

Resilience to potential trauma and adversity through regulatory flexibility

George A. Bonanno¹✉, Shuquan Chen¹ & Isaac R. Galatzer-Levy²

Abstract

Responses to highly aversive or potentially traumatic events are typically defined in terms of binary outcomes, most commonly the presence or absence of post-traumatic stress disorder (PTSD). However, most people exposed to trauma do not develop PTSD or other forms of psychopathology. Moreover, a binary conceptualization says little about how resilient adaptation arises. In this Review, we describe a broader approach that goes beyond binary distinctions and identifies multiple outcome trajectories following potentially traumatic events and the psychological mechanisms that inform them. We first lay out the conceptual and statistical basis for this approach and then summarize prototypical trajectories (chronically elevated symptoms, moderate symptoms that gradually worsen, acute symptoms followed by recovery and stable psychological health or resilience) as well as trajectories that account for the period before the potentially traumatic event (prospective trajectories). Next, we consider the correlates of these trajectories and note the limited capacity of these correlates to robustly predict the most prevalent resilience trajectory. We suggest that this limitation can be addressed by considering regulatory flexibility and its various components. Finally, we discuss implications from research on regulatory flexibility and resilience trajectories for developing training and intervention strategies to protect against negative effects of potentially traumatic effects.

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¹Department of Counseling and Clinical Psychology, Teachers College, Columbia University, New York, NY, USA.

²Department of Psychiatry, New York University School of Medicine, New York, NY, USA. ✉e-mail: gab38@tc.columbia.edu

Introduction

Post-traumatic stress disorder (PTSD) was formalized as a diagnostic category more than four decades ago. Since then, foundational epidemiological research has led to a broad consensus that violent or life-threatening events can result in lasting trauma-related psychopathology¹. However, the definition of traumatic stress has consistently changed across editions of the *Diagnostic and Statistical Manual of Mental Disorders*², resulting in a ‘conceptual bracket creep’³ that classifies an increasingly expanding array of aversive events as traumas. These changes reflect debate regarding the distinction between normal adaptive responses to substantial life stress and responses that might lead to intractable psychopathology.

The traditional, and still dominant, approach to defining post-traumatic stress follows the polythetic method of psychiatric nosology in which an individual must qualify for symptoms over a specified threshold in multiple domains. Although the limitations of this general diagnostic approach are well known^{4–6}, the controversy and confusion occasioned by PTSD have been exceptional⁷. The threshold for PTSD requires symptoms that have persisted in varying frequency counts across four distinct domains (hyperarousal, re-experiencing, avoidance, negative cognition and mood). Owing to its complexity, this algorithm produces large amounts of underlying heterogeneity in both the diagnostic group and the group that is defined as healthy. For example, an analysis of the most recent incarnation of the PTSD diagnosis² identified 636,120 unique symptom presentations⁸. The categorical distinction of PTSD versus no PTSD (or non-psychopathology) also obfuscates the nature of health and resilience^{9,10}. For example, individuals presenting with 18 out of 20 possible PTSD symptoms can nonetheless be categorized in the same broad population with no PTSD as individuals with few or no PTSD symptoms⁸.

Most people exposed to a potentially traumatic event do not develop PTSD or other psychological disorders^{1,11}. This is readily apparent in symptom distributions. Symptoms of psychopathological disorders, including PTSD, commonly produce a strong positive skew (Fig. 1a). From a binary, diagnosis-focused perspective, the primary area of interest is the elongated tail of the distribution, where PTSD and other forms of psychopathology tend to be located. The remainder of the population – the majority who do not develop psychopathology – are simply collapsed into a single undifferentiated group of presumed resilience. The limitation of this approach is that it fails to account for the heterogeneous nature of such a large resilient group.

In response to these limitations, researchers have increasingly sought to understand clinically relevant populations using data-driven computational approaches. Specifically, latent symptom profiles¹² and symptom networks¹³ have been used to parse cross-sectional patterning, whereas latent growth mixture modelling of symptom trajectories has been used to capture variations in adjustment over time. Trajectory modelling relies on iterative computational methods that identify ‘latent’ or not directly observable mixtures of distributions underlying a single observable distribution^{14,15}. The general principle of mixture modelling also applies to longitudinal and prospective data on stressful life events, including potentially traumatic events (Fig. 1b).

