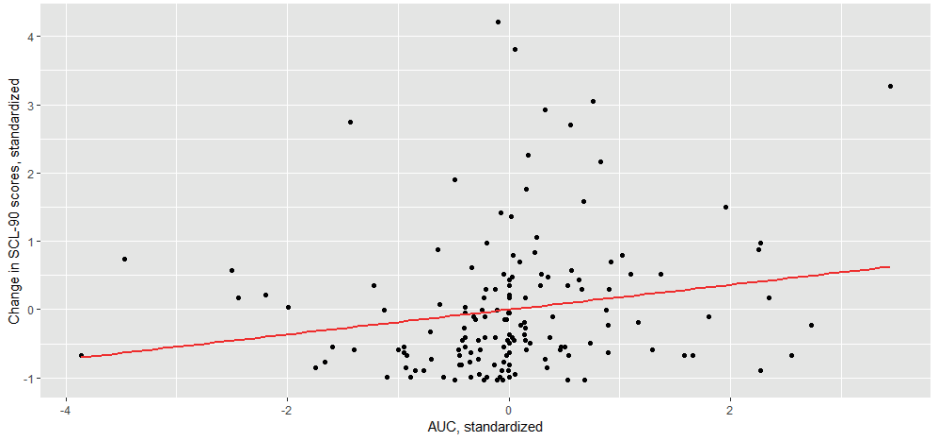


In these figures, the y-axis depicts the b-coefficients representing the effect of affect (negative or Figure A, positive for Figure B) from the model at the corresponding lag after the unpleasant events. Lag 0 corresponds to the contemporaneous association at the moment of the unpleasant event, and lags 1-4 – the associations 90, 180, 270, and 360 minutes, respectively, between the event and affect. The solid grey line represents the pattern of recovery of negative affect for the Stable group, and the dashed black line represents the pattern of recovery of negative affect for the Increase group. Stars indicate significant differences for the level of affect from person-specific mean levels of affect.

Speed of affect recovery from daily unpleasant events as a predictor of individual symptom trajectories

For negative affect, AUCb was not significantly associated with SCL-90 scores on T1 (corrected for scores at T0), although there was a trend towards significance (Beta = 0.09, p= 0.06). For positive affect, AUC was not associated with SCL-90 scores on T1 (Beta=-0.02, p=0.70).

Figure 3. Speed of negative affect recovery as a predictor of individual symptom trajectories



In this figure, the y-axis depicts the change from T0 to T1 in standardized SCL-90 scores and the x-axis – the standardized AUCb of the negative affect recovery. The line represents a fitted regression line.

DISCUSSION

This study examined whether the speed of affect recovery from small perturbations in daily life differs between adolescents with different psychopathological symptom trajectories in the following year. Results show that, as hypothesized, in individuals who will develop more symptoms in the following year, their affect recovered slower after the unpleasant event than for people with no increase in symptoms in the following year. This effect was present for both negative and positive affect; however, the difference between groups in the recovery of negative affect was borderline significant. The reversed analysis similarly showed an association between speed of affect recovery and individual future symptom trajectories but did not reach significance.

Complex systems principles and psychopathology

This study supports the idea that the complex systems approach can be applied to psychopathology. This approach assumes that the system can shift between alternative states, such as having different levels of symptoms. These results add to the growing body of research suggesting that dynamic stability indicators of complex systems, which estimate the process of 'critical slowing down,' may also apply to mental health. The current results have shown that a direct measure of hereof – namely speed of affect recovery from small perturbations – predicted mental health outcomes. Moreover, although the two groups were similar in levels of symptomatology at baseline, they already differed in this dynamic measure of resilience. Additional information is thus captured in the dynamic examination of the speed of recovery compared to simple mean levels of stressors, affect states, and levels of symptoms. Therefore, a complex system approach to mental health may contribute to a more accurate and reliable prediction of risk and resilience in psychopathology.

The dynamic concept of resilience

Psychological resilience is a popular topic in contemporary mental health research, as many scholars believe that focusing on protective mechanisms may yield insights for prevention and treatment (8,18,114). However, most studies examine resilience using static measurements, such as retrospective questionnaires estimating personal competencies, acceptance of change, social abilities and support, coping strategies, levels of optimism, meaning in life, etc. (27,229,230). However, in most of its definitions, the concept of resilience is about people's ability to withstand adverse circumstances, making the concept a dynamic one (221,231,232). Although static measures may tap into essential aspects of resilience, they are unlikely to capture a dynamic concept fully. Defining resilience from a complex systems perspective has the advantage that it can be assessed in a direct, dynamic way by prospectively measuring the impact of minor perturbations on the system. The current study shows the feasibility of such a dynamic assessment of resilience in the field of psychopathology. Therefore, this may become a valuable tool to assess and monitor change in psychological resilience both for research and clinical practice.

Methodological issues

The current study has several methodological issues. The group comparison results in the first analysis are only borderline significant and show a trend toward significance in the second analysis. We may thus have been short on power. Additionally, the time interval between assessments was quite long, adding much noise to the data. Therefore, the results of this study should be considered preliminary until reproduced with more data observations and higher temporal precision.

Clinical translation and future directions

The above method of assessing people's current resilience state may have clinical value to monitor individual resilience and as a new potential target for intervention and prevention strategies. However, there are some essential steps in translating this study outcome to clinical practice. First, findings need to be translated from the group to the individual level. The differences between individuals concerning affect dynamics may be substantial (58), and it is imperative to investigate which changes are of clinical relevance and for whom. Our results represent the average effect over many and, therefore, average individual differences in affect dynamics.

Moreover, individuals may also differ at the moment when they precisely developed symptoms, and this moment was not assessed in the current study as only a single follow-up measure was used. Thus, new personalized designs, with frequent follow-ups of symptom measures, are required to establish how well the recovery speed predicts future course in individuals. Therefore, an essential next step is to reproduce these findings on the individual level.

Second, as an indicator of system stability, we can assume that recovery speed is not a constant but will change over time. If we thus want to monitor changes in people's resilience, we should measure how the speed of recovery from daily unpleasant events *changes over time*. Such measurement would require a design in which individuals are monitored with ESM over a more extended period (e.g., several months). The feasibility of such designs in patients has recently been established (unpublished communication).

Third, for this study, we assumed that the change in levels of future symptoms is a valid proxy for the presence of a *sudden* symptom transition occurring at some point within the covered time frame. We did not assess directly whether a *sudden* transition occurred and at what moment in time. Therefore, for future studies, it is also essential to follow participants through transitions between states and directly assess the timing and shape of this transition and the changes in the speed of recovery with respect to them.

Chapter 5

Reflections on psychological resilience: A comparison of three conceptually different operationalizations in predicting mental health

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ABSTRACT

Background: Psychological resilience refers to maintaining mental health or recovering quickly after stress. Despite the popularity of resilience research, there is no consensus understanding or operationalization of resilience. We compared three indicators of resilience that each involved a different operationalization of the construct: a) General resilience as one's self-reported general ability to overcome adversities; b) Daily resilience as one's momentarily experienced ability to overcome adversities; and c) Recovery speed as evident in the pattern of negative affect recovery after small adversities in daily life. These three indicators were constructed per person to investigate their cross-sectional associations, stability over time, and predictive validity regarding mental health.

Methods: Data were derived from a prospective study that comprises 96 individuals at different levels of psychosis risk. The data collection involved questionnaires assessed at baseline (T0) and after one (T1) and two (T2) years, and 90-days intensive longitudinal measurement at T0 and T1. General resilience was assessed using the Brief Resilience Scale (BRS) and daily resilience by averaging daily resilience scores across 90 days. Recovery speed was calculated by applying vector-autoregressive models with consecutive impulse response simulations to diary data on negative affect and daily stressors. These indicators were correlated concurrently (at T0 and T1) to assess their overlap and prospectively (between T0 and T1) to estimate their stability. Their predictive potential was assessed by regression analysis with the change in mental health (SCL-90) after one year as an outcome, the three resilience indicators as predictors, and stressful life events during that year as a moderator.

Results: General and Daily Resilience indicators showed moderate positive correlations at baseline (rho = 0.35, p-value < 0.002) and follow-up (rho = 0.30, p-value = 0.03). Recovery speed was not associated with the other two indicators. General resilience (rho = 0.61, p-value <0.001) and Daily resilience (rho = 0.83, p-value < 0.001) were highly stable and Recovery speed was moderately stable (rho = 0.27, p-value = 0.05). Only Daily resilience predicted future mental health significantly, with a moderate effect size (β= -0.22, p< 0.002). The resilience indicators did not interact with stressful events when predicting mental health.

Conclusion: General and Daily resilience captured different properties of psychological adaptation to adversity and showed temporal stability. Daily resilience predicted psychopathology over one year, suggesting potential clinical and research relevance. The idea that affect recovery speed reflects resilience against psychopathology was not supported.

INTRODUCTION[3]

Most people will be exposed to risk factors for mental illness during their life (Bonanno et al., 2011; Coyne, 1991; Vanaelst et al., 2012). Risk factors for mental health problems include childhood adversity, negative life events, trauma, and acute and chronic stress (235,236). Mental health research traditionally focused on identifying these risk factors and investigating how these may influence psychopathological development. Over the past 50 years, attention has turned towards resources that may protect people against developing new or more severe symptoms and mental disorders (17). Stable mental health and quick recovery in the context of adversities is referred to as "psychological resilience" (Bonanno, 2004; Davydov et al., 2010; Schultze-Lutter et al., 2016).

A better understanding of resilience may help people to avoid or mitigate developing psychopathology and enrich preventive and therapeutic clinical interventions and help reduce the prevalence and burden of psychopathology (Bos et al., 2016; Davydov et al., 2010; Jeste et al., 2015; Duckworth et al., 2005). The idea of resilience originated in the observation of its outcome (10): in the case of psychological resilience, this refers to people staying mentally healthy (or recovering quickly) in the face of adversities (10); for example, the ability to cope well with the death of a spouse over time (Bonanno, 2004). Despite the wide use of the term "'resilience,'" there is currently no consensus definition (7,239); some approaches view resilience as the process or ability to bounce back, others see it as stable health despite adversity (8). Some authors view resilience as a more or less stable trait (26,27), while others argue that resilience depends on a context- and time-dependent combination of factors (Bonanno, 2004; Bonanno et al., 2011). The present paper uses an integrative and unitary view on resilience as" "mental immunity" that emerges from interactions within complex multifaceted biopsychosocial systems (10). This complex dynamic system view implies that resilience can change from moment to moment and between contexts, but this does not preclude more stable individual differences maintained across time and context.

Psychological resilience has close connections to and partly overlaps with the concept of self-regulation. The two concepts are, however, not identical. Self-regulation refers to processes by which people initiate, maintain, and control their thoughts, behaviors, or emotions, to produce the desired outcome or avoid an undesired outcome (240,241) and thus has an explicitly volitional nature. Although self-regulation can be seen as a predictor of resilience (242), resilience captures a broader mental health phenomenon

3 Please note that Introduction and Methods sections in this version comprise some minor differences from the Registered Report version. Some important changes were indicated by a footnote. None of the changes denote fundamental changes to the original set-up.

that other factors may influence. Furthermore, whereas self-regulation is defined as a general process, the concept of resilience is used exclusively within the context of reacting to any adversity and stress.

The complexity and versatility of the phenomenon of resilience resulted in various theoretical perspectives and operationalizations in the literature. In this paper, we compare three of those. The first perspective considers resilience as the perceived ability to successfully recover or bounce back from adversity. This "general resilience" captures the declarative aspect of resilience via self-reported statements such as "It does not take me long to recover from a stressful event" (an example item from the Brief Resilience Scale; Smith et al., 2008). These measures were designed to tap into how someone understands their ability to cope with adversity in general as part of their self-concept (see Table 1). Theoretically, this summary statement of ' 'one's characteristic response when facing adversity relates to concepts such as ego-resiliency, ability to handle difficulties (28,244), dispositional optimism, and self-efficacy (Larsen et al., 2020), which are known to protect against psychopathology (Conversano et al., 2010; Jenaabadi et al., 2015; Brownell et al., 2014).

A second approach is to understand resilience as the natural process of one's daily ability to cope with adversities in daily life. This "daily resilience" is typically operationalized in intensive longitudinal data collection with items like "today I could handle what came my way" (45,245–247). Daily resilience items assess one's moment-to-moment perceived ability to recover from actual stressful events. Repeated resilience measures over weeks or months can be collapsed into an individual summary description of daily resilience, which is assumed to show overlap with the single assessment of general resilience. However, they may capture different information and be more reliable (see Table 1). This more natural daily resilience measure reduces the retrospective bias associated with the declarative approach, which is likely to be more strongly influenced by individual differences and current emotional states (45).

The third operationalization of psychological resilience is the actual process of recovering from daily stressors. As opposed to the first two indicators of resilience, this "recovery speed" does not rely on the self-reported perception of recovery. The hallmark operationalization of this recovery process is negative affect reactivity, defined as the contemporaneous association between stressors and negative affect (Cohen et al., 2005). Negative affect reactivity is often impaired in people with or at risk for psychopathological symptoms (Booij et al., 2018; Cohen et al., 2005; Myin-Germeys et al., 2003; Myin-Germeys & van Os, 2007; Vaessen et al., 2019; van Winkel et al., 2015). Building on these studies, we took a more inclusive approach and investigated the duration and the amplitude of negative affect responses to daily stressors. This operationalization of

resilience as the recovery from stressors is closely tied to the dynamic systems framework, in which a set of generic process indicators are thought to predict a complex ' 'system's liability to change (24,69–71,253). Speed of recovery from minor perturbations is one of these general resilience indicators (24). Previous research from our group has shown that the speed of negative affect recovery after daily life adversities can predict trajectories of psychopathological symptoms (254).

Table 1. Comparison between three operationalizations of resilience in the current study

Indicator	Definition	The hypothesized aspect of resilience	Assessment
General resilience	Self-beliefs about general ability to successfully recover from adversity	Stable aspects of resilience as a declarative set of self-schemata and beliefs about one's capacity to bounce back after adversity	Self-report questionnaire
Daily resilience	Daily life experiences of ability to cope with adversity in everyday life	The moment-to-moment perceived ability to recover from actual stressful events.	90-days repeated assessments of self-perceived ability to deal with daily adversity
Recovery speed	Duration and amplitude of negative affect response to from daily unpleasant events	A direct measure of the process of overcoming small adversities in daily life	An impulse response function on the vector-autoregressive model applied to 90-day ratings of negative affect and daily adversity

The three operationalizations that we summarized in Table 1 capture unique but complementary conceptualizations of psychological resilience. Hitherto, no direct comparisons of these different operationalizations of resilience have been available, and it remains unclear whether and to what extent these conceptualizations overlap. Additionally, although being resilient leads to a better mental health outcome by definition (8,17), we are unaware of a direct comparison of dynamic and general resilience indicators on their ability to predict mental health.

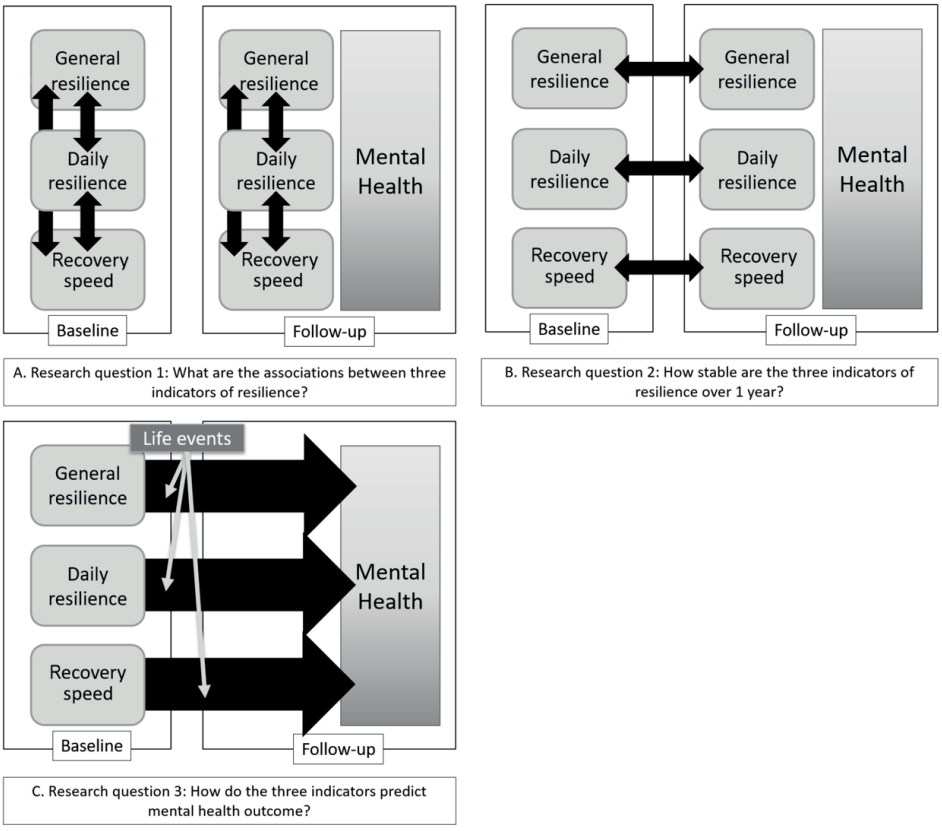
Given the high prevalence of mental disorders worldwide and the importance of resilience for good mental health (17), it is of particular interest to study resilience in (sub)-clinical groups with an increased risk for psychopathology. These individuals may not meet the criteria for a clinical disorder but do experience distress and may benefit from resilience-enhancing interventions (31,210), also a prevention strategy. Individuals with sub-clinical psychotic symptoms provide a relevant sample to study resilience. Some of them may remain in subclinical psychotic states and never transition to a psychotic episode but still suffer from other psychopathology, impaired functioning, and reduced quality of life (255,256). High-risk people who will not develop a psychotic episode despite belonging to a specific risk group could be considered relatively resilient and provide an

excellent opportunity to assess and compare our three resilience indicators. That said, investigating resilience in people with high risk for psychopathology in general and psychosis, in particular, might restrict the generalizability of the findings to populations without mental health problems and those with severe mental disorders.

The present paper aims to improve our understanding of psychological resilience in individuals at risk for psychosis by studying the three conceptualizations of psychological resilience in Table 1 in relation to one another, prospectively, and in the presence of adversity, in a population at risk for psychosis. Specifically, we investigated (1) how the three conceptualizations mentioned above of resilience are associated with each other at the same time point; (2) differences between the three measures in their stability over time; and (3) to what extent these measures buffer the effects of adversity on mental health outcome after one year (see Figure 1).

Although all three of our resilience operationalizations were aimed to assess recovery from adversity, they use different time frames and different conceptualizations of stress. Each resilience indicator may thus tap into unique aspects of resilience: one may need a relatively long time to recover from negative affect but still be satisfied with how they handled things. Based on the notions that General and Daily resilience are measured with items that overlap in content and that Daily resilience and Recovery speed are both based on dairy data (as opposed to General resilience), we hypothesized the following. (i) General resilience shows stronger associations with Daily resilience than with Recovery speed; and (ii) Recovery speed is stronger associated with Daily resilience than General resilience (see Table 2, question 1). Regarding the stability of the resilience indicators (question 2), we hypothesized that General resilience is more stable than Daily resilience and Recovery speed. This expectation was based on the fact that commonly used general resilience questionnaires intend to measure relatively stable differences in the—perceived—ability to bounce back (as evidenced by the use of words such as" "usually" and "tend to"). In contrast, Daily resilience and Recovery speed are assessed to be more changeable over time. We refrained from specific hypotheses concerning whether and how the resilience indicators predict future mental health after adversity (question 3) because an empirical and theoretical basis to guide solid expectations is lacking.

Figure 1. Schematic representation of research questions



In this figure, parts A, B, C depict research questions 1, 2, and 3, respectively. 'General resilience,' 'Daily resilience,' and 'Recovery speed' refer to the three operationalizations of resilience. 'Mental health' refers to mental health problems measured after one year (only one measurement wave is depicted for parsimony and readability), and 'Life events' refers to adverse life events happening between the measurement waves. Arrows represent the various associations that will be investigated with each research question.

Table 2. Research questions, hypotheses, analysis plan, and interpretation given to different outcomes.

Question		Hypotheses	Analysis Plan	The interpretation of different outcomes
1.	What are the associations between three indicators of resilience?	General resilience is associated more strongly with Daily resilience than with Recovery speed. Recovery speed is associated more strongly with Daily resilience than with General resilience.	Correlations between the three resilience indicators at each assessment wave. Comparison of correlations.	The correlations reflect the extent to which the three resilience indicators measured the same concept.
2.	What is the one-year temporal stability of the three indicators of resilience?	General resilience is more stable over one year than Daily resilience and Recovery speed.	Correlations between resilience indicators at T0 and T1 Differences between correlations.	The correlations indicate how the indicator level at T1 is similar to its level at T0. We interpreted this correlation as the stability of the resilience indicator.
3.	How do the three indicators predict mental health outcomes in the presence of adversity?	No expectations.	Multilevel linear regression models with and without interaction effects of resilience indicators with adversity. To compare differences in regression coefficients.	The regression coefficients indicate to what extent higher resilience levels were associated with a change in mental health on the subsequent measurement wave.

METHODS

Study design and sample

The data came from the Mapping Individual Routes of Risk and Resilience (MIRORR) study (Booij et al., 2018). This observational study has followed young adults with different levels of risk for psychosis over three years with four assessment waves, with follow-ups after one, two, and three years after baseline. Questionnaires and interviews about mental health, risk factors, protection, and resilience were assessed at all waves. In addition, the first two waves contained three months of intensive longitudinal data collection using daily diaries. These 90 consecutive daily reports covered psychopathological symptoms, emotions, functioning, and stress. The current work used questionnaires and diary data from the first two waves to answer the first and second research questions. We used repeated measures design for the third research question, including resilience data from the first two waves and life events and mental health data from the second and third waves.

Recruitment for the study started in September 2015. The sample comprised four subgroups. Subgroup 1 consisted of participants from the general population with a relatively high level of subclinical psychotic experiences, not seeking mental health care. For this subgroup, we recruited 100 individuals from the general population who completed the Community Assessment of Psychic Experience (CAPE) questionnaire (123). The 25 individuals with the highest scores were invited to participate in the main study. Subgroups 2-4 comprised people receiving mental health care for a broad range of psychopathological problems. Allocation to subgroups 2, 3, or 4 was based on the level of psychotic experiences, which served as an indicator of risk for developing psychosis. Subgroup allocation was based on early detection practices in which all newly referred mental health care patients are screened for psychotic symptomatology, regardless of the type of symptoms they are referred for (258). After screening by the Prodromal Questionnaire (PQ)-16 (259), participants with a score of <6 (meaning mild, non-psychotic psychopathology) were allocated to subgroup 2. Individuals with a score of ≥6 points of PQ-16 were further screened by the Comprehensive Assessment of At Risk Mental State (CAARMS) (260), which assesses the presence of an Ultra-high risk (UHR) for psychosis. Individuals without UHR status for psychosis were assigned to group 3, and individuals with UHR status for psychosis were assigned to group 4. Thus, each subgroup represented a higher risk for developing psychosis (see the study protocol for detail (Booij et al., 2018). Please note that subgroup allocation was not used in the current study and is presented here for reference only.

All participants included in the current work were aged 18 or older and provided written informed consent for participation (for details, see study protocol (Booij et al., 2018)). The study was conducted under the Declaration of Helsinki and was approved by the medical ethical committee of the University Medical Center Groningen (NL52974.042.15). The study protocol trial registration number is NL6058 (www.trialregister.nl).

Sample characteristics

Data for this paper were extracted on 30 May 2021, while the data collection continued for the third follow-up. For baseline (T0), data were available for 96 people, from whom n=25 were allocated to subgroup 1, n=27 to subgroup 2, n=24 to subgroup 3, and n=20 to subgroup 4[4]. For the first follow-up (T1) one year later, data from 89 people (of whom 68 have also completed diary data) were available; for the second follow-up (T2) two years later, questionnaire data from 81[5] participants were available. At baseline, participants

4 Information about the data extraction date, the number of people on baseline (T0) and subgroup allocation were not included in Registered Report version.

5 The Registered Report stated 78. The number changed due to continuation of data collection for some participants between the time of submitting Registered Report and extracting the data for the current version

were on average 24.7 (SD 4.2) years old, mostly female (76%), and mainly had completed upper secondary education (54.2%). The baseline level of severity of psychopathological symptoms, as measured with the Symptom Check List-90 (SCL-90) (261) (see *Instruments*), was on average 186.7 (SD 59.4), which roughly corresponds to "high" and "very high" levels for the general population (Arrindell et al., 2003). The average number of past adverse events (in the year prior to baseline assessment) recorded with the Brugha List of Threatening Experiences (262) (see *Instruments*) was 1.5 (SD 2.0).

Instruments

Daily diary procedure

The time-series data comprised 90 daily questionnaires administered every evening on a smartphone. These diary items covered a broad range of feelings and experiences and retrospective ("Today, I felt…") as well as momentary ("At this moment, I feel…") items. Only the retrospective items were used to construct the resilience indicators from the past day's information in this study. All specific items are described below. All missing diary data points were imputed before analysis using the Exponential moving average strategy; a rationale and overview of this process are provided in Supplementary materials.[6]

Mental health

Baseline mental health was assessed with the Symptom Check List-90 (SCL-90; (261), which measures the severity of 90 psychopathological symptoms in the past seven days on 5-point Likert scales ranging from 1 ("Not at All") to 5 ("Extremely"). We used the sum score of all items because previous research had indicated that all 90 items loaded strongly on the latent construct of psychological distress (191). Furthermore, we used all three measurement waves to maximize statistical power. Lower scores indicate better mental health.

Adverse life events

The number of adverse life events in the past year was recorded with the Brugha List of Threatening Experiences (262), which comprises 12 major categories of stressful life events (Table 3) measured as "yes/no," which were selected because of their established long-term consequences.

6 Compared to Registered Report, the outline of the imputation strategy has been shortened and moved from the analysis part to the Daily diary procedure part, and a more detailed version is presented in Supplementary materials. The reasons for this decision were readability, the fact that the Registered Report did not make clear that imputations were also performed for the Daily Resilience item.

Table 3. The stressful life events with the most impact in adulthood: The Brugha List of Threatening Experiences

1.	Serious illness or injury to the subject
2.	Serious illness or injury to a close relative
3.	Death of first-degree relative including child or spouse
4.	Death of a close family friend or second-degree relative
5.	Separation due to marital difficulties
6.	Broke off a steady relationship
7.	A serious problem with a close friend, neighbor, or relative
8.	Unemployed/seeking work for more than one month
9.	Subject sacked from a job
10.	Major financial crisis
11.	Problems with police and court appearance
12.	Something valuable lost or stolen

Resilience indicators

For this study, three different resilience indicators were estimated, at both T0 and T1:

General Resilience was operationalized as the mean score of the Brief Resilience Scale (BRS; (263). The BRS consists of 6 items assessing perceived ability to overcome adversity (Table 4) scored on a 5-point Likert scale (1 = "strongly disagree," 5 = "strongly agree").

Table 4. The items in the Brief Resilience Scale (263)

1.	I tend to bounce back quickly after hard times
2.	I have a hard time making it through stressful events.
3.	It does not take me long to recover from a stressful event.
4.	It is hard for me to snap back when something bad happens.
5.	I usually come through difficult times with little trouble.
6.	I tend to take a long time to get over setbacks in my life.

The Brief Resilience Scale was administered before and after diary periods (see Booij et al., 2018). We only used the BRS data collected *before* the diary period, as the diary data collection may have influenced the BRS scores. For one participant who had not provided BRS data before the diary assessment, we used the post-diary BRS-score instead.[7]

7 This information on The Brief Resilience Scale data was absent in Registered Report because by then the data had not been accessed. As a sensitivity analysis we fit the model without this person, and results were identical, see Supplementary materials for details.

Daily Resilience was operationalized as the individual mean level of the daily resilience score ("Today I could handle what came my way"; scores ranging from 0 ["Not at all"] to 100 ["Very much"]) across 90 days.

Recovery Speed was operationalized as the duration and amplitude of the trajectory of negative affect response to its mean level after experiencing a negatively appraised event, using the 90 diary assessments. Negative affect was constructed as the mean daily score on six affect items from the circumplex model of affect, including both low arousal ("I felt apathetic/tired/down today") and high arousal ("I felt anxious/restless/irritable today"; see Yik, Russell, & Steiger, 2011) items, with scores in the range from 0 ("Not at all") to 100 ("Very much"). The negatively appraised events variable was operationalized by asking participants to "think about the most important negative event of today" and subsequently to rate the level of unpleasantness ("how unpleasant was this event?") on a scale from 0 ("Very unpleasant") to 100 ("Neutral").

Analysis

Vector autoregressive (VAR) analyses for the construction of the Recovery Speed indicator

Individual-specific models of the association between the unpleasantness of negative events and the level of negative affect at consecutive time points were estimated using vector autoregressive (VAR) analyses (264). These VAR model estimates were the input for an impulse response (IRF) analysis (265). IRF analysis allows simulating the averaged response of the system described by the VAR model to the sudden increase of one of the variables in the model. Here, we used IRF analysis to simulate the sudden increase in the level of the negative event and to assess the following response in the level of negative affect for several consecutive time points. The area under the curve of this response (AUC) was calculated and used as a measure of dynamic resilience. A higher AUC represents longer time and higher amplitude of negative affect, which is thought to indicate lower resilience; see Supplementary materials for all details.[8]

Research question 1: What are the associations between three indicators of resilience?

The three resilience measures (General resilience, Daily resilience, and Recovery speed) were first examined to see whether their distribution and outliers allowed to use Pearson correlation coefficients or indicated Spearman rank correlation coefficients, which are more robust against non-linearity and outliers. Correlations between the three resilience measures at each assessment wave were estimated and compared pairwise via Fisher's z-transformation based on the procedure by Meng and colleagues (266) with a calculator

8 This detailed explanation was moved to Supplementary materials to improve parsimony and readability.

developed by Lenhard, W. & Lenhard, A. for the comparisons of correlations from dependent samples (267). In case of violation of the assumptions of Pearson correlation, we applied the same comparison procedure to Spearman rank correlations, as was suggested by Myers and colleagues (268)[9] .

Research question 2: How stable are the three resilience indicators over one year?

The correlations between the two assessments of each indicator were estimated (e.g., between General resilience at baseline and General resilience at follow-up). Before the analysis, the assumptions were checked and corrected, and correlations were compared similarly to the procedure followed for Research question 1 but using an approach for independent samples as there was no overlap between studied correlations (267). However, the case of comparing stability differs from standard procedures for comparing correlations due to the measurements belonging to the same participants. Mathematically, the stability score is similar to the measure of test-retest reliability, although here assessing different research questions (269), and there is a lack of studies on the best statistical approaches to compare test-retest reliability. Therefore, we used the approach mentioned above of pairwise comparisons and applied additional Bonferroni correction (resulting alpha = 0.016) to this set of tests to compensate for the increased probability of Type 1 error due to the data belonging to the same participants[10].

Research question 3: How do the three indicators predict mental health in the presence of adversity?

A series of multilevel linear regressions were specified to estimate how well the resilience measures at one assessment wave predicted mental health one year later (in the presence of adversity), including interactions between the resilience indicators and adversity. The number of negative events between measurement waves (between T0 and T1, and between T1 and T2, respectively) measured as a sum score of LTE items was used as an adversity index. The resilience indicators were hypothesized to protect against mental health deterioration, particularly in adversity. As the data came from a (sub)-clinical sample of participants who already faced the adversity of being at risk of psychosis, we first interpreted the main effects of the resilience indicators and added interaction effects with adversity to the models as a second step. For each resilience indicator separately, a multilevel model was fitted with the SCL-90 sum score as the outcome variable, and the following variables as predictors: i) a lagged (i.e., measured at the previous time point) resilience indicator score, ii) the number of negative events that happened between the

9 Please note that the information about the instrument and the comparison of Spearman's rho coefficients was not included in the Registered Report.

10 Please note that the issue with comparison between stability measures and proposed solution was not mentioned in Registered Report version.

assessment waves, iii) the interaction between the lagged resilience score and the number of negative events between assessment waves, iv) the SCL-90 score at the previous assessment wave. Because the data describe the same people at two assessment points, random intercepts (for individuals) were added to account for the shared variance (270). We checked the assumptions of the linear mixed models (linearity, homogeneity of variance, and normality of residuals) and performed data transformations in case of violations. To compare how the three resilience indicators predicted future mental health outcomes in the presence of adversity, the differences between the resilience indicators, both in their main effects and their interactions with the two adversity indices, were assessed by comparing the Beta coefficients from the models using a Z-score test (271). However, a Z-score test was developed for comparing Beta coefficients between regression models with different outcome variables, which is not the case for our research question. Therefore, in addition to the Z-score test, we constructed the model described above (without interaction effects) with all three resilience indicators as predictors following the Wald test with pairwise comparisons.

Multiple comparison correction

The comparison between resilience indicators was conducted on the between-person level. We assessed three related but separate research questions. Because of the differences in the analytical methods, predictors, and outcomes, research questions 1 and 2 were considered one family of tests, and research question 3 another. Because of the study's exploratory nature, we applied a False Discovery Rate correction on our alpha level of 0.05 following the Benjamini–Hochberg (136) procedure within each family of tests.

Power analysis11

A power analysis (presented in Supplement 1) indicated moderate to high power to estimate effect sizes (set as r= .40) for research question 1 (baseline: 90%; follow-up: 75%) and research question 2 (General resilience: 88%; Daily resilience: 75%; Recovery speed: 75%), see Supplement 3 for the R-script. For research question 3, we found that the General Resilience indicator could detect regression coefficients between ~0.07 and ~0.14 (small effects) and higher with a power of ≥60%. In contrast, for Daily resilience and Recovery speed, only effect sizes between ~0.10 and ~0.18 (medium effects) and higher could be detected with a power of ≥60%. Because of the limited power, the results for this research question should be considered to provide preliminary evidence.