In this Review, we first summarize research that has used mixture modelling to identify trajectories of adjustment in the aftermath of potentially traumatic events and other major stressors, such as the COVID-19 pandemic. Across this research, resilience (defined as a stable trajectory of healthy functioning) has been consistently observed as the most common outcome. Next, we shift to the correlates of resilience and the so-called ‘resilience paradox’¹⁶. Specifically, we consider

that although it is possible to accurately predict the proportion of individuals exposed to trauma who are likely to show resilient outcomes, predicting which individuals will be in the resilient category is paradoxically weak. We propose that the primary reason for this paradox is that the resources and strategies associated with resilience typically exert relatively small effects owing to, among other things, situational variability and cost–benefit trade-offs. We further propose that the most effective route to resilience requires the flexible use of resources and strategies to accommodate the operative constraints of specific person–situation interactions. We next review the components of regulatory flexibility¹⁷, and consider how regulatory flexibility might be enhanced to promote future resilient outcomes. Finally, we conclude by considering methodological innovations and new approaches for future research on regulatory flexibility, resilience, and their relationship in real time.

Trajectories of resilience and dysfunction

In this section, we review research that has identified trajectories of resilience and dysfunction following potentially traumatic events and other stressors. Most of this work has relied on latent growth mixture modelling, which incorporates growth parameters into the modelling solution¹⁸ to facilitate the identification of heterogeneous patterns of responsivity and change over time.

Although an advance over static categorization, growth mixture modelling nonetheless has its own limitations. These include problems with convergence and modelling decisions that might lead to over-fitting or under-fitting trajectory classes¹⁹. Additionally, because growth modelling is probabilistic, a trajectory solution might result from factors other than those hypothesized by the researcher, such as incomplete sampling or poor measurement scaling²⁰. However, these problems can be addressed by transparency in reporting modelling decisions²¹ and, most critically, the replication of trajectory results in diverse samples¹⁴.

Prototypical trajectories

The prevailing binary view of traumatic stress that focused on the presence versus absence of a PTSD diagnosis was challenged in the early 2000s (refs. 9,22) on the basis of a growing body of evidence indicating that responses to potentially traumatic events could be more fully characterized by four prototypical outcome trajectories. First, a trajectory of emerging chronic elevations in symptoms and distress similar to chronic PTSD or other forms of psychopathology but defined by symptom frequency, severity and long-term course rather than diagnostic cut-off points. Second, a recovery trajectory characterized by initially elevated symptoms and distress that gradually decrease over time. Third, a delayed trajectory with initially low to moderate levels of symptoms and distress that gradually increase over time. Last, the most common trajectory, resilience – described by initially low levels of symptoms and distress that remain stable over time (Fig. 2). Specifically, resilience is defined⁹ as occurring when individuals in otherwise normal circumstances are exposed to a potentially traumatic event but maintain relatively stable, healthy levels of psychological and physical functioning. The resilience trajectory also encompasses positive aspects of adjustment^{9,10,22,23} and has been identified using positive metrics, such as well-being and life satisfaction^{24,25}. For example, low-symptom resilience trajectories have been linked to ratings of positive adjustment provided anonymously by close friends and relatives²⁶, comfort from positive memories of the deceased among bereaved individuals²⁷, and positive body image and sexuality among patients with breast cancer²⁸.

Myriad studies have now repeatedly identified the same four trajectories – chronic symptoms, recovery, delayed symptoms and resilience – in response to a diverse range of life stressors^{29–31}. A comprehensive review³⁰ observed these four trajectories in strikingly similar proportions across 67 trajectory analyses. Four of the analyses focused exclusively on clinical samples or samples comprising primarily individuals with high to moderate symptoms, which excluded the possibility of a low-symptom resilience trajectory²⁹. Of the 63 remaining analyses, the resilience trajectory was by far the most common pattern, observed on average in a two-thirds majority (66%) of participants across studies. Importantly, heterogeneity in the trajectory prevalence across studies was not due to the type of outcome (PTSD, depression, anxiety or general stress) or the modelling approach (latent class growth analysis, latent growth mixture modelling or mixed parameters); heterogeneity was related to the study population, such as first responder, police, military or community samples³⁰.