11 Please note that the detailed power analysis was included in the Registered Report but has now been moved to Supplementary materials.

RESULTS

Study design and sample

A descriptive overview of the measures used in this study is presented in Table 4.

Table 4. Descriptive statistics of variables used in the current study

Cross-sectionally assessed questionnaires				
		To	**T1**	**T2**
*BRS**	N	96	69	NA
	Mean	2.67	2.77	NA
	SD	0.74	0.79	NA
	Min-Max	1.00-4.00	1.17-4.17	NA
SCL-90	N	96	89	81
	Mean	186.70	162.9	158.90
	SD	59.43	52.01	52.05
	Min-Max	99 - 341	95 - 323	95 – 357
LTE[12]	N	NA	89	81
	Mean	NA	1.44	1.56
	SD	NA	1.40	1.65
	Min-Max	NA	0-5	0-7
Diary Data[13]		**To**	**T1**	
Daily Resilience	Overall mean	52.18	54.90	
	Overall SD	22.87	22.25	
	Between-person SD	13.70	14.10	
	Within-person SD	18.30	17.30	
Recovery Speed	N	96	66	
	Mean	5.11	4.35	
	SD	4.33	3.26	
	Min-max+	0.00 - 17.79 (-1.18 - 2.93)	0.00 - 16.14 (-1.34 - 3.62)	
Negative affect	Overall mean	32.54	28.70	
	Overall SD	20.86	18.59	
	Between-person SD	16.00	14.10	
	Within-person SD	13.30	12.20	
Negative event	Overall mean	49.36	50.60	
	Overall SD	31.96	29.66	
	Between-person SD	17.60	15.00	

12 Please note that LTE assessed the number of negative life events before the corresponding assessment wave, i.e. LTE score on first follow-up corresponded to the total number of large negative events happened between To and T1

13 Please note that the descriptive statistics is provided for the data before imputation, with the exception for Speed of Recovery indicator which was build based on the imputed data.

	Within-person SD	26.80	25.60
Missing observations	Mean	6.97	5.30
	SD	5.34	4.30
	Min-max	0-21	0-19

Note. *Resilience indicators highlighted by italic. + Standardized min-max. N= number of participants. NA.= Not applicable. SD = Standard deviation. T0 = Baseline. T1= First follow-up. T2= Second follow-up.

Vector autoregressive models for the construction of the Recovery Speed indicator

At baseline, the optimal number of lags for the VAR models was generally one (N= 67) or two (N= 15), but some participants required three (N=5), four (N=3), five (N=3), six (N=1), or seven lags (N=2). Also, at follow-up, the optimal number of lags for the VAR models was typically one (N= 50 individuals) or two (N= 9 individuals), but some participants required three (N=3), four (N=1), six (N=2), or even eight lags (N=1). The individualized lag optimum was used for the VAR models unless the model's assumptions were violated, and increasing or decreasing the number of lags was the best solution for the violation. All models and strategies to resolve violations of assumptions are outlined in detail in supplementary materials.[14] After the models were correctly specified, we used the Impulse response function analysis and calculated the resulting areas under the curves (see scores in Table 4). Because the AUC scores do not have a straightforward interpretation, we standardized the AUC scores to mean 0 and SD 1 (see Table 4 for the standardized min and max).

Research question 1: What are the associations between three indicators of resilience?

As Recovery speed was not normally distributed at T0 and T1, Spearman Rank correlations were calculated. Correlations between the three resilience indicators are presented in Table 5. We found moderate positive associations between General resilience and Daily resilience at T0 and T1. General and Daily resilience correlations were larger than all correlations involving the Recovery speed indicator at T0 and T1 based on pairwise comparisons. Namely, at both T0 and T1, the correlation between General and Daily resilience was significantly larger than the correlation between General resilience and Recovery speed (T0 FDR. Adjusted p-value <0.001, T1 FDR. Adjusted p-value = 0.01) and correlation between Daily resilience and Recovery speed (T0 FDR. Adjusted p-value =

14 Among the 96 resulting models at baseline the model of 18 participants violated at least one assumption and among the 66 models at follow-up 9 violated at least one assumption. All of these cases were resolved by following the proposed strategies (see Supplementary materials included in this dissertation and available online)

0.02; T1 FDR. Adjusted p-value < 0.001); whereas correlations between General resilience and Recovery speed and Daily resilience and Recovery speed did not differ (T0 FDR. Adjusted p-value = 0.14; T1 FDR. Adjusted p-value = 0.38).

Table 5. Spearman rho of cross-correlations between three indicators of resilience

	Baseline (T0)		First follow-up (T1)	
Resilience:	General	Daily	General	Daily
Daily	0.35* (CI: 0.16 -0.51)	-	0.30* (CI: 0.06 - 0.51)	-
Recovery speed	-0.16 (CI: -0.35 -0.04)	-0.01 (CI: -0.21 -0.19)	-0.10 (CI: -0.33 -0.15)	-0.15 (CI: -0.38 - 0.10)

* *p*-value after FDR correction < 0.03; General refers to General resilience indicator, Daily – to Daily resilience indicator, Recovery – to Recovery speed indicator; Rho – Spearman Rank Correlation coefficient, CI – Confidence intervals for the Spearman Rank Correlation coefficient

Research question 2: How stable are the three resilience indicators over one year?

General Resilience was stable over the one year between the waves (rho = 0.61 (CI[15]: 0.44 - 0.74), FRD-corrected *p*< 0.001) and Daily Resilience even more (rho = 0.83 (CI: 0.74 - 0.90), FRD-corrected *p* <0.001). Recovery Speed showed a moderate temporal stability (rho = 0.27 (CI: 0.03 - 0.48), FRD-corrected *p*= 0.05). Comparisons between stabilities (against alpha <= 0.016, see above) showed significant differences between all stability indexes, i.e., General resilience vs Daily resilience, p-value = 0.01; General resilience vs Recovery speed, p-value = 0.01; Daily resilience vs Recovery speed, p-value <0.001. However, due to an overlap in shared variance, these results should be interpreted with caution.

Research question 3: How do the three indicators predict mental health outcomes?

The multilevel regression analyses, both model with and without interaction between resilience indicators and the number of large negative life events, are presented in Table 6. All models adhered to assumptions on heteroscedasticity and normality of residuals. Daily Resilience proved a moderately strong predictor of mental health one year later (SCL-90) while correcting for severity one year previously (β= -0.22, FRD-corrected *p*<0.001), while General Resilience and Recovery speed were not predictive of psychopathology in a significant way. Z-score test (271) showed significant differences between all beta-coefficients across models (all p-values < 0.001); Wald test, however, showed that the only difference between Daily resilience Beta-coefficient and Recovery speed was significant (FDR-adjusted p-value = 0.04). None of the resilience indicators

15 95% confidence intervals

showed a significant interaction with negative life events. Hence, in the case of daily resilience, it was predictive of next year's mental health, and this effect did not depend on the number of life events experienced during that year.

Table 6. Multilevel regression model of three resilience measures predicting mental health (SCL-90) one year later and interactions between resilience and number of recent negative life events.

Model	Resilience	Beta	CI	FRD adj. p
Main effect model*:	General	-0.11	-0.25 - 0.02	0.15
	Daily	-0.22	-0.34 - -0.10	<0.003
	Recovery Speed	-0.01	-0.13 - 0.11	0.88
Interaction with number of negative life events+	General	-0.03	-0.10 - 0.04	0.39
	Daily	0.00	-0.01 - 0.01	0.71
	Recovery Speed	0.02	-0.06 - 0.10	0.62

Note. β= Beta coefficient. CI= Confidence interval.
* β-coefficient represents the main effect of resilience indicator.
+ β-coefficient represents the interaction between resilience indicator and number of negative life events

Sensitivity analyses and post-hoc observations

Daily resilience was the only significant predictor of adverse mental health over one year. The Daily resilience indicator was built by averaging data from 90-time points. To examine whether significant predictions could also be made based on fewer assessments, we fit a series of post-hoc sensitivity analyses, calculating the predictive validity of Daily resilience indicator based on randomly selected subsets of observations, namely: 75% of observations, 50%, 25%, 5%, first five and first observation. These sensitivity analyses indicated that up until data from the five first observations, the Daily resilience indicator significantly predicted the mental health outcomes one year later (see Table 7).

We excluded all participants who reported the 25% lowest variability levels at the negative event variable as a sensitivity check. For some participants, the within-person variability of the stressfulness of negative events was extremely low, which may have introduced floor effects in the VAR models, and subsequently in the impulse response function analyses, which we used to create the Recovery Speed indicator. For such people, the effect of the increase in one standard deviation would be higher than for people with high within-subject variability, potentially limiting the between-people comparison of the Recovery speed measures. However, our sensitivity check revealed no substantial differences between the total sample and the sub-sample with higher levels of negative event variability (Supplement 1).

Table 7. Sensitivity analyses for Daily Resilience as a predictor of mental health (SCL-90) one year later based on different randomly selected subsets of the observations.

Observations	Number	Beta	CI	P
100%	90	-0.85	-1.32 to -0.39	<0.001
75%	67	-0.86	-1.32 to -0.39	<0.001
50%	45	-0.77	-1.23 to -0.31	<0.002
25%	22	-0.80	-1.25 to -0.35	<0.001
5%	5	-0.55	-0.97 to -0.14	<0.01
First 5	5	-0.54	-0.96 to -0.13	0.01
First	1	-0.27	-0.55 to 0.02	0.07

Note. The Daily resilience measure was not standardized; thus, the effect size describes the change in one mental health symptom score (SCL-90) per unit change in Daily resilience. Because the original model did not support an interaction between Daily resilience and the number of negative life events over the next year, only models without the interaction term were used for the sensitivity analysis. B= Beta coefficient. CI= Confidence interval.

DISCUSSION

This study aimed to compare three conceptual operationalizations of psychological resilience in terms of their (a) concurrent associations, (b) temporal stability, and (c) ability to predict psychopathology one year later. These three operationalizations were: General resilience (self-reported general ability to overcome adversity), Daily resilience (momentarily experienced ability to overcome daily adversity), and Recovery speed (trajectory of negative affect recovery after daily life adversities). For concurrent associations, we observed moderate positive associations between General and Daily resilience at baseline and one-year follow-up, whereas both measures were unrelated to Recovery Speed at both time points. For temporal stability, our models showed that General and Daily Resilience were highly stable over one year, whereas the stability of the Recovery Speed was moderate. Regarding the ability to predict psychopathology one year later, we found that Daily resilience predicted changes in psychopathological symptoms after one year with moderate effect size and high sensitivity. This prediction was still equally accurate with a random subset of 25% of the assessments. These results suggest that both the General and Daily resilience measures showed substantial stability and that Daily resilience was a better predictor of later psychopathology. Recovery Speed was neither stable over time nor predictive of future psychopathology. These results are now discussed in more detail below.

Daily and General Resilience

A major contribution of our study is the finding of high temporal stability and predictive validity of the Daily Resilience indicator for future psychopathology. Despite its simplicity, this average of daily measurements was not used before in resilience research.

Most studies used intensive longitudinal data to investigate more complex theory-based dynamic patterns in daily life experiences than the simple average across time. Our findings align with accumulating evidence that dynamic measures do not predict much additional variance in outcomes like depression, subjective wellbeing, or neuroticism on top of the mean score of negative affect (272,273).

One potential reason for the Daily Resilience indicator's high stability and predictive validity could be the relatively long period covered by the diary period. Three months of data collection allow researchers to reduce the effect of (random) daily fluctuations, which helps establish the mean score with higher accuracy. However, our sensitivity analyses suggest that even five daily measurements suffice to predict psychopathology one-year later reasonably well, contrarily to the idea that the length of the time series determines its predictive validity. Therefore, our results confirm the added value of repeated measures compared to one-time assessments, as evident by the lack of predictive potential of General resilience and the first observation of the Daily resilience. At the same time, the results suggest that the number of needed observations may be relatively small. As time-intensive data collection may burden participants (245), the option to reduce the number of observations while maintaining validity has clinical relevance.

Another interesting finding is that our interaction analysis showed no interactions of Daily resilience with major negative life events. In fact, we did not find any interactions between the three resilience indicators and major negative life events. One probable explanation for this finding is the limited exposure to severe life events combined with a lack of statistical power. However, in the specific case of Daily resilience, one could argue that expectations of an interaction effect – or at least a trend towards significance – are not unreasonable, given its relatively high effect size. Another explanation for the absence of any interactions could be that the mechanisms that facilitate recovery from larger negative life events may differ from daily strategies measured by Daily resilience. For example, after a tragic event causing long-term negative affect, persons may still effectively implement specific resilience mechanisms to cope with daily challenges, even though these mechanisms do not help recover from the tragedy. Given the high predictive potential of Daily resilience, one may wonder whether these daily life processes and resilience to daily challenges are at least as (if not more) critical for the development of symptoms than resilience to large negative events. This idea is supported by research on the additive burden of chronic minor stressors and their detrimental effect on mental and general health (39,40,274). Finally, it must be noted that although none of the studied resilience indicators have shown interactions with major negative life events, the aspect of interaction with stressors was partly captured in the conceptualization of all three resilience indicators themselves. Both General and Daily resilience assess the perceived ability to handle stressors, and for Recovery speed, stressors were directly included in

the calculations of the indicator. This presence of the stressors in conceptualizations of resilience indicators and the absence of the interactions with large negative events, alongside the high predictive potential of Daily resilience, further support the idea that different relevant resilience processes may be at play at different levels of stressors.

Concerning the predictive potential of resilience indicators, it is unclear why Daily resilience predicted future mental health changes while General Resilience did not. Both indicators are conceptually close and measure the same concept of perceived ability to bounce back from adversity. In previous studies, the BRS - the questionnaire on which General resilience was built- has been shown to predict mental health changes (275). In our study, General resilience was likely not predictive due to the limited power for the analysis, which potentially was not enough to detect the potentially more minor effects of General resilience. Given conceptual similarities between Daily and General resilience, our finding that only Daily resilience significantly predicted mental health outcome is intriguing. Some possible explanations for only Daily resilience being predictive may come from the differences in time scales that the indicators capture between General and Daily resilience indicators. It may be speculated that it is easier for people to answer the more straightforward diary question about the past day (45) than to assess their general tendencies without recall bias. Assessing general tendencies can also be more influenced by the current mood or the current negative life event when filling in the questionnaire (276), whereas for the Daily resilience, this effect is more negated by the repeated assessments.

Speed of recovery indicator

One aim of this study was to construct - for the first time – a Recovery Speed indicator on an individual level. Previous studies, including our own (Kuranova et al., 2020), suggested that Recovery Speed constructed on a group level is associated with current (226) and future mental health levels (De Calheiros Velozo, J. Lafit, et al., n.d. personal communication;). Inspired by these results, we assessed Recovery speed at the individual level and found this was unrelated to the other two resilience indicators, moderately stable over one year and not predictive of future mental health. We discuss possible explanations for these results and how they relate to other studies on Recovery speed working from a complex systems approach to psychopathology.

The absence of associations between Recovery speed and the other two resilience indicators may be because Recovery speed measures a different aspect of resilience. While both Daily and General resilience focus on subjective perceptions of being resilient, Recovery Speed assesses the pattern of affect recovery. It is possible that perceptions of "being able to recover" are not connected to affect recovery but rather to behavior and perception of "handling the problem."

There are several explanations for the contrast between previous studies and our current results that do not support the predictive potential of Recovery speed. Similar to the other indicators, we had low power to capture the effect and potentially lower than prior studies. Although a strong point of our study was that we constructed the Recovery speed on an individual level, leading to a more precise measure, previous works had substantially larger samples than our current one. Another explanation for this discrepancy between studies in terms of predictive potential of Recovery speed lies in differences in time scales. All previous studies assessed Recovery speed on a denser time scale than we did, such as ten observations per day versus one observation per day in the current study. The recovery speed effect may exist only on the smaller timescale.

Another possible reason for the lack of predictive potential of Recovery speed in our study may relate to the nature of the sample. The premise behind this indicator came from complex systems theory, which proposed that the recovery speed decelerates closely before a transition between "healthy" and "more psychopathological" states (and vice-versa) (278,279). However, it is not clear what can be considered "a transition" in terms of mental health, as often the change in the level of symptoms is gradual (280) and nonlinear (281). Therefore, a comparison of the predictive potential of recovery speeds might be informative only if all people are in the same "healthy" or "pathological" states at the time of assessment. After the already happened transition, an effect at the group level may become seemingly absent. Our sample comprised people at different stages of risk for psychosis, with most individuals having other types of symptomatology as well. Hence, a transition might have already happened for some people. In previous studies or the predictive potential of recovery speed, samples were less heterogeneous (254,277)

Taken together, our results remain inconclusive regarding the relevance of assessing Recovery speed at the individual level and a daily scale. To better understand it, we need to investigate it further, possibly comparing different time scales, employing more homogenous samples, and working towards more detailed descriptions of 'transitions.'

Methodological issues[16]

When comparing our results to other studies on psychological resilience, several methodological considerations should be considered. First, regarding the sampling strategy and generalizability, our high-risk sample reported more mental health symptoms at baseline and was subjected to more stressors than the general population, and the majority of our sample was receiving mental health care. Our results should

16 Please note that in Registered Report version Methodological Issues were listed in the Methods section. Furthermore, the current version contains additional issues not evident at earlier stages of the project

not be generalized to either the general population or clinical populations; instead, one should keep in mind that our sample reflects individuals with different levels of risk for psychosis, and our findings should be interpreted accordingly.

Second, adversity was assessed using the number of negative life events (Brugha List of Threatening Experiences), which does not account for the severity of the experienced stress. Additionally, we could not assess the exact moment the adversity happened between two assessment waves, and this could have had a different effect on participants at the time of the measurement wave. However, given the time scale (one year) between the assessment waves and the fact that all stressful life events had been selected for their long-term impact on functioning and mental health (262,282), we believe that averaged effect still may be informative. Furthermore, the method used to calculate the Recovery speed was used for the first time with some arbitrary decisions. Specifically, due to the methodological limitations of the impulse-response function, we chose only to include the effect of the stressors on negative affect and not vice-versa in the contemporaneous association between the stressful event and negative affect, which might have made the estimated recovery pattern less accurate[17]. Finally, the power analysis shows that the proposed analysis for the third research question does not have sufficient power to detect small effect sizes. This lack of power leads to a decreased chance of true-positive and an increased chance of false-positive findings, and therefore, all results for this research question should be considered preliminary.

Conclusion, future directions, and relevance

The overarching aim of this study was to improve our understanding of psychological resilience by exploring three closely related but different indicators of resilience. Our indicators assessed the ability to recover from stressors but differed in the time frame (daily, weekly, long-term), subjectivity, and the types of stressors they captured. For Recovery Speed, the data type and sample that we used were probably suboptimal to create an informative indicator. For General Resilience, our results suggest that this indicator reflects some long-term tendencies in self-beliefs about resilience, but these self-beliefs are not associated with future mental health outcomes. However, the central finding of our work was the potential scientific and clinical relevance of the Daily Resilience indicator, which was found to be relatively stable over one year and to predict mental health outcomes. These findings highlight the potential relevance of implementing longitudinal designs with multiple observations and exploring the daily life experiences of resilience in research and clinical practice. In particular, the simplicity of this indicator and its higher stability and predictive validity compared to the Recovery Speed indicator built from the same diary data suggest the necessity of critical appraisal

17 Please note that this consideration was not included in the Registered Report version when the Methodologic issues section was part of the Methods section.

of the complex dynamic-based measures. This notion was already proposed in the previous studies (272,273). Such more straightforward indicators are easier to implement, and their construction does not require computational power or elaborated models, which increases the possibility of errors (283). Most importantly, our results suggest that such indicators do not require many observations to be informative, and therefore such assessment will not greatly increase participants' burden.

The next step is to replicate the findings on the Daily resilience measure being predictive for future mental health in different populations and at different time intervals. If replicated, we argue that it is relevant for future studies to investigate the possibilities for creating and validating a clinical prediction tool based on a diary with one or two simple questions administrated to patients or people at risk for developing psychopathological disorders for use by clinical practitioners as a measure of resilience and outcome prediction. The other resilience indicators included in this study should be investigated in different designs and populations to explore further which aspects of resilience they tap into and the extent to which they predict mental health. Altogether, our results highlight that psychological resilience is a multifaceted construct, and as such, requires further exploration of its different aspects in relation to each other, adversity, and future mental health changes.

Chapter 6

General Discussion

Summary of the main findings

In the studies described in this dissertation, we aimed to further resilience research in the context of psychiatry. We used networks and complex systems theories perspectives by focusing on longitudinal interactions between resilience factors and adversity. Specifically, we focused on the flow of daily life and how such resilience-related patterns of daily life experiences can predict changes in mental health. In this Discussion, I summarize the findings, discuss the potential for resilience indicators to predict future levels of mental health, explore relationships between protective factors and adversity, and mention possibilities to translate these protective factors and interactions with adversity to the level of daily life. After that, I discuss what opportunities for resilience research are provided by applying a complex systems theory view on resilience and what challenges arise. Following this, I describe an even broader perspective of seeing resilience as "mental immunity" and how this perspective can help to develop an integrative framework for studying resilience. Finally, I discuss the relevance of our findings from scientific, clinical, and societal perspectives and finalize the chapter by exploring some possible avenues for future resilience research.

In Chapter 2, we aimed to assess whether personal (e.g., personal traits, optimism) and social (e.g., having a partner) protective factors influenced the association between the frequency of psychotic experiences (divided into three subdomains "Bizarre experiences," "Delusional ideations," and "Perceptual anomalies") and the distress caused by them. It is relevant to study especially this distressing effect (and factors that may prevent that effect) because psychotic experiences are more pathological when they are distressing (91). We found that having a partner as well as reporting high levels of optimism, self-enhancing humor, openness, extraversion, and emotional stability moderated the association between Delusional ideations and secondary distress, such that individuals with (high scores on) these factors showed less secondary distress for delusional ideations than individuals without or with low scores on these factors. Thus, our results highlighted the importance of studying the interactions between protective factors and stressors.

In Chapter 3, we investigated the resilience-related dynamics of everyday experiences applying a network approach. We aimed to disentangle the processes behind a successful recovery from stressors. We constructed networks of dynamics of daily affect states and found that a greater influence of positive emotions and the absence of feedback loops ("vicious cycles") between negative emotions were associated with better mental health a year later. These results show the possibility of uncovering some resilience-related mechanisms in daily life and, importantly, that these may be related to later mental health levels.

In Chapter 4, we investigated whether the speed of affect recovery after small perturbations—a general resilience indicator according to complex systems theory—predicted changes in mental health. We defined the "speed of recovery" as the time it took for a level of affect to return to baseline after experiencing unpleasant events in daily life. At the group level, we found that affect recovered slower in participants with worse mental health outcomes after one year than in participants with stable mental health.

In Chapter 5, we constructed three conceptually different resilience indicators and compared them. These three indicators were General resilience (assessing the long-term ability to handle adversity), Daily resilience (assessing the ability to handle adversity on a daily level), and speed of recovery (assessing the affect recovery after daily life stressors). Contrary to the results of Chapter 4, we found that the speed of recovery, when measured on the individual level, did not predict individual differences in mental health changes. Instead, we found that the daily life indicator predicted mental health changes over a year.

Resilience indicators and future mental health

One of the overarching aims of our project was to further the understanding of resilience as a dynamic process by establishing clear temporal connections between the assessed resilience-related patterns, aspects, or indicators (henceforth unified by the term "indicators" for readability) and future levels of mental health. Most of the tested indicators in this dissertation had predictive potential with varying effect sizes. Altogether, although the possibilities of direct comparisons between the studies are limited, the indicator with the highest predictive potential appeared to be the mean level of the daily perceived ability to cope with adversity in everyday life (see Chapter 5). Contrary to our expectations, speed of recovery, the indicator adapted explicitly from the complex systems theory for its ability to predict impending change, was found to predict mental health changes in Chapter 4 but not in Chapter 5. Although some conceptual and methodological differences between the studies may explain this contradiction (see Chapter 5 and below for a detailed overview), the difference in the predictive potential of the speed of recovery and simpler mean-based one-item indicator is an intriguing finding.

It is unclear why the way people perceived how well they had been able to "handle what came their way" predicted future mental health with larger effect size and more precision than a more complex but more objective dynamic indicator. Similar results have been demonstrated by some other authors, postulating the question of the added value of assessing complex patterns in the dynamics of daily life experiences (272,273). However, the complex and simple measures may assess different aspects of daily life dynamics. While in Chapter 5 simple mean-level indicator assessed "what is the level of

resilience this day," it is possible that more complex dynamics-based measures reflect the underlying mechanisms of resilience, assessing "how was the resilient outcome achieved." Thus, the mean-based indicator may not explain how interactions between daily experiences function but partly cover the results of these interactions (being able to handle adversity), thus being highly associated with the functioning of the system as a whole (272,273). While simpler measures may predict and assess resilience better, more complex ones may be necessary to unravel the processes that led to this level of resilience and highlight the possibilities to stimulate these processes. Therefore, despite challenges in constructing and validating complex measures, they may be essential for developing new interventions to increase psychological resilience; thus, both types of measures will be fruitfully used in future resilience research for different purposes.

Understanding resilience as interactions between protective factors and adversity

To unravel the resilience mechanisms, it is imperative to view any potential resilience indicators in the context of adversity. Resilience, by definition, is a process initiated by facing adversity, whatever form the adversity may take (284). Therefore, we aimed to combine protective factors and adversity assessment and investigate their interactions as parts of the same (dynamical) system. We used various operationalizations of such interactions, from the direct buffering effect of protective factors on associations between adversity and outcome (Chapter 2) to more complex dynamical measures of recovery from stressors (Chapter 4, 5). Moreover, Chapter 5 aimed to investigate whether different potential resilience indicators buffer the effect of future adversities on mental health (29). Altogether, our results suggest that assessing interactions between protective factors and adversity may add value over assessing only the level of symptoms in predicting mental health changes.

Moreover, our results highlight the need to carefully define the levels of adversity and resilience-related processes. For example, Chapter 4 showed that recovery speed from micro daily stressors, which may happen several times a day (spilled coffee, traffic jam, being late to a meeting), was connected to future mental health. However, in Chapter 5, we found that the speed of recovery from a potentially more considerable stressor ("the most stressful event of the day") did not predict mental health changes (for possible methodological explanations of the findings, see Chapter 5). Additionally, due to the differences between stressors, it is possible that experiencing average-to-large stressors (losing a phone, getting in a minor traffic accident without physical harm) changes the individual's frame of reference for the following small-to-average stressors, making the recorded data before and after the incident incomparable.

The relevance of differences between types and levels of adversity is also highlighted by the absence of interactions between resilience indicators assessing the response to stressors and major life events in predicting future mental health changes (Chapter 5). Although the mean level of daily perceived ability to handle stressors was strongly associated with mental health outcomes, higher levels of this indicator did not buffer the effect of major adverse life events on mental health over the next year. Neither did higher scores of the Brief Resilience Scale, a questionnaire created to assess how well people can bounce back from major adverse life events (243). For the mean-level indicator, its high predictive potential and absence of interactions with major life events may be explained by the notion that the protective mechanisms that this indicator reflects function daily and do not mitigate the effect of large or chronic stressors. For example, a person can suffer from bereavement and yet handle daily hassles successfully. Again, this highlights the fact that resilience is a multi-layered construct.

Interestingly, in this case, our results suggest that the resilience-related processes on the level of daily life, i.e., handling minor stressors, are at least as (if not more) critical for symptom development and mitigation as resilience to major adverse events. This notion is in line with the growing body of stress research on the additive burden of chronic minor stressors and their detrimental effect on mental and general health (39,40,274). Therefore, I believe that any study on psychological resilience will benefit from careful consideration of whether the adversity and the proposed resilience-related factors function on the same level.

Resilience in daily life

Given the relevance of studying potential resilience mechanisms on a micro level, we have investigated several different resilience-related patterns in the dynamics of daily life experiences. Conceptually, we aimed to translate some protective factors known from previous studies to the processes that can be observed in daily life.

One of the central resilience-related constructs is the "ability to bounce back" (284). On a daily level, we operationalized this as the recovery of negative affect after the experience of stressors (with faster recovery meaning better ability to bounce back), as well as self-reported ability to "handle what came my way." It must be noted that this concept is closely related to stress reactivity, which has been previously studied on the level of daily life, with most results suggesting lower stress reactivity being protective against psychopathology (48,50,190,226,235). One step further, but also related, is negative affectivity, which is usually associated with neuroticism. In daily life, neuroticism can be operationalized by studying the severity and persistence of negative affect (190,285). We adopted a similar operationalization in Chapter 3 and studied the dynamics of affect states, with the focus on interconnections between negative affect states (e.g., "feeling

down," "feeling irritated") and positive states (e.g., "feeling cheerful," "feeling relaxed"). We found that negative affect states may interact with each other in a way that allows for self-reinforcing loops ("vicious cycles") to arise and that the presence of such "vicious cycles" was associated with a worse future course of psychopathology. It can be theorized that individuals may become trapped in these "vicious cycles" of self-reinforcing negative affect states and that such a process may contribute to the development of the symptoms. In this case, the absence of opportunities for "vicious" cycles to arise may be considered a protective factor. Such absence may be facilitated by the strong (positive) influence of positive affect on the emotion dynamics and the possibilities for positive affect states to interrupt the formation of "vicious cycles."

Another opportunity provided by studying resilience in daily life is to include (direct and indirect) assessments of events and behaviors. Despite the relevance of studying dynamics of affect states only, one may expect protective factors to interact with stressful events and influence behavior. It can be speculated that the positive behavior change (for example, increased physical activity or social engagement) may be important for resilience but not be fully captured in the dynamics of affect states only. In line with this notion, our results from Chapter 5 suggest that (proxy for) behavior item assessing how a person was able to "handle what came their way" this day was more informative compared to assessing how fast affect recovered after the (relatively) same stressful events.

Assessing behavior also allows us to examine the functioning of the reward system in daily life. The reward system drives our behavior towards pleasurable stimuli and is responsible for the positive emotions after reaching them. Impaired functioning of the reward system is associated with anhedonia and depression (286,287), and effective reward functioning has been shown to buffer the effects of adversity in neurological research (288,289). To assess this factor in daily life, Bakker and colleagues (68) attempted to translate the neurological findings on reward components (290) to micro experiences of "reward anticipation," "active behavior," and "positive emotions." They showed that reduced connections between reward components were associated with higher concurrent depressive symptoms, suggesting that the reward system's functioning assessed in daily life is a protective factor. Currently, we are adopting similar principles to replicate the study of Bakker and colleagues prospectively and on an individual level. Our preliminary findings suggest that although individual characteristics of reward dynamics may vary greatly, the strength of positive connections between elements in the reward circle is associated with both current and future levels of mental health. Altogether, these results suggest that studying dynamics between affect states, events, and behaviors in daily life can substantially expand our understanding of resilience processes.

The complex systems approach to resilience

Complex systems theory states that complex systems can undergo substantial changes and transitions from one stable state to another. The probability of this impending change can be captured in one universal characteristic of resilience to change, i.e., the system's capacity to recover from minor perturbations (24). Applied to mental health, we can understand a transition as a clinically relevant change in the level of psychopathological symptoms such as from a "healthy" to "pathological" state and vice-versa (60) (291). Building on this, we can investigate the overall level of mental health resilience – the probability of such transition — by assessing recovery speed from minor perturbations. In this dissertation, such a recovery speed indicator was considered a translation of the "bouncing back" concept to daily life experiences and a complex systems indicator of resilience to a transition. Here we have attempted for the first time to use this complex systems indicator in mental health research, i.e., to directly assess the speed of affect recovery from minor stressors. As mentioned earlier, we obtained mixed results, with Chapter 4 showing that bouncing back over several hours predicted mental health changes, while Chapter 4 showing that bouncing back over days (Chapter 5) did not predict mental health changes. Most other studies have also assessed bouncing back over several hours rather than days(226) (277), so the difference in temporal scales may be a possible explanation for the lack of predictive potential of bouncing back over days. This raises the question of what can serve as "minor" perturbations for the system and how the recovery rates from smaller and larger stressors relate to each other.

Applying complex systems theory to mental health posits other intriguing questions. The theory assumes the existence of alternative states of the system, yet there is no consensus on how exactly we define the nature of such states or transitions between them. Often, the development of symptoms has been described as sudden by both patients and researchers (292,293), distinguishing the states clearly. However, for many others, the change is gradual (280) and nonlinear (281), and it is unclear how to establish where one state ends and another begins. Moreover, there is evidence suggesting that not only "health" and full-blown "psychopathology" may exist as stable states but also subthreshold symptoms(294). This challenge to distinguish the different states may also explain the discrepancy between our results in Chapters 4 and 5. In Chapter 4, participants were sampled from the general population and had a similar baseline level of symptoms, whereas, in Chapter 5, participants had different levels of psychopathological symptoms. Thus, in Chapter 5, some people at the time of assessment might have been in a "healthy" state, and others already in a more "pathological" one, possibly rendering the recovery speed indicator non-informative for the latter case. Although the severity of symptoms was considered in the analysis, it is unclear how it related to the system's states and how the relationship between the level of symptoms and the system's state differs between individuals. For example, two people may have the same symptoms but be in different states due to the

dynamics between these symptoms and protective factors. To further complicate the notion, it is possible that for the same individual, there exist several "pathological" states (e.g., representing different syndromes or different severity (294)), and the resilience of the "healthy" state against these states may not be equal (180,291,295). This possibility of several "pathological" states is also proposed in the mental health immunity framework Davydov and colleagues (29), where it is suggested that people can be resilient against some type of stressors and vulnerable to another. Likewise, the resilience of different pathological states can vary greatly. Additionally, it is also unclear whether only one "healthy" state exists, especially given the frequent observations of post-traumatic growth (235), which may be interpreted as a new, even "healthier" state.