Prevalence of the resilience trajectory

Some of the highest prevalence rates for the resilience trajectory have come from studies of deployed military veterans^{32–36}. For example, a large-scale study that assessed soldiers before they deployed for combat operations and then repeatedly in the years after they left the military reported an 83% prevalence for the resilience trajectory³². One possible explanation for this result is that the resilient veterans had experienced less intense combat exposure. To test this idea, another study directly compared trajectories of deployed soldiers with and without substantial combat exposure within the same analysis³³. Although the prevalence of the resilience trajectory was even higher (89%) in soldiers without combat exposure, it was still very high (81%) in those with combat exposure. Perhaps the best explanation for the unusually high prevalence of resilience in these studies, even among those with substantial combat exposure, stems from the fact that soldiers are exhaustively trained prior to deployment and, therefore, are well-equipped to handle potentially traumatic experiences. Consistent with this account, comparative studies found that the resilience trajectory after disasters was more prevalent among trained professional responders (for example, police) than untrained responders (for example, construction workers)^{34,35}.

Although the prevalence of resilience is lower among people exposed to other types of potentially traumatic event without the benefit of prior training than in combat veterans, the majority still show a resilience trajectory. For example, the prevalence of resilience among civilians hospitalized for traumatic injuries, such as automobile accidents, assault or gunshot wounds, ranges from 62% to 73%^{36,37}. Similar rates have also emerged in the context of health threats, with a robust majority of individuals showing a resilient trajectory following a cancer diagnosis^{38–40}, limb amputation⁴¹, spinal cord injury⁴² and heart attack^{43–45}.

The resilience trajectory has also been found in most individuals exposed to both natural and man-made disasters, such as hurricanes, tsunamis, terrorist attacks and mass shootings²³. Among older adults residing in areas heavily impacted by Hurricane Ike, 79% showed a trajectory of low or no PTSD symptoms in the aftermath of the disaster, whereas only 16% and 5% showed chronic and delayed trajectories, respectively⁴⁶. Similarly, more than 70% of Swedish tourists exposed to the 2004 Indian Ocean tsunami remained resilient⁴⁷.

Comparable proportions have also been reported for youths exposed to disaster. For example, 70% of youths exposed to Hurricane Katrina exhibited a resilience trajectory, a smaller but substantial group