Moreover, a distinction has to be made in studying resilience in the context of preventing the onset of psychopathology and studying resilience in recovering from psychopathology. Some studies suggest that specific early warning signals may predict both worsening and improvements in functioning (296), but we are unaware of studies using the indicator reflecting the speed of recovery from minor stressors predicting impending improvement. Though one may ask whether the level of stability of pathological state that prevents recovery to health should be called "resilience" in the first place, from complex systems theory, there is no essential difference between "healthy" and "pathological" states, and assessment of the resilience of the latter may be just as relevant for research and clinical practice.

On the notion of assessing the stability of "pathological" states, the findings of Bakker and colleagues on reward system dynamics (68) and our preliminary findings from the replication of their work may theoretically be interpreted as indicators of critical slowing down for "pathological" states. For people with depression, higher connectivity between reward systems components also means more prolonged lingering of positive experiential states. This prolonged lingering of positive states was associated with better future outcomes. Somewhat aligning are our results from Chapter 4 that suggest that only the recovery of negative affect predicted an increase of symptoms. It may be speculated that for a "healthy" state, the dynamics of negative affect may be more informative, as an increase in negative affect is not characteristic of a healthy state, whereas, for the "pathological" state, the dynamics of positive affect may contain more information because positive affect dynamics are more lacking in such a pathological state. These interpretations are in line with the results from the study by De Leemput and colleagues, who have found early warning signals in the dynamics of negative affect before the development of depression episode, and in the dynamics of positive affect before the termination of depression episode (223).

Resilience as the mental immune system

Interestingly, the application of systems thinking to resilience is not necessarily limited to the concepts of systems states and transitions between them. Complex systems theory's core is that the system is more than the sum of its elements and cannot be fully understood by studying these separately (297). Concerning mental health, many researchers propose such an understanding (60,72). But what is psychological resilience in the system of mental health? Resilience operationalized as the speed of recovery may be a valuable tool for assessing and predicting mental health change. However, this operationalization covers only one aspect of resilience (affect recovery) and does not explain how resilience functions, why it occurs, and its place in the mental health system. A more integrative approach to resilience is needed to further answer this question, with resilience being seen not as a process and an outcome of overcoming adversities (https://dictionary.apa.org/resilience), but as a complex system of interacting protective factors itself. Effective functioning of this resilience system would then result in observed resilient processes and outcomes. From this perspective, one may think about mental health as a complex fractal system, with psychological resilience being a part of mental health and a complex system itself, similarly to the human body being a complex system and a brain being one of its parts and yet a complex system as well.

From such understanding, psychological resilience – or mental immunity, the term Davydov and colleagues (2010) proposed — is quite similar to the somatic immune system. Davydov and colleagues applied a general immunity model to resilience research and proposed to combine somatic health immunity and mental health immunity (resilience) in one immunity model because somatic health and mental health are inextricably linked (29). In their model, Davydov and colleagues highlight the differences between natural (subject-related) and external (society-related) factors that facilitate health protection. For somatic immunity, examples of subject-related factors are passive immunity and the inflammation response, and examples of society-related factors are vaccination programs and quality of sanitary barriers. For mental immunity, examples of subject-related factors are genetic and epigenetic characteristics and personality traits such as optimism and emotional stability, and examples of society-related factors are the quality of interpersonal relationships and community support.

Applying the mental health immunity understanding to psychological resilience provides a comprehensive framework for studying resilience. For this dissertation, different aims and findings of the chapters can be viewed as representing some aspects of "mental immunity" and be compared to the immune system. In Chapters 4 and 5, we attempted to create indicators that capture mental health immunity's overall level of functioning. Such indicators supposedly reflect the interactions between elements on all levels and layers of the model; very roughly, these indicators can be seen as corresponding to measuring

the C-reactive protein level to assess the level of immune response to the infection and inflammation in terms of somatic health (298). In other studies, we investigated subject-related factors and experiences (Chapters 2 and 3), which can be seen as roughly corresponding to studying the physiology of cellular and tissue inflammation responses.

Viewing psychological resilience from this immunity framework elucidates that most of the current resilience research in mental health, this dissertation included, focus on subject-related factors and experiences, ranging from biological predisposition to personal traits (235). In contrast, factors related to the interactions with society, be it close inter-personal relationships or available resources, are rarely examined in resilience research in psychiatry. Societal policies and circumstances are more frequently investigated in the context of community or population resilience than at the individual level. (235). Such diverging of research questions between fields is natural; however, in the case of studying psychological resilience, one may wonder whether focusing mainly on the individual factors can sufficiently elucidate mechanisms of resilience. It has been shown that contextual factors are crucial for the resilience and may outweigh individual factors (25,29,299), as any individual reaction to adversity is limited by the available resources, which are primarily determined by socioeconomic circumstances (300,301). For example, there may exist a case of an optimistic and emotionally stable person from a poor neighborhood who may recover slower and develop more symptoms after a major adverse event than a wealthy but pessimistic and highly neurotic person. These differences could be explained by the additional stress of the socioeconomic circumstances but would be overlooked unless specifically included in the study. Adopting the mental immunity understanding of resilience allows combining individual and population-level studies in one comprehensive framework and further unraveling the mechanisms of resilience functioning.

Relevance of the findings and future perspectives

Our results highlight the relevance of studying resilience in the context of adversity, longitudinally and prospectively, focusing on the dynamics of daily experiences. We have shown that it is possible to capture several resilience-related patterns in the dynamics of daily experiences. Some of these patterns may reflect the mechanisms involved in the process of resilience in action (i.e., the process of responding to stressors), and others may indicate the system's state (i.e., the level of resilience) as a whole. I propose that resilience is a multifaceted phenomenon that may emerge through different mechanisms on different time scales and levels of adversity that an individual faces. Moreover, psychological resilience can be best understood as mental immunity - a complex system that protects mental health, not unlike the immune system for physical health. This framework can be fruitfully used to generate new hypotheses and research questions.

For clinical practice, our work first emphasizes the possibility of assessing daily resilience using a (single) diary item (Chapter 5) to be later transformed into a simple but informative diagnostic and prognostic tool, which can be easily implemented in healthcare. Second, we highlight the importance of studying protective factors alongside psychopathological symptoms, as protective factors mitigate the development of symptoms and positively affect prognosis. Third, we identified possible options for developing new interventions to increase resilience in daily life. An example of such an intervention may be constructing personal affective networks to reveal the paths constituting "vicious cycles" of negative experiences and target these paths specifically. Several studies have already investigated the efficacy of using affective networks in clinical settings, with mixed but promising results (214,302–304).

The societal relevance of our findings relates to the fact that our results highlight the complexity of resilience phenomenon and differences between people, warranting the notion that, to capture fully (and potentially enhance) mechanisms of resilience, protective and risk factors need to be studied at different levels (personally, immediate environment, societal factors). Promoting mental health at a societal level may be practical alongside resilience-enhancing interventions on individual protective factors, such as mindfulness training. An example of a societal-level large-scale intervention is the implementation of a universal basic income. Results of studies evaluating this policy suggest that it improves mental health, reduces stress levels, and increases individual well-being (34,305).

For future research, an essential next step is to check the robustness and reproducibility of our findings by replicating the studies on resilience indicators in other populations and with different follow-up lengths for the outcomes. For resilience-related patterns in daily life, it is essential to use similar construction methods to time-series data collected at different time scales, e.g., several times during a day instead of once a day and vice versa. Such replication is especially warranted for the speed of recovery indicator, as Chapters 4 and 5 contradicted. The recovery speed indicator was built on complex systems theory. Although promising, future studies using the same theory will greatly benefit from establishing what can be considered similar or different states and how to assess the transitions between these states in the context of mental health (291,294).

Additionally, results from Chapters 4 and 5 suggest that resilience mechanisms may differ per type and level of adversity. An important next step will be to assess several levels of adversity alongside protective factors in the same dataset to investigate their interrelations. Furthermore, research should investigate the effect of larger-scale protective factors, such as socioeconomic factors, on dynamic interactions between daily experiences and stressors.

Chapter 7

Nederlandse samenvatting
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NEDERLANDSE SAMENVATTING

Achtergrond

Tegenslagen zijn een onvermijdelijk onderdeel van het leven die vaak niet kunnen worden voorspeld of voorkomen en die de geestelijke gezondheid aanzienlijk in gevaar kunnen brengen (1–4). Desondanks ontwikkelen de meeste mensen die te maken krijgen met stressvolle gebeurtenissen geen psychische stoornis (4–6). Psychologische veerkracht is een van de dingen die mensen beschermt tegen de schadelijke effecten van tegenslagen (6–8). Veerkracht is het succesvol omgaan met tegenspoed, wat leidt tot het behoud of snel herstel van geestelijke gezondheid en welzijn (7,9). We bestuderen psychologische veerkracht om te begrijpen hoe het werkt en om het te kunnen verbeteren en zodoende mensen beter te beschermen tegen tegenslag. Dit idee heeft al veel onderzoek naar veerkracht geïnspireerd en de interesse groeit nog steeds (10,11). De relevantie van veerkracht is bijvoorbeeld duidelijk gebleken in de huidige COVID-19-pandemie (12–15) of in internationale conflicten. Mijn proefschrift heeft tot doel ons begrip van psychologische veerkracht te vergroten door te onderzoeken hoe het functioneert en hoe het kan worden gemeten.

Psychologische veerkracht is een complex fenomeen. De aanpassing aan stressoren gebeurt op vele niveaus en kan op al deze niveaus worden bestudeerd, variërend van genetica tot persoonlijke eigenschappen en maatschappelijke factoren. Het combineren van verschillende visies in één allesomvattend beeld is essentieel om beter te begrijpen hoe psychologische veerkracht werkt. In dit proefschrift heb ik de benadering van Davydov en collega's (2010) gevolgd. Ze duiden veerkracht als “mentale immuniteit”. Mentale immuniteit is een systeem van verschillende biologische, psychologische en maatschappelijke factoren die met elkaar, en met tegenslag, interacteren waardoor het een adaptieve reactie op en herstel van tegenspoed mogelijk maakt (29). Een dergelijke definitie van veerkracht omvat de directe wisselwerking met tegenslag als een essentieel onderdeel van het herstelproces. Zoals het immuunsysteem anders reageert op verschillende pathogenen, kan de mentale immuniteit anders reageren op verschillende stressoren. Daarom is het van cruciaal belang om rekening te houden met zowel de aard van stressoren als hoe de mentale immuniteit daarop reageert. Dit proefschrift had tot doel beschermende factoren, stressoren en interacties tussen beide te onderzoeken om veerkrachtmechanismen te ontrafelen.

Aangezien het behoud of herstel van geestelijke gezondheid iets is wat over de tijd gemeten wordt, is het noodzakelijk om mensen dus minstens twee maal te bevragen over hun ervaringen, zodat deze ontwikkeling over tijd gevangen kan worden. Veel eerdere onderzoeken bekijken het niveau van veerkracht en symptomen van psychische stoornissen tegelijkertijd. Een dergelijke benadering is niet voldoende om vast te

stellen of een hoge mate van veerkracht stressoren vermindert of vice versa (44). In dit proefschrift wilde ik vaststellen of veerkracht veranderingen in de geestelijke gezondheid kan voorspellen. Om interacties tussen tegenslag en veerkracht te bestuderen en het herstelproces over de tijd te kunnen beschrijven, heb ik een specifiek type data gebruikt dat bestaat uit vele metingen voor één persoon. Voorbeelden van dergelijke gegevensverzameling kunnen een dagboek zijn dat mensen gedurende enkele maanden eenmaal per dag invullen of apps die meerdere keren per dag een persoon vragen om enkele eenvoudige vragen over hun stemming en ervaringen te beantwoorden (45). Met dergelijke gegevens is het mogelijk om te zien wat er met mensen gebeurt in het dagelijks leven en hoe dit in de loop van de tijd verandert. Erdere onderzoeken tonen aan dat de manier waarop mensen omgaan met dingen in het dagelijks leven verband houdt met huidige en toekomstige psychische stoornissen (48,54,306). Op eenzelfde manier kan wat er in het dagelijks leven gebeurt verband houden met veerkracht. Dergelijke aan veerkracht gerelateerde alledaagse ervaringen kunnen beschermen tegen toekomstige psychische stoornissen (307).

Om te onderzoeken hoe veerkracht zich manifesteert in het dagelijks leven, hebben we twee theoretische kaders gebruikt: netwerktheorie en complexe systeemtheorie. Volgens de netwerktheorie ontwikkelen psychische stoornissen zich als het gevolg van directe interacties tussen symptomen, ervaringen, stressoren en risico- en beschermende factoren. Dit in tegenstelling tot somatische aandoeningen, waar de waargenomen symptomen worden veroorzaakt door een onderliggende oorzaak. Ter illustratie, hoesten, pijn op de borst en kortademigheid kunnen symptomen zijn van de onderliggende ziekte longkanker. Bij psychische stoornissen is er misschien niet één gemeenschappelijke oorzaak: iemand ervaart bijvoorbeeld tegenslag, wat leidt tot slapeloosheid en verdriet, wat leidt tot vermoeidheid en sociale terugtrekking, die weer leidt tot meer somberheid, enzovoort (59–62). De netwerkbenadering stelt ons in staat om dergelijke interacties tussen symptomen en ervaringen in het dagelijks leven te visualiseren en te bestuderen. Deze interacties tussen beschermende factoren, stressoren en symptomen kunnen ook de psychologische veerkracht van de persoon weerspiegelen. Dit is de reden waarom de netwerkbenadering inzichtelijk kan zijn voor onderzoek naar veerkracht.

Om het idee van interacties tussen meerdere elementen ook vanuit een andere hoek te bekijken, hebben we de dynamiek van dagelijkse levenservaringen ook onderzocht met behulp van de definitie van veerkracht uit de theorie van complexe systemen. Volgens deze theorie is het geheel meer dan de som der delen en creëren de interacties tussen elementen samen een nieuw systeem. Het brein is een goed voorbeeld van zo'n complex systeem" de hersenen vormen een complex systeem van neuronen en andere cellen, maar de werking van de hersenen kan niet worden bestudeerd door te focussen op individuele neuronen. Een ander voorbeeld is een aandelenmarkt waar bedrijven

kunnen slagen of falen. Marktschommelingen kunnen echter niet worden verklaard door hoe goed individuele bedrijven het doen; hiervoor moet naar de economie als geheel gekeken worden. Dergelijke complexe systemen kunnen ingrijpende veranderingen ondergaan: klimaten verschuiven, bijvoorbeeld van ijstijden naar opwarming van de aarde, ecosystemen verschuiven van een bosstaat naar een moerasstaat en financiële markten storten in (24,60,69). Een intrigerend kenmerk van complexe systemen is dat deze veranderingen op dezelfde manier kunnen worden voorspeld voor verschillende systemen, ook al vinden dergelijke veranderingen plaats door talrijke kleinere interacties die per systeem verschillen. De waarschijnlijkheid van een omslag in een systeem hangt samen met de veerkracht van het systeem. De aanname is dat de snelheid waarmee een systeem herstelt van kleine verstoringen, een indicatie geeft van de veerkracht van een systeem. Als we het voorbeeld van de aandelenmarkt gebruiken, zullen de aandelenkoersen veranderen en langzamer dan normaal terugkeren naar de gemiddelde waarde als er een omslag in het systeem nadert (24,70,71). Als dezelfde principes werken voor geestelijke gezondheid, dan kunnen we veronderstellen dat als iemand langzamer herstelt van kleine dagelijkse stressoren, diens veerkracht afneemt en het risico op psychische stoornissen dus toeneemt (72,73). In dit proefschrift hebben we bijvoorbeeld voor het eerst onderzocht of langzamer emotioneel herstel na dagelijkse stressfactoren inderdaad het risico op psychische stoornissen voorspelde.

Samenvattend, in dit proefschrift heb ik psychologische veerkracht onderzocht door te focussen op interacties tussen veerkracht factoren en tegenspoed, en daarbij specifiek in het dagelijks leven. Ik paste perspectieven uit de netwerk- en complexe systeemtheorieën toe om te onderzoeken hoe veerkracht in het dagelijks leven kan worden begrepen en hoe het veranderingen in de geestelijke gezondheid voorspelt. Hiermee wil ik ons begrip van psychologische veerkracht vergroten, nieuwe manieren bieden om deze te meten en uiteindelijk inspiratie bieden voor nieuwe diagnostische instrumenten en interventies om veerkracht te vergroten.

Studies in dit proefschrift

In hoofdstuk 2 hebben we de interacties tussen beschermende factoren en stress onderzocht. Om precies te zijn hebben we onderzocht hoe een aantal vermeende veerkracht-verhogende factoren de stress die veroorzaakt wordt door het hebben van psychotische ervaringen kunnen verminderen. Omdat psychotische ervaringen vooral een negatieve impact hebben als ze als stressvol worden ervaren, is het relevant om vooral dit stresserende effect (en factoren die dat effect kunnen voorkomen) te bestuderen (91). We ontdekten dat het hebben van een partner en het rapporteren van een hoog niveau van optimisme, zelfverbeteringen humor, openheid, extraversie en emotionele stabiliteit

de stress die door bepaalde psychotische ervaringen werd veroorzaakt, verminderde. Onze resultaten benadrukten dus het belang van het bestuderen van de interacties tussen beschermende factoren en stress.