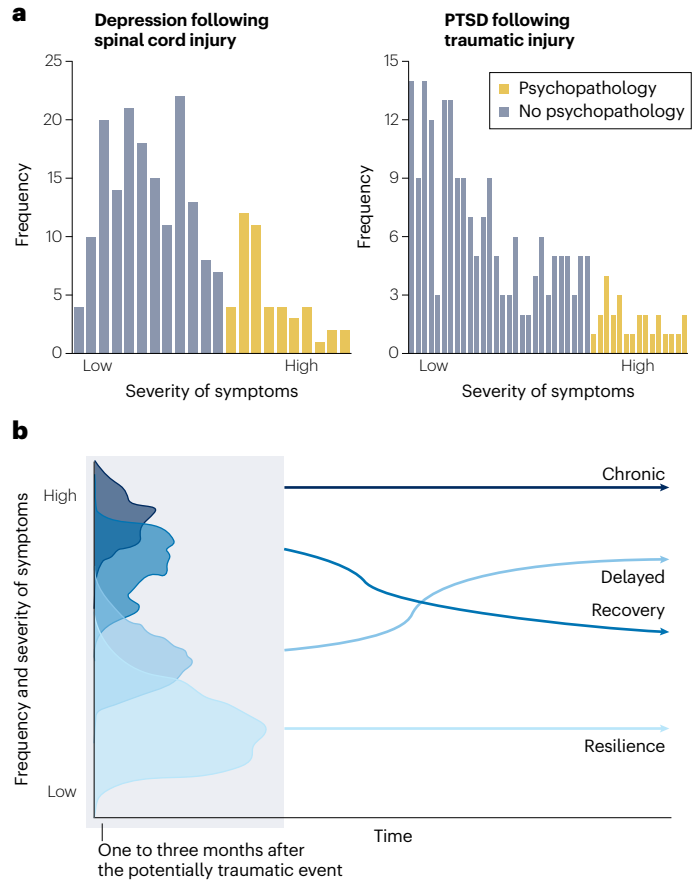


Fig. 1 | Distribution of mental health outcomes in binary and mixture models. **a**, Severity of depression symptoms following a spinal cord injury (left) and severity of post-traumatic stress disorder (PTSD) symptoms following traumatic injury (right). Binary psychopathological outcomes indicating the presence and absence of a disorder are coloured yellow and grey, respectively. **b**, Cross-sectional mixture distributions of symptom severity after a potentially traumatic event (left) and longitudinal trajectories showing four possible patterns of adaptation at follow-up (right). Graphs in panel **a** were created using data from refs. 37,42,43,52,72.

showed the recovery pattern (27%) and a relatively small group (4%) exhibited a chronic symptom trajectory⁴⁸. In the aftermath of the Wenchuan earthquake in China, one study showed that more than 80% of adolescents exhibited a resilience trajectory of low PTSD symptoms⁴⁹, and another study reported that almost 70% presented with a resilient trajectory (measured as a stable absence of sleep problems)⁵⁰. Although many college students exposed to mass violence tend to experience chronically elevated anxiety, the majority (56–61%) nonetheless evidence a resilience trajectory^{51,52}. Two disaster studies reported a lower than usual resilience rate (37% and 29%)^{53,54}. However, these studies identified two parallel trajectories with relatively low symptoms that, when combined, approximate the usual resilience prevalence.

Resilience has also been common in trajectory studies of global health events, such as the COVID-19 pandemic. A global pandemic presents especially demanding challenges because traumatic stress is often elevated, and a unique set of stressors broadly impacts multiple life domains (such as employment and living arrangements) over an

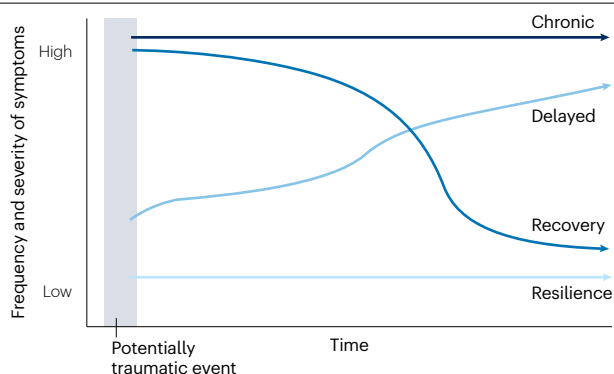


Fig. 2 | Prototypical trajectories following a potentially traumatic event. The four prototypical trajectories of response to potentially traumatic events include a chronic trajectory of prolonged elevations in symptoms and distress; a delayed trajectory of initially mild to moderate symptoms and distress that gradually worsen over time; a recovery trajectory of initially high symptoms and distress that gradually decrease to low levels; and a resilience trajectory of stable, low levels of symptoms and distress. Figure adapted with permission from ref. 9, APA.

extended period of time. At the same time, access to important protective factors such as social and economic support resources might be blocked⁵⁵. Nonetheless, research shows that during the COVID-19 pandemic a majority of individuals exhibited a low symptom resilience trajectory. The resilience trajectory was the majority response (57–93%), for example, in longitudinal studies conducted in Poland⁵⁶, Israel⁵⁷, the United Kingdom⁵⁸, Germany⁵⁹, Argentina⁶⁰ and Hubei Province, China, where COVID-19 was first detected⁶¹. A review of 28 studies revealed that the prevalence rates of resilience and dysfunction trajectories in studies conducted during the COVID-19 outbreak³¹ were similar to those observed before the pandemic. In particular, the prevalence of the resilience trajectory was observed at an identical prevalence (66%, on average, across studies)³⁰ compared with pre-COVID-19 studies³⁰. The primary exceptions were that the recovery trajectory was, on average, less prevalent in studies conducted during (13%) compared with prior to (21%) the COVID-19 pandemic, and an unusual trajectory of moderate to mild persistent distress was observed in almost twice as many studies conducted during (27%) compared with prior to (15%) the COVID-19 pandemic.

Prospective trajectories

Owing to their inherently unpredictable nature, research on potentially traumatic events has traditionally assessed their impact after the event using retrospective sampling methods. However, retrospective sampling is susceptible to selection bias, which might underestimate the prevalence of the resilience trajectory. For example, individuals with fewer symptoms are less likely to volunteer for research on trauma than individuals with more severe conditions. This selection bias will decrease the number of study participants who show a resilience trajectory (defined by stable low symptoms), and therefore the proportion of resilience trajectories observed. Prospective designs avoid selection bias because participants are already enrolled in the study when the potentially traumatic event occurs. This methodological advantage reduces bias in resilience trajectory rates, which are higher in prospective studies (74%) than initially observed in retrospective designs (66%)³⁰.

Prospective trajectory studies have also been able to probe research questions and identify trajectories not observable in retrospective designs. For example, retrospective studies probing the prevalence of resilience after multiple potentially traumatic events have been inconclusive^{62,63}. However, a prospective study found that the prevalence of the resilience trajectory was nearly identical among individuals who experienced either one (62%) or more than one (60%) life-threatening medical event⁶⁴. Another prospective study that included repeated assessments across a 7-year period beginning before the 2008 economic crisis (the Great Recession) and culminating after the 2012 Hurricane Sandy disaster⁶⁵ also observed a high prevalence (84%) for the resilience trajectory. Both studies also identified a trajectory of incremental chronic symptoms that increased in severity following experience of multiple stressor events.

A particularly important advantage of prospective studies is that they can reliably parse the course of pre-event psychopathology (Fig. 3). For example, the trajectory of chronically elevated symptoms following a potentially traumatic event can be parsed into two distinct prospective patterns: a trajectory of pre-existing chronic symptoms characterized by elevated symptoms prior to the event that remain elevated after the exposure, and a trajectory of emerging chronic symptoms characterized by low symptom levels prior to the event and chronically high symptom levels after the exposure. The distinction between these two prospective trajectories (pre-existing chronic and emerging chronic symptoms) has allowed researchers to interrogate important health consequences associated with potentially traumatic events. For instance, depression has shown a well-established association with premature mortality⁶⁶, particularly in the aftermath of potentially traumatic events⁶⁷. In this context, treatment for depression becomes an important, if not lifesaving, concern. Yet questions remain, such as how aggressively treatment should be pursued or whether all patients who are depressed might be equally at risk^{68,69}. Prospective trajectory research has helped clarify this issue by demonstrating that only depression that was not evident prior to the potentially traumatic event but then emerged after it (emerging chronic depression), and not pre-existing chronic depression, was consistently associated with premature mortality^{43,64,70} (and D. Sanghvi, S.C. and G.A.B., unpublished work). Relatedly, in the context of job loss, individuals showing an emerging chronic depression trajectory are the least likely to be re-employed⁷¹.

Another pattern identified in prospective studies is the pre-existing symptom improvement trajectory. In contrast to the recovery trajectory, which describes increased symptoms following the potentially traumatic event and then a gradual decline, the improvement trajectory is characterized by elevated symptoms prior to the event that decrease rapidly after its onset (Fig. 3). This pattern is somewhat surprising because potentially traumatic events are widely assumed to either increase symptoms or, in the case of resilience, have minimal impact on symptom levels, but not to reduce symptoms. First identified in a prospective study of bereavement⁷², the pre-existing symptom improvement trajectory has since been observed in relation to a diverse range of potentially traumatic events⁷³. Possible explanations for this trajectory include relief after the stress of caring for a dying loved one⁷², unrealized anxiety during combat deployment⁷⁴, and increased support and attention from mental health professionals³⁸.