In hoofdstuk 3 hebben we netwerken geconstrueerd van interacties tussen dagelijkse emotionele ervaringen (bv je somber of angstig voelen) en deze vergeleken tussen groepen adolescenten met en zonder een toename van psychopathologie een jaar later. We ontdekten dat een grotere invloed van positieve emoties en de afwezigheid van feedbackloops ("vicieuze cirkels") tussen negatieve emoties geassocieerd waren met een betere toekomstige geestelijke gezondheid. Deze resultaten laten zien dat het mogelijk is om veerkracht gerelateerde mechanismen in het dagelijks leven aan het licht te brengen en, belangrijker nog, dat deze verband kunnen houden met latere mentale gezondheidsniveaus.

In hoofdstuk 4 hebben we onderzocht hoe een indicator van veerkracht uit de complexe systeem theorie het beloop van geestelijke gezondheid op groepsniveau voorspelt. We definieerden deze indicator, de 'snelheid van herstel van kleine perturbaties', als de tijd die nodig was voor het terugkeren van het niveau van affect naar het gemiddelde van die persoon, na het ervaren van onaangename gebeurtenissen in het dagelijks leven. Op groepsniveau vonden we zoals verwacht dat affect langzamer herstelde bij deelnemers waarbij de geestelijke gezondheidsuitkomsten na een jaar verslechterd waren dan bij deelnemers met een stabiele geestelijke gezondheid.

In hoofdstuk 5 vergeleken we drie verschillende indicatoren van psychologische veerkracht bij mensen met milde psychotische ervaringen. De drie indicatoren zijn: een algemene inschatting van iemands vermogen om tegenslagen te overwinnen, dagelijkse ervaringen met het vermogen om tegenslagen te overwinnen en een die de snelheid van affectherstel na kleine tegenslagen in het dagelijks leven weerspiegelt (vergelijkbaar met die in hoofdstuk 4). In deze studie werden veerkrachtindicatoren op individueel niveau exploreerd. We onderzochten hoe sterk ze met elkaar correleren, hoe stabiel ze zijn over de tijd en hoe goed ze veranderingen in de mentale gezondheid voorspellen. In tegenstelling tot hoofdstuk 4 vonden we dat wanneer we op individueel niveau kijken, snelheid van herstel geen veranderingen in mentale gezondheid over de tijd voorspelt. In plaats daarvan ontdekten we dat de indicator voor het dagelijks leven veranderingen in de geestelijke gezondheid over een jaar voorspelde.

Complexe en simpele veerkrachtindicatoren en voorspelling van toekomstige geestelijke gezondheid

Een van de doelstellingen van ons project was om te onderzoeken of veerkracht veranderingen in de geestelijke gezondheid kan voorspellen. De meeste van de geteste veerkrachtindicatoren in dit proefschrift hadden enig voorspellend potentieel. In tegenstelling tot onze verwachtingen, was snelheid van herstel, de veerkrachtindicator uit de complexe systeemtheorie, wel gerelateerd aan veranderingen in de geestelijke gezondheid in hoofdstuk 4 maar niet in hoofdstuk 5.

In de studie die beschreven wordt in hoofdstuk 5 bleek het gemiddelde dagelijkse ervaren vermogen om “te verwerken wat op mijn pad kwam” de beste voorspeller van herstel te zijn. Het is interessant dat zo'n "simpele" indicator beter presteerde dan de complexere maar ogenschijnlijk objectievere herstelsnelheid. Het is mogelijk dat de herstelsnelheid delen van het proces achter veerkracht weerspiegelt, terwijl een eenvoudig vermogen om "om te gaan met wat op mijn pad kwam" het resultaat is van alle processen. De complexe indicator kan de vraag: "hoe snel is de veerkracht bereikt" beantwoorden, en de eenvoudige de vraag: "hoe hoog is het niveau van veerkracht” (272,273). Het algehele niveau van veerkracht komt voort uit meerdere onderliggende processen, waarvan de snelheid van herstel slechts een deel weerspiegelt. Hoewel het niveau van veerkracht de meest complete maat van het concept en de beste voorspeller van herstel is, kunnen complexere maten nodig zijn om de precieze processen te ontrafelen die tot dit niveau van veerkracht hebben geleid. Daarom kunnen ze, ondanks de uitdagingen bij het construeren en valideren van dergelijke maten, nog steeds essentieel zijn voor het ontwikkelen van nieuwe interventies om de psychologische veerkracht te vergroten. Met andere woorden, deze twee maten voor veerkracht lijken verschillende doelen te dienen.

Veerkracht begrijpen als interacties tussen beschermende factoren en tegenspoed

Veerkracht is per definitie een proces dat in gang wordt gezet door het hoofd te bieden aan tegenspoed, welke vorm de tegenslag ook mag aannemen (284). Daarom wilden we de beschermende werking van veerkracht onderzoeken in de context van tegenspoed. In de studies in dit proefschrift was dat meestal het ervaringen van stress: het ervaren van psychotische ervaringen als stressvol of het ervaren van dagelijkse stressvolle situaties. Onze resultaten suggereren dat verschillende veerkrachtmechanismen een antwoord kunnen bieden op de verschillende niveaus van tegenspoed. Hoofdstuk 4 liet bijvoorbeeld zien dat herstel van dagelijkse micro-stressoren (kleine dagelijkse vervelende situaties, zoals bijvoorbeeld gemorste koffie, file, te laat komen op een vergadering) verband hield met toekomstige geestelijke gezondheid, terwijl de resultaten in hoofdstuk 5 suggereren

dat het herstel van een potentieel grotere stressor ("de meest stressvolle gebeurtenis van de dag", bijvoorbeeld een ruzie met een partner of hevige hoofdpijn) geen veranderingen in de geestelijke gezondheid voorspelde.

Voor nog grotere stressoren, zoals ernstige ongunstige levensgebeurtenissen, bufferde geen van de veerkrachtindicatoren het effect van belangrijke levensgebeurtenissen op het niveau van toekomstige symptomen. Dit is een intrigerende bevinding, aangezien het gemiddelde niveau van "ik kon vandaag aan wat op mijn pad kwam" sterk samenhing met toekomstige geestelijke gezondheid. Het is mogelijk dat het item "ik kon vandaag aan wat op mijn pad kwam" vooral het dagelijkse veerkrachtige functioneren weerspiegelt en niet hoe men reageert op grote of chronische stressoren. Een persoon kan bijvoorbeeld van slag zijn door een sterfgeval en tegelijkertijd menen met succes om te gaan met dagelijkse beslommeringen. Dit benadrukt het feit dat veerkracht, evenals stress, een multidimensionaal begrip is.

Interessant is dat onze resultaten suggereren dat de veerkrachtgerelateerde processen op het niveau van het dagelijks leven, dat wil zeggen het omgaan met kleine stressoren, cruciaal zijn voor de ontwikkeling en vermindering van symptomen van psychopathologie. Dit idee sluit aan bij het groeiende aantal stressonderzoeken naar de opgetelde belasting van lichte maar chronische stressoren en hun nadelige effect op de mentale en algemene gezondheid (39,40,274). Daarom geloof ik dat elk onderzoek naar psychologische veerkracht baat zal hebben bij een zorgvuldige afweging of de tegenslag en de voorgestelde aan veerkracht gerelateerde factoren op hetzelfde niveau functioneren.

Veerkracht in het dagelijks leven

De bovenstaande resultaten tonen de relevantie van het bestuderen van potentiële veerkrachtmechanismen op het niveau van het dagelijks leven. Een van de centrale concepten die verband houden met veerkracht is het "vermogen om terug te veren" (284). Op het dagelijkse niveau kan dit worden beschouwd als een snel herstel van negatieve emoties na blootstelling stressoren en het zelf gerapporteerde vermogen om met deze stressoren om te gaan. Toegepast op mentale gezondheid, kunnen we dergelijke transities begrijpen als klinisch relevante veranderingen in het niveau van symptomen, zoals van een psychisch gezonde naar een psychisch ongezonde toestand en vice versa (60) (291). Op zijn beurt kan het herstel van verstoringen worden begrepen als emotionele stoornissen na stressvolle ervaringen.

Dicht bij het idee van terugveren ligt het concept van persistentie van negatieve emoties (190,285). In hoofdstuk 3 hebben we dit construct onderzocht door de dynamiek van gemoedstoestanden te bestuderen, met de nadruk op onderlinge verbanden tussen negatieve emoties. We ontdekten dat negatieve emoties een wisselwerking met elkaar aan

gaan, waardoor zelfversterkende spiralen kunnen ontstaan. Dergelijke vicieuze cirkels voorspelden een slechter beloop van psychopathologie. Het lijkt erop dat mensen vast kunnen komen te zitten in deze zichzelf versterkende staten van negatief affect en dat een dergelijk proces bijdraagt aan de ontwikkeling van psychopathologische symptomen. Dat zou betekenen dat het ontbreken van vicieuze cirkels in iemands patroon van negatieve emoties kan worden beschouwd als een beschermende factor voor psychopathologie. Dit benadrukt het belang van het herkennen en doorbreken van dit soort vicieuze cirkels in het behandelen van (vroege) psychische klachten.

Veerkracht als de immuniteit voor de geestelijke gezondheid

Onze resultaten suggereren dat we, om ons begrip van veerkracht te vergroten, zorgvuldig moeten nadenken over de aard en omvang van zowel stressoren als beschermende factoren en de tijdschalen waarop deze bestaan. Het creëren van een overkoepelende definitie van veerkracht en het functioneren ervan is hiervoor essentieel. Intuïtief is het concept van veerkracht duidelijk - het is wat ons beschermt tegen de schadelijke effecten van tegenspoed - maar dit idee kan niet worden gebruikt om onze kennis over dit onderwerp systematisch te organiseren. Daarom stel ik voor om een meer integratieve benadering van Davydov en collega's te volgen om veerkracht te definiëren als een mentale immuniteit.

Vanuit deze benadering lijkt psychologische veerkracht in meerdere opzichten op het somatische immuunsysteem. Zo geldt voor beide vormen van immuniteit dat ze worden bepaald door zowel persoonsgebonden als sociale en maatschappelijke factoren. Persoonsgebonden factoren die van invloed zijn op van beide soorten immuniteit zijn bijvoorbeeld (epi)genetische kenmerken en persoonlijkheidstrekken zoals optimisme, emotionele stabiliteit een gezonde levensstijl. Sociale en maatschappelijke factoren omvatten onder meer interpersoonlijke relaties en steun van de gemeenschap.

De manieren om veerkracht te meten die in dit proefschrift gebruikt zijn passen bij de visie dat veerkracht overeenkomsten vertoont met somatische immuniteit. In hoofdstukken 4 en 5 hebben we indicatoren gecreëerd voor het algehele niveau van veerkracht, die grofweg overeenkomen met het eiwit CRP (C-reactief proteïne) om de somatische immuunrespons te meten (298). In hoofdstukken 2 en 3 hebben we persoonsgebonden beïnvloedende factoren en ervaringen onderzocht, analoog aan het bestuderen van de fysiologie van cellulaire en weefselontstekingsreacties.

Het hierboven beschreven immuniteitskader legt ook een kritieke kwestie bloot. Het grootste deel van het huidige onderzoek naar veerkracht in de geestelijke gezondheid, inclusief dit proefschrift, richt zich op persoonsgebonden factoren en ervaringen (235). Factoren die verband houden met de samenleving, of het nu gaat om interpersoonlijke

relaties of beschikbare middelen voor het zorgsysteem, worden zelden onderzocht in veerkrachtonderzoek in de psychiatrie (235). Bij het begrijpen en bevorderen van mentale gezondheid kan men zich echter afvragen of het voldoende is om het onderzoek vooral op individuele factoren te richten, omdat contextuele factoren (d.w.z. maatschappelijke factoren, middelen die mensen hebben, acute en chronische stressoren waarmee mensen worden geconfronteerd) cruciaal zijn voor de veerkracht en mogelijk zwaarder wegen dan individuele factoren (25,29,299). Een optimaal en compleet begrip verkrijgen van psychologische veerkracht wordt belemmerd als maatschappelijke factoren niet meegenomen worden. t. Een optimistisch en emotioneel stabiel persoon uit een arme buurt zou bijvoorbeeld langzamer kunnen herstellen van tegenslag dan een pessimistisch en neurotisch persoon uit een rijke buurt. Dit is dan een gevolg van de beperkte middelen waar de arme persoon toegang tot heeft, uitgaande van zaken als toegang en tijd voor lichaamsbeweging en een goede nachtrust. Als contextuele factoren echter niet in een studie worden meegenomen, lijkt het alsof optimisme en emotionele stabiliteit geen positieve relatie met veerkracht hebben.

Conclusie

Onze resultaten benadrukken de relevantie van het bestuderen van veerkracht in directe interactie met tegenspoed, longitudinaal en prospectief, en vanuit de dynamiek van dagelijkse ervaringen. Sommige dagelijkse veerkrachtpatronen weerspiegelen specifieke mechanismen die betrokken zijn bij veerkracht (d.w.z. reacties op stressoren), anderen de toestand van het systeem als geheel (d.w.z. het niveau van veerkracht). Sommige van de beschreven indicatoren zouden verder getest kunnen worden voor gebruik in diagnostische en prognostische instrumenten; anderen zijn eerder relevant om mechanismen te ontrafelen die ten grondslag liggen aan veerkracht en zo bij te dragen aan de ontwikkeling van veerkracht verhogende interventies. Op basis van de resultaten die in dit proefschrift beschreven staan denk ik dat psychologische veerkracht het best kan worden begrepen als mentale immuniteit: een complex systeem dat de geestelijke gezondheid beschermt, net zoals het immuunsysteem dat doet voor de lichamelijke gezondheid. Dit raamwerk kan worden gebruikt om nieuwe hypothesen en onderzoeksvragen te genereren.

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ABOUT THE AUTHOR

Anna Vladimirovna Kuranova was born on June 1, 1991, in Moscow, Russia. After finishing high school in 2008, she started her medical doctor specialist program at Moscow State University, at the Faculty of Fundamental Medicine. She worked as a research assistant on immunology, endocrinology, and mental health projects alongside her studies. She was awarded several scholarships for excellent academic performance, scientific research, and leadership skills. For her graduation thesis, she studied the healthcare-seeking behavior of patients with non-psychotic mental disorders. After finishing her medical education (cum laude) in 2014, she took a gap year. She worked as a medical editor for the national TV program promoting medical literacy. After that time, in 2015, she received an Orange Tulip scholarship for a research master's program in Clinical and Psychosocial Epidemiology at the University of Groningen and moved to the Netherlands. During her research master, she finished the Master Honors College program at the University of Groningen and participated as a scientific consultant and editor in a non-profit project, "Equality," which promoted the popularization of science and gender equality. She wrote her graduation thesis with Prof. Marieke Wichers and Dr. Hanneke Wigman. Her thesis studied associations between micro-level affect dynamics and the future course of psychopathology in adolescents. For this work, she received the best poster presentation award at the "Psychiatry and public health" section of The International Student Congress Of (bio)Medical Sciences conference in 2017. After her masters, she was granted a PhD scholarship and position at the University of Groningen. In 2017, she started her PhD on dynamical approaches to studying psychological resilience in the Interdisciplinary Center of Psychopathology and Emotion regulation at University Medical Center Groningen. Her team of supervisors expanded with the participation of Dr. Sanne Booij and Prof. Tineke Oldehinkel. Next year Anna was awarded a travel grant for a short talk at the 4th International Symposium on Resilience Research 2018, Mainz, Germany. She received an award for top publication from the research school and a 1-st place Jury Award for the photography contest "Portrait your research" at PhD day Groningen, 2018. That photograph is displayed on the cover of this book. Moreover, she organized several events, including the annual research school conference "SHARE day," and supervised a successful research master thesis. Anna is an open science enthusiast and was the first researcher to publish an article as a registered report in her department.

In addition to PhD project, in 2021, Anna started a second professional training program in psychology and psychotherapy, which she is currently attending. In 2022, Anna began working as a postdoctoral researcher in Radboudumc, Nijmegen, in the national COVID19 Outcomes in Older People (the COOP) study with Dr. René Melis, Dr. Bas Bredie, and Dr. Geeske Peeters. Her role in the projects involves studying physical resilience and metabolomics health profiles in elderly patients with COVID. Anna is dedicated to continuing her involvement in research and social initiatives to improve individuals and communities' psychological and physical resilience and well-being.

SUPPLEMENTARY MATERIALS

Supplementary materials for Chapter 2

Table S1. Distribution of filled in modules and percent of missings in the total sample and across subsamples of PEs

Modules	Total sample		Bizarre experiences subsample		Delusional ideations subsample		Perceptional anomalies subsample	
	N	% NA	N	% NA	*N*	*% NA*	*N*	*% NA*
Having a partner	2870	0	1127	0	2735	0	353	0
Having a pet	2770	3.48	1082	3.99	2640	3.47	339	3.97
LOT-R	2565	10.63	995	11.71	2445	10.60	309	12.46
Humor Style Questionnaire	2593	9.65	1002	11.09	2471	9.65	312	11.62
NEO Five Factor Inventory	2719	5.26	1068	5.23	2595	5.12	338	4.24

Table s2. Spearman's rank correlation test for Distribution of the associations between protective factors and frequency of PEs (CAPE A) per subsamples of PEs.