Although compelling, explanations for the pre-existing symptom improvement trajectory are almost always post hoc and rarely tested. The sole exception is a prospective study of the 2007 mass shooting at Virginia Tech⁵¹. A sizeable number of the students exposed to the

shooting evidenced trajectories of emerging chronic anxiety (23%) and emerging chronic (9%) or delayed (10%) depression reactions. Yet, as with so many other potentially traumatic events, despite the severity of the event, the majority of the exposed students evidenced the resilience trajectory for both anxiety (56%) and depression (59%). A relatively small portion of students were characterized by the pre-existing symptom improvement pattern. Specifically, 7% and 13% of exposed students showed elevated symptoms of depression and anxiety, respectively, prior to the shooting, followed by low levels of these symptoms 2, 6 and 12 months after the shooting. Researchers examined the hypothesis that, owing to their pre-existing struggles and subsequent experience of a potentially traumatic event, these students received greater support from other people after the event, which, in turn, helped them function better. Consistent with this explanation, the students who showed the improved trajectory reported a marked increase in interpersonal resources and greater emotional support from family and friends relative to before the event and relative to others who experienced the event. These results were later described as part of a broader phenomenon of psychosocial gains from adversity⁷³.

The resilience paradox

The replicability of diverse trajectory patterns leads to the question of what mechanisms are involved in promoting a resilient outcome. One of the most common explanations is that people find their way to resilience by virtue of a resilient personality⁷⁵ that encompasses the key traits necessary for adapting well in the face of adversity. This explanation partly owes its popularity to the fact that a resilient personality is easily assessed using a single self-report questionnaire⁷⁶. Unfortunately, a closer look at scales used to measure resilient personalities reveals serious problems. Most critically, although resilience scales correlate with psychological adjustment when measured cross-sectionally, there is no evidence that they predict long-term adjustment in the form of a resilience trajectory following adversity¹⁶. Prospective and longitudinal studies have examined whether resilience scales predict overall mental health in the aftermath of adversity and again found no supportive evidence^{77–80}. Resilience scales also failed to predict a positive outcome following an experimental stress paradigm⁸¹. In this study, individuals scoring high on a resilience personality measure reported low distress before and after the stress task. Nonetheless, they showed the same increases in physiological and behavioural indicators of distress as other participants, prompting the investigators to conclude that the resilience personality is likely to be nothing more than an “artifact of a self-deceptive answering style”.

There are logical reasons why the measurement of a resilient personality would fail to predict resilient outcomes. Because the resilient trajectory is so prevalent, those who can be categorized as resilient will naturally be more heterogeneous and, therefore, the correlates of a resilient trajectory will be more multifaceted than could be captured by a single resilience scale^{22,82–84}. Although the quality of evidence varies, myriad correlates of resilience have been observed, including demographic factors, personality traits not limited to resilience, coping and emotion regulation strategies, social and economic resources, past and current stressors, exercise and positive emotions^{2,29,85}. Genetic, biological and neuroanatomical correlates of resilience have also been reported^{86–89}.

Crucially, the size of these associations tends to be small (for example, correlations less than 0.30 or, when multiple predictors are considered, measures of variance explained ranging from 0.01 to 0.06) and inconsistent^{29,90}. Even variations in trauma exposure, assumed to be

a driving mechanism in trauma reactions, commonly produce similarly small or even non-significant effects^{7,91–94}. This general issue has been called the ‘resilience paradox’¹⁶: the correlates of resilience are widely known to be the primary components of resilience, but when used as predictors of future resilient outcomes, these correlates paradoxically fail to explain more than a modest portion of the variance.

It is important to note that small effects per se are not necessarily problematic. Many traits and behaviours exert small effects. For example, human behavioural traits are associated with multiple genetic variants, each accounting for a small percentage of the trait variability⁹⁵. Relatedly, although personality has a consistent influence on behaviour, the effects are generally small in magnitude⁹⁶. Making sense of such effects is an essential task of psychological science^{97,98}. Problems arise only when the nature of small effects is ignored or when small effects are presumed to be more impactful than they actually are. Such oversights become especially problematic in programmes designed to build resilience, which tend to focus on enhancing a limited set of traits or even a single trait, with the presumption that this single enhancement will promote markedly improved resilience^{4,99}.

There are many reasons why the correlates of resilience would show small effects, most notably situational variability and cost–benefit trade-offs. The demands and characteristics of different situations vary greatly: an automobile accident presents different challenges from those of a natural disaster, which is different from an episode of abuse and so on. Owing to their long-lasting impact, the effects of potentially traumatic events also tend to vary markedly even within the same event across time. The challenges people experience immediately after the event differ from the challenges they experience hours, days or weeks later. Linked to situational variation is the unavoidable fact that traits and behaviours produce both benefits and costs^{100,101}. To cite an animal example, when Thomson’s gazelles detect a stalking predator, such as a cheetah or lion, they do not always flee and sometimes they approach

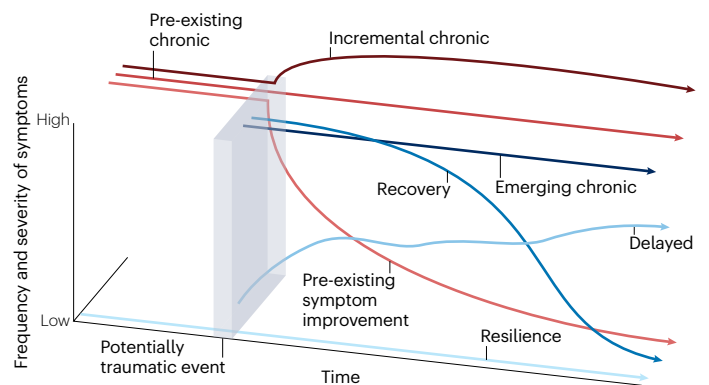


Fig. 3 | Prototypical and prospective trajectories following a potentially traumatic event. Prototypical trajectories (shades of blue) identified in retrospective research designs. Prospective trajectories (shades of red) can be observed only in studies using prospective research designs. Prospective trajectories include a pre-existing chronic trajectory of elevated symptoms and distress present before the potentially traumatic event that remain elevated afterwards, a pre-existing improvement trajectory characterized by elevated symptoms and distress that were present before the potentially traumatic event and decrease relatively soon after, and an incremental chronic trajectory of elevated symptoms and distress following a potentially traumatic event that increase to higher levels following exposure to one or more additional events. Figure adapted with permission from ref. 30, Elsevier.

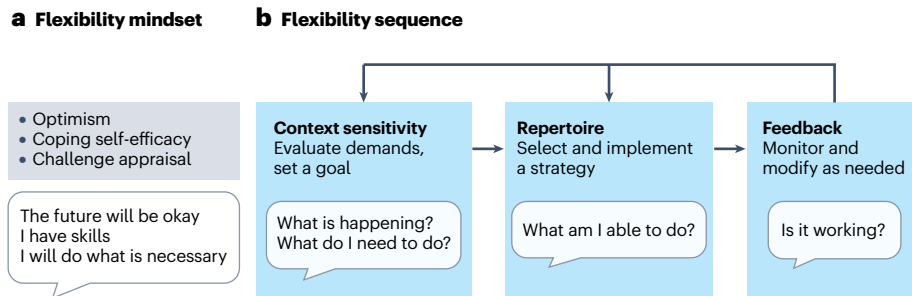


Fig. 4 | The motivational and mechanistic components of regulatory flexibility. **a**, The flexibility mindset provides the motivation needed to flexibly change behaviour, and comprises several mutually reinforcing beliefs such as optimism, coping self-efficacy and challenge appraisal. **b**, The flexibility sequence is a three-step mechanistic process that leads to behavioural adjustments. The