Protective factors	Bizarre experiences subsample		Delusional ideations subsample	
	rho	*P-value*	*rho*	*P-value*
Optimism	0.01	0.06	0.05	0.01
Affiliative humor style	-0.06	0.004	0.04	0.03
Self-enhancing humor style	-0.06	0.002	0.03	0.12
Extraversion	-0.07	<0.001	-0.04	0.03
Agreeableness	-0.07	<0.001	-0.15	<0.001
Conscientiousness	-0.12	<0.001	-0.13	<0.001
Openness	0.07	<0.001	0.23	<0.001
Emotional stability	-0.23	<0.001	-0.25	<0.001

Note. that the p-values were not corrected for multiple testing

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Authors' contributions: AK, JW, SB, and MW formulated the research hypothesis and questions. PJ, BJ, KW, and JW participated in data collection and study design. PJ and BJ contributed to data management. JW and AK managed literature searches and statistical analyses and wrote the first version of the manuscript. SB and MW participated in editing and finalizing the manuscript. All authors have contributed to and have approved the final manuscript. We thank Drs. Hans Burgerhof, who kindly advised on some aspects of statistical analysis

R script for this Chapter is not included in the dissertation for readability and is available online.

Supplementary materials for Chapter 3

S1 Table. The network connections between ESM variables based on the B-coefficients from the autoregressive multilevel regression models and 95% confidence intervals for B-coefficients

The Stable group

		To					
		Cheerful		*Relaxed*		Energetic	
		B	CI	B	CI	B	CI
From	Cheerful	.16*	.10-.21	.10*	.04-.16	.07*	.02-.11
	Relaxed	.01	-.02-.07	.07*	.01-.13	.04	-.00-.08
	Energetic	.07*	.05-.17	.06*	.01-.13	.22*	.16-.28
	Irritated	-.04	-.06-.03	-.01	-.06-.03	.00	-.04-.05
	Down	-.06	-.08-.05	-.00	-.05-.05	-.04	-.10-.02
	Lonely	-.03	-.07-.03	-.04	-.08-.01	.01	-.04-.05

The Increase group

		To					
		Cheerful		Relaxed		Energetic	
		B	CI	B	CI	B	CI
From	Cheerful	.12*	*.06-.19*	.05	*-.00-.10*	.07*	*.02-.11*
	Relaxed	.05*	*.00-.10*	.03	*-.03-.09*	.03	*-.02-.08*
	Energetic	.15*	*.09-.20*	.07*	*.02-.13*	.13*	*.08-.19*
	Irritated	-.00	*-.04-.04*	-.01	*-.05-.04*	-.01	*-.05-.03*
	Down	-.05	*-.11-.01*	-.00	*-.07-.06*	-.04	*-.10-.01*
	Lonely	-.03	*-.08-.02*	-.04	*-.10-.01*	-.02	*-.08-.03*

Note. * - p-value was smaller than 0.05

S2 Table. Results of the permutation test

Measure	**The Stable Group**	**The Increase Group**	**Group difference**		**P-value**
			Diff.	%	
Negative connectivity	0.17	0.34	0.18	207	0.43
Positive on negative	0.24	0.15	0.09	159	0.67
Negative on positive	0.16	0.22	0.06	132	0.82
Out-strength Cheerful	0.33	0.17	0.16	197	0.28
Out-strength Relaxed	0.1	0.12	0.02	120	0.72
Out-strength Energetic	0.26	0.35	0.09	133	0.58

Note: "negative connectivity" refers to the strength of the network connections between negative affect states; "positive on negative" and "negative on positive" refers to the overall effect of the positive states ('cheerful,' 'relaxed,' 'energetic') on the negative states ('irritated,' 'down,' 'lonely') and vice-versa;

To						
	Irritated		*Down*		*Lonely*	
	B	*CI*	*B*	*CI*	*B*	*CI*
	-.04	-.09-.01	-.06*	-.10-(-.02)	-.03	-.08-.02
	.02	-.03-.07	-.03	-.07-.01	-.00	-.05-.04
	-.03	-.09-.02	-.04	-.09-.00	-.00	-.06-.05
	.10*	.05-.16	.04	-.00-.08	.02	-.02-.06
	-.01	-.07-.06	-.06	-.00-.12	.05	-.00-.11
	-.01	-.06-.04	.00	.00-.07	.05	-.00-.11

To						
	Irritated		Down		Lonely	
	B	CI	B	*CI*	*B*	*CI*
	.03	-.02-.08	-.00	-.04-.04	-.03	-.07-.02
	-.01	-.07-.05	-.01	-.04-.03	-.00	-.05-.04
	-.09*	-.15-(-.03)	-.03	-.08-.02	-.02	-.07-.03
	.09*	.03-.15	. 06*	.02-.09	.01	-.03-.04
	.05	-.03-.12	.13*	.08-.19	.11*	.06-.16
	-.01	-.06-.05	.08*	.06-.13	.10*	.03-.16

S3 Text. A detailed explanation of the calculations for the aims of the study

Our first aim was to examine whether the network of the Increase group had stronger connections between negative affect states than the network of the Stable group. For this aim, models were fitted with the original groups, and the difference in negative connectivity between the groups was calculated using the permutation test. We calculated the sum of all connections between negative states (real values of all the possible paths *between* the nodes 'irritated,' 'down,' and 'lonely,' excluding autocorrelations) for the Increase group and subtracting that from the sum of the connections between negative states for the Stable group. After that, group labels ('Stable' or 'Increase') were randomly reassigned to the participants, and models were fitted again to those new random groups. This procedure was repeated 10,000 times; in this way, the permutation distribution of the possible group differences was created. After that, the observed group differences were compared to the permutation distribution to obtain p-values. A more detailed explanation of the procedure may be found elsewhere (171).

Our second aim was to investigate the difference in the influence of positive affect states in the networks. For this, we used two approaches. First, we evaluated out-degree centrality for all three positive nodes ('Cheerful,' 'Relaxed,' and 'Energetic') for the two groups separately. Out-degree centrality represents the strength of outward connections from this node to the others. Out-degree was calculated as the sum of the absolute values of all outgoing connections (excluding autocorrelation) for each positive node. Therefore, a high out-degree means that this node has more influence on other nodes in the network. For this comparison, we also used the permutation testing with the above-described procedure, using the differences in the out-strengths of the positive affect states instead of negative connectivity (i.e., out-degree for 'cheerful' in the one group was compared with out-degree for' cheerful' for the other group, and so on), and tested these differences with the permutation test using 10,000 permutations. Second, we calculated the sum of all connection values from the positive affect states to the negative affect states and vice versa. We used the real values instead of the absolute values because we wanted to see only the suppressing effect: if some nodes upregulated the nodes with opposite modality, it would have canceled out a part of the overall effect. Then these differences between groups were also tested with the same permutation procedure with 10,000 permutations.

Our final aim was to explore the dynamic structure of the networks in terms of the potential in the network to end up in possible vicious cycles. For this purpose, we visualized only the significant connections (based on the p-values obtained from the multilevel mixed models) and evaluated the resulting structures of the networks visually.

S4 Text. Limited multiverse analysis

In the current work, the group allocation was based on the tertiles of the change in SCL-90 symptoms. Such allocation was to use as many participants as possible and come up with the groups with the same starting level of symptoms and different future symptoms trajectories. However, the cutoff between groups and precise group allocation was somewhat subjective and depended on the algorithm used in the R-function (*xtile* from 'stata' package by M. Gomez, link). Therefore, there were many alternative possible group allocations with different cutoff scores.

Thus, to explore to what extend the cutoff for the SCL-90 scores for creating the different groups influences the results, we performed a limited multiverse analysis (based on Steegen et al., 2016 (203)), restricted only to different choices with regards to group allocation. Thus, we created all potential alternative "Stable" and "Increase" groups based on the different cutoff scores of SCL-90 change, with the following parameters. Each group should have (i) at least 70 people (power restriction), (ii) comparable levels of SCL-90 scores and mean level of all six affect states at baseline, and (iii) different levels of SCL-90 scores at follow-up. After that, as the main findings of our study lie in visual assessment of the group networks (with only significant edges visualized), we have created such networks for all possible group combinations. For each network, we specified (i) the number of possible vicious cycles, (ii) the number of nodes in the negative "cluster," (iii) the number of downregulating paths from positive cluster to negative one or separate negative nodes.

Results: There were 29 possible group allocations. For all versions of "Increase groups," the network structure remained almost similar, with three interconnected negative nodes in one negative cluster comprising possibilities for a "vicious circle." The networks for "Stable" groups had more variations but (almost) all had a similar structure to the one reported in the main analysis and fitted the pattern of (almost) absence of "vicious" cycles, fewer negative clusters and connections, and more downregulating connections from positive cluster to negative nodes. Specifically, only one (~3.5%) contained the possibility for a "vicious cycle" among these networks. Eight (~27.6%) networks of a "stable" groups contained upregulating connections between any three negative nodes (without forming self-reinforcing loops, i.e., two connections and three nodes, e.g., from "Lonely" to "Down" and from "Irritated" to "Down"). 14 (~48.3%) networks of a "stable" groups contained upregulating connections between any two negative nodes (i.e., one connection between two nodes, e.g., from "Lonely" to "Down"; except for the network with "vicious cycle" containing two connections between two negative nodes), and seven (~24.1%) contained no connections between negative nodes and therefore no negative cluster at all. Moreover, all networks of both groups contained downregulating connections from a positive cluster to at least one negative node. However, among 29 networks of "stable" groups, 11

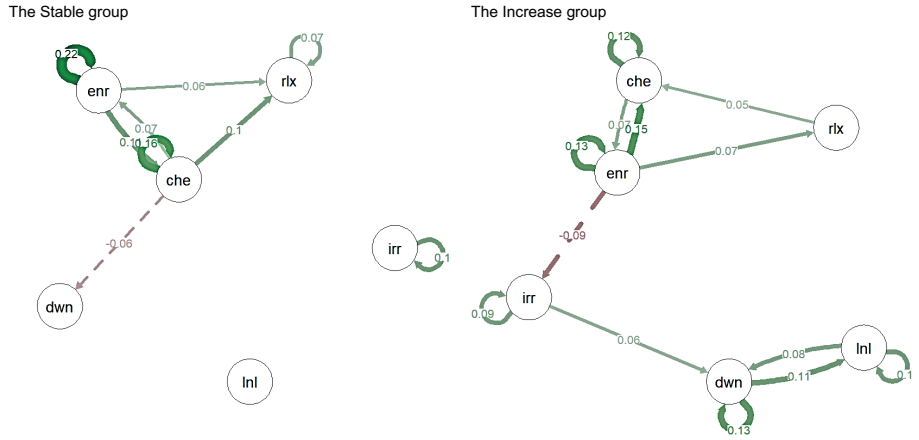
(~37.9%) contained two downregulating connections from positive clusters to negative nodes, whereas all the networks of "increase" groups contained only one such connection. Table S3 shows the combinations of group networks and their characteristics. Because all networks of the "Increase" group were similar, only characteristics of "Stable" groups are presented in table s3.

S5 Table. All possible networks of "stable" and "increase groups" and characteristics of the "stable" groups.

Table S5 was not included in the dissertation due to its length and can be accessed online at https://doi.org/10.1371/journal.pone.0247458.s003

S6 Text. R script. R script was not included in the dissertation due to readability and can be accessed online at https://doi.org/10.1371/journal.pone.0247458.s006

S7 Figure. Networks of affect states: all paths



In this figure, affect states networks are visualized for the Stable and the Increase groups. All paths are presented without considering their statistical significance. Presented are temporal networks, meaning that the connections represent the effect of the variable at time point t-1 on the variable at the time point t. Solid green edges represent positive connections from one node to the other, meaning that the increase in one node variable at time point t-1 is associated with increase in the other variable at time t. Dashed red edges represent negative connections, meaning that the decrease in one node variable at time point t-1 is associated with decrease in the other variable at time t. Circular edges represent autocorrelations, i.e. the effect of the variable at time point t-1 on itself at t. 'Che' - 'cheerful', 'rlx' -'relaxed', 'enr' -'energetic', 'dwn' -'down', 'irr' -'irritated', 'lnl' - 'lonely'.

Supplementary materials for Chapter 4

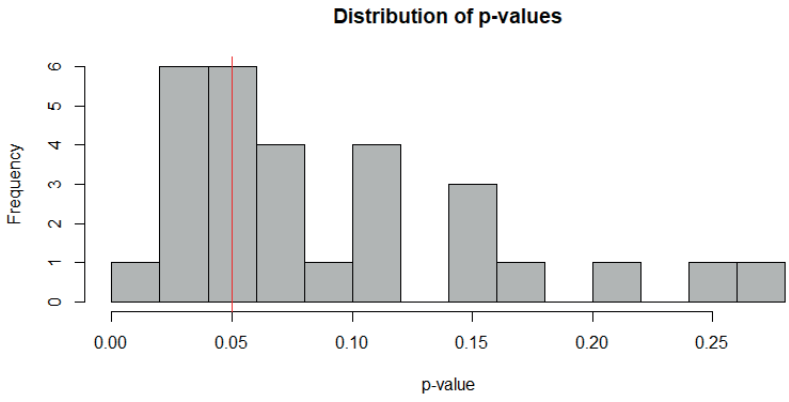
Limited multiverse analysis

In the current work, the group allocation was based on the tertiles of the change in SCL-90 symptoms. Such allocation was to use as many participants as possible and come up with the groups with the same starting level of symptoms and different future symptoms trajectories. However, the cutoff between groups and precise group allocation was somewhat subjective and depended on the algorithm used in the R-function (*xtile* from 'stata' package by M. Gomez, link). Therefore, there were many alternative possible group allocations with different cutoff scores.

Thus, to explore to what extend the cutoff for the SCL-90 scores for creating the different groups influences the results, we performed a limited multiverse analysis (based on Steegen et al., 2016), restricted only to different choices with regards to group allocation. We needed to repeat the analysis for all possible group allocations. In order to simplify the process, we also restricted the analysis to one model for the time point at which the difference between groups was statistically significant. Thus, we tested all possible combinations of potential alternative "Stable" and "Increase" groups based on the different cutoff scores of SCL-90 change, with the following parameters: (i) the groups, should have at least 70 people and (ii) have comparable levels of SCL-90 scores, affect and unpleasant event levels at baseline, and (iii) different levels of SCL-90 scores at follow-up. After that, the p-values obtained from these analyses were plotted, and the distribution was assessed visually based on the following principle: If an effect is absent, the distribution of the p-values is expected to be flat because each p-value is equally probable in the absence of an effect. If an effect is present, the distribution will be skewed to zero, as the probability of low p-values is higher.

Results: There were 29 possible group allocations. As the Stable and Increase groups differed significantly in the effect of unpleasant events on negative affect at t-1, we have modeled the group difference in the effect of unpleasant events on negative affect at t-1 (using equation II, see the main document) for all 29 groups. This resulted in 29 p-values. 11 of them were <0.05. The distribution of p-values is presented in figure s1. The figure shows the skewed to zero distribution. This result can be interpreted as the robustness of the effect to the subjectivity of the group allocations.

Figure s1. Distribution of p-values for the group difference in the effect of unpleasant events on negative affect at t-1 for all 29 possible groups.



In this figure, the x-axis depicts the size of the p-values obtained from the model of the effect of unpleasant events on negative affect at t-1 for 29 possible groups, and the y-axis depicts the frequency of these p-values.

Supplementary R script was not included in this dissertation for readability and can be found online.

Supplementary materials for Chapter 5

Imputation strategies comparison

To construct Daily Resilience and Recovery Speed indicators, we imputed the missing diary data before the analysis. For that, first, we have chosen the optimal approach for the current dataset, which was decided by comparing six imputation strategies: two multiple imputation strategies (MICE; (308) and Amelia (309)) and four single imputation strategies (mean imputation, Kalman smoothing (310), Exponential moving average, Linear moving average (311)). The procedure and results of the comparison are explained below.

From 96 participants, six had complete diary data at T0 for all 90 time-points. To resemble the missing patterns of data from other 90 participants (mean = 9% of missing data points, min = 0%, max = 23%), 5%, 10%, and 25% of data points were randomly deleted from data of these six individuals. Next, the six imputation strategies were performed with 1000 iterations for these randomly deleted data points for the diary items used in the current paper. Namely, the item "Today I could handle what came my way" was used for Daily Resilience. For Recovery speed, items "I felt apathetic today," "I felt tired today," "I felt down today," "I felt anxious today," "I felt restless today," "I felt irritable today," "think about the most important negative event of today" followed by "how unpleasant was this event?" were used. After this, the differences between the averaged imputed values for 1000 iterations, and actual values were calculated by mean squared errors per imputation strategy. The imputation strategy Exponential moving average showed the smallest mean squared error and was therefore chosen as imputation strategy.

Construction of Recovery Speed indicator

All analyses were performed in R, version 4.1.0, using the 'vars' package for the VAR modeling (312). First, the lagged associations between the unpleasantness of negative events and negative affect scores were estimated using vector-autoregressive modeling. The VAR model consisted of a set of multivariate regression equations of the system of two variables, where each variable was regressed on the time-lagged values of itself and the other variable. That is, levels of negative affect at time t were predicted by negative affect scores at measurement occasions t_{-1}; t_{-2}; - t_{-p} and by the unpleasantness of the negative event at measurement occasions t_{-1}; t_{-2}; - t_{-p}. The time lag between t-1 and t was one day in this study, between t-2 and t two days, and so on.

This model was fitted for each individual separately. The number of estimated lags depended on the best AIC criterion for each individual[18]. All models were tested for three assumptions. The stationarity assumption means that the residuals' mean, variance, and autocorrelation structure do not change over time. The homoscedasticity assumption states that residuals are similar across different values of independent variables. The white noise assumption holds that residuals are not correlated. When these assumptions were violated, several strategies were implemented: the individual number of lags was decreased or increased, a lagged version of one or two variables was added, an exogenous variable (e.g., time trend or day of the week) and/or dummy variable indicating outliers were added[19]. The individual was omitted from the analysis if none of those mentioned above or alternative solutions solved the unmet assumption.

The impulse-response function and AUC

Impulse response function (IRF) analysis (265) allowed us to model how a system reacted to a shock. One variable was given an instantaneous impulse, and we then examined how this shock propagated through the system and impacted the other variables over time. Concerning our research questions, IRF is ideally suited to simulate the pattern of affect recovery after negative events. This function allows us to simulate a shock of one SD of the unpleasantness of the events and model the pattern of negative affect recovery over several lags. In this study, we chose to simulate response for 14 time points, including the contemporaneous association[20].

Since we were interested in the effects of an increase in negative (unpleasant) events on negative affect, both on the same day as well as on the following days, the orthogonalized impulse response function (OIRF) was used (313). A limitation of the OIRF is its sensitivity to the order of the same day (lag 0) variables in the VAR model; therefore, it is not possible to disentangle the directionality of the lag 0 effects. In this study, we choose the following order; negative event at lag 0 leading to lag 0 negative affect. This consideration is covered in more detail in the limitations paragraph of the Discussion section.

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18 Please note that the Registered Report contained different strategy: "The number of estimated lags depended on the AIC criterion for each individual with a maximum of three. Three lags were chosen as we deem it unlikely that unpleasant daily events four days ago explain current negative affect above and beyond negative affect and other unpleasant events over the past three days. However, if the AIC criterion will favor more than three lags for more than 20% of the individuals under study, we will increase the maximum number of lags for all individuals. The reason for the change in the final version was the optimization of the analytical approaches that allowed to estimate the best lag for each individual separately, thus increasing model fit by further tailoring them to individual data.

19 Please note that the listed solutions differ from the Registered Report, as this version was written after implementing these strategies, some of these being mentioned as "alternative solutions" in previous version.

20 Please note that this information was not included in Registered Report version.

After the IRF was modeled, the area under the function curve with respect to baseline (AUCb) was calculated with the formula proposed by Pruessner and colleagues (228). The resulted AUCb was used as the Recovery Speed indicator for this individual.

Power analysis

Most data for the current paper have already been collected, and it is impossible to increase the sample further. Thus, we estimated the power achieved with the given sample size and proposed analyses. Although we used the False Discovery Rate correction following the Benjamini–Hochberg procedure (136), for the following power analysis, the alpha-level for the tests within the family of tests were calculated based on the Bonferroni correction principle, as it is not possible to apply the Benjamini–Hochberg procedure before the results are known. Consequently, the power analysis is more conservative than necessary. All power analyses were conducted with the "pwr" (314) package.

The power analysis for the Recovery Speed index was based on the power of the VAR models. Because the purpose of VAR models in the current work is to create a personalized dynamic resilience measure, the generalizability of the associations between the unpleasantness of events and negative affect beyond the period of dairy data collection (as represented by the p-values for the B-coefficients) is irrelevant for our research questions. Moreover, exact power estimation for individual VAR models is not straightforward, as it is impossible to estimate the expected effect size, direction of causality, exact number of lagged influences, and presence of bidirectional and feedback effect. Based on previous work, 60 to 90 measurements are recommended to identify reciprocal associations between multiple variables (Bos et al., 2012; Lütkepohl, 2005; Rosmalen et al., 2012; Van Gils et al., 2014).

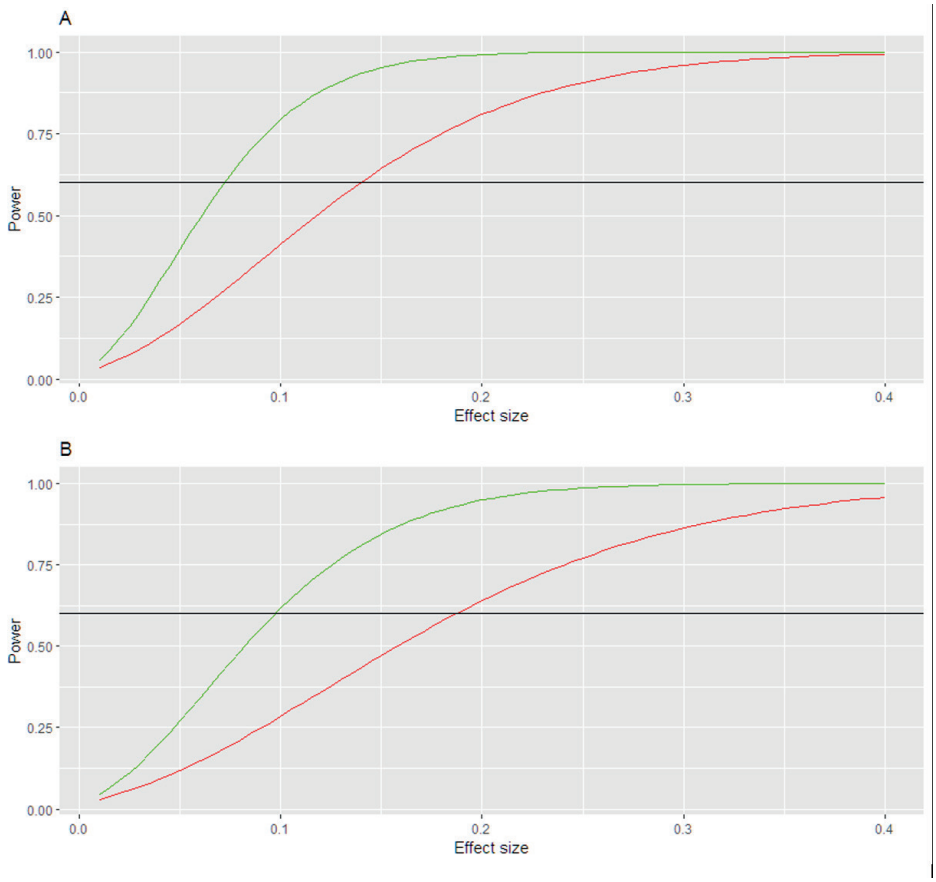
We used correlation analyses for research questions 1 and 2 on the cross-sectional and temporal associations between resilience indicators. The effect sizes were expected to range from moderate to large, given that the resilience indicators were expected to reflect different parts of the same theoretical construct. Therefore, the expected effect size of the correlation analysis was set at 0.40, based on the conventional effect magnitude by Cohen (Cohen, 1988). There were nine comparisons for these research questions, and therefore, the overall alpha for the family of tests was 0.05/9 (~ 0.0056). Additionally, the sample size differs between T0 (96[21]) and T1 wave due to the second diary study being optional and drop-out from the study (on T1 89 filled in questionnaire data from whom 68 also filled in diary data). Therefore, the power for the correlation analyses between different predictors at T0 is estimated at 0.90 and 0.75 on T1. Between the same predictors over time, the power was 0.88 for the General resilience predictor and 0.75 for Daily resilience and Recovery speed (see online for the R-script at link).

21 Please note that the number in Registered Report incorrectly stated 95

Multilevel regression analysis was used for research question 3 on the predictive value of the three resilience indicators for mental health one year later. For reasons of parsimony, we performed a power analysis separately for the unilevel model for individuals at T1 and the unilevel model for people at both T1 and T2 (ignoring the fact that the same people were assessed twice) because the power for the actual multilevel model lied between these two calculations.

Overall, there were three comparisons using alpha 0.016 (0.05/3). In these models, based on the F-test for linear regression, the degrees of freedom were represented as u, the numerator degrees of freedom, that is, the number of coefficients in the model, and v, the denominator degrees of freedom, so that n (sample size) = v+u+1. Therefore, in these models, u was four (resilience predictor, the baseline levels of mental symptoms, the number of adverse life (LTE) events between assessments, and the interaction between the LTE and resilience predictor), and the v for first follow-up was 84 (89-4-1) for the General indicator and 63 (68-4-1) for Daily resilience and Recovery speed, and 162 for both follow-ups (89+78-4-1) for General indicator and 120 (68+57-4-1) for Daily resilience and Recovery speed. We did not have theoretical expectations about the effect size (f^2), and therefore built power curves for both models:

Figure 2. Power curves for General resilience indicator (A) and Daily and Recovery speed resilience indicators (B).



In these figures, the x-axis describes the level of power for the test, and the y-axis is the effect size. The upper green line depicts the power curve for the unilevel model for data from both follow-ups, whereas the lower red line depicts the power curve for unilevel models for the data from the first follow-up only. The black vertical line corresponds to 60% power.

In sum, for the General resilience indicator, effect sizes between ~0.07 and ~0.14 (small effects) and higher could be detected with power ≥60%. For Daily resilience and Recovery speed, only effect sizes between ~0.1 and ~0.18 (medium effects) and higher could be detected, which is a major limitation, and therefore the results for this research question are considered preliminary evidence.

Descriptive statistics for daily items used to create a negative affect score

Table S1, dairy items used to create a negative affect score

	Diary data [22]		
		T0	**T1**
Apathetic	Overall mean	31.08	27.82
	Overall SD	26.78	25.66
	Between-person SD	16.6	16.2
	Within-person SD	21.0	20.0
Tired	Overall mean	45.49	43.43
	Overall SD	28.10	26.54
	Between-person SD	17.9	16.3
	Within-person SD	21.6	21.0
Down	Overall mean	30.22	24.59
	Overall SD	27.83	25.32
	Between-person SD	20.4	19.0
	Within-person SD	19.0	16.8
Anxious	Overall mean	25.34	21.11
	Overall SD	26.57	23.82
	Between-person SD	20.4	18.4
	Within-person SD	16.8	15.2
Restless	Overall mean	36.57	32.39
	Overall SD	28.15	26.11
	Between-person SD	19.8	18.1
	Within-person SD	19.9	18.9
Irritable	Overall mean	26.54	22.86
	Overall SD	25.64	23.42
	Between-person SD	18.0	15.4
	Within-person SD	18.2	17.8

Sensitivity checks details

The participant with the post-diary BRS-score

We only used the BRS data collected *before* the diary period, as the diary data collection may have influenced the BRS scores. For one participant who had not provided BRS data before the diary assessment, we used the post-diary BRS-score instead. We performed all analyses involving BRS, i.e., the General resilience indicator, with the data excluding this participant as a sensitivity check. Please note that we did not perform FDR correction here.

22 Please note that the descriptive statistics is provided for the data before imputation, with the exception for Speed of Recovery indicator which was build based on the imputed data.

Research question 1:

Spearman Rank correlations between resilience indicators and p-values for the pairwise comparisons between them for the dataset with the excluded participant who did not provide BRS data before the dairy assessment

	Spearman Rank Correlations between resilience indicators		p-values**
To	**General X Daily** Rho = 0.34* (CI: 0.15-0.51) vs Rho = 0.35* (CI: 0.16-0.51)	**General * Recovery** Rho = -0.17 (CI: -0.34-0.03) vs Rho = -0.16 (CI: -0.35-0.04)	<0.00
	General X Daily Rho = 0.34* (CI: 0.15-0.51) vs Rho = 0.35* (CI: 0.16-0.51)	**Daily * Recovery** Rho = -0.01 (CI: -0.21-0.19)	0.01
	General X Recovery Rho = -0.17 (CI: -0.34-0.03) vs Rho = -0.16 (CI: -0.35-0.04	**Daily * Recovery** Rho = -0.01 (CI: -0.21-0.19)	0.09
T1	**General X Daily** Rho = 0.30* (CI: 0.06 - 0.51)	**General X Recovery** Rho = -0.10 (CI: -0.33-0.15)	0.01
	General X Daily Rho = 0.30* (CI: 0.06 - 0.51)	Daily X Recovery Rho = -0.15 (CI: -0.38 to 0.10)	<0.001
	General X Recovery Rho = -0.10 (CI: -0.33-0.15)	Daily X Recovery Rho = -0.15 (CI: -0.38 to 0.10)	0.38

* *p*-value after FDR correction < 0.03; ** without FDR-correction; "vs. … " indicates results from the main analysis; Red indicates differences between sensitivity check and main results. General refers to General resilience indicator, Daily – to Daily resilience indicator, Recovery – to Recovery speed indicator; Rho – Spearman Rank Correlation coefficient, CI – Confidence intervals for the Spearman Rank Correlation coefficient, T0 – baseline assessment, T1 – one-year follow-up.

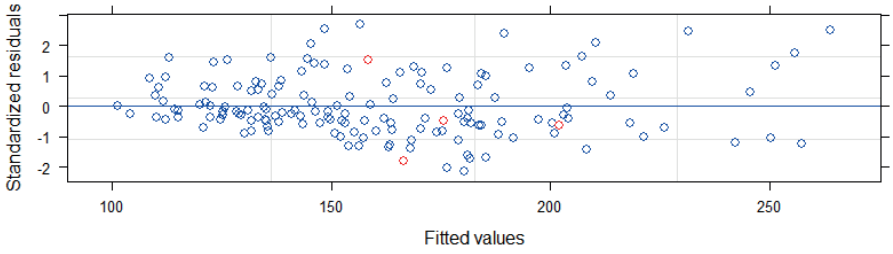
Research question 2.

The stability of General resilience calculated with the excluded participant was 0.6051 vs. 0.6070 obtained in the main analysis. We did not test differences in stabilities further due to unclearly with the best possible correction for data belonging to the same participants.

Research question 3.

B-coefficient for the General resilience calculated with the excluded participant was -8.55 with a p-value 0.07 vs. -8.04 with a p-value 0.09 obtained in the main analysis. The added observation was a possible outlier in the model. However, the residual vs. fitted analysis did not indicate that data from this participant (red) is an outlier.

Figure S1. Residual vs. Fitted diagnostic plot for the model assessing predictive validity of General resilience indicator with the highlighted data points (in red) from the participant with the post-diary BRS-score.



Exclusion of participants with lowest 25% variability in Negative affect scores.

Here we only performed analyses involving the Recovery speed indicator, as the low variability of Negative affect might have influenced only this indicator. The exclusion was performed based on T0 data. As excluding 25% of the sample inevitably changes effect sizes, we compared directions and consistency of the results.

Research question 1:

T0: Recovery speed X General resilience = -0.25 (CI: -0.453 to -0.016); p-value = 0.04

T0: Recovery speed X Daily resilience = -0.05 (CI: -0.278 to 0.184), p-value = 0.6797

T0: Difference between correlations: z-score = -0.67, p-value = 0.25

T1: Recovery speed X General resilience = - 0.09 (CI -0.36 to 0.19); p-value = 0.05

T1: Recovery speed X Daily resilience = -0.13 (CI: -0.395 to 0.153), p-value = 0.6797

T1: Difference between correlations: z-score = 0.23, p-value = 0.409

Research question 2: Stability of Recovery speed was 0.20, p-value < 0.0001; we did not perform further comparisons here due to unclearly with the best possibilities for correction for data belonging to the same participants.

Research question 3: B-coefficient for the Recovery speed calculated with excluded participants was 0.74 with a p-value 0.37 vs. -0.04 with a p-value of 0.96 obtained in the main analysis

Ethics approval and consent to participate: All participants included in the current work were aged 18 or older and provided written informed consent for participation (for details, see study protocol (257)). The study was conducted in accordance with the Declaration of Helsinki and was approved by the medical ethical committee of the University Medical Center Groningen (NL52974.042.15). The study protocol trial registration number is NL6058 (www.trialregister.nl).

Availability of data and materials: As there is a possibility to identify participants based on their clinical and intensive longitudinal diary data, the datasets generated and/or analyzed during the current study cannot be made publicly available based on European law.

Code availability: all code files are publicly available at Open Science Framework at https://osf.io/cqv7y/?view_only=18e0a63fcddc4027b827eb1ea949bb0f

Competing interests: The authors declare that they have no competing interests.

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Authors' contributions: All authors formulated the research hypotheses, questions, and analytical approaches. JW and SB participated in data collection, study design, and data management. JW, SB, BJ, and AK managed literature searches and power analyses and wrote the first version of the manuscript. AK, JW, SB, BJ, and AO participated in editing and finalizing the manuscript. All authors have contributed to and have approved the final manuscript.

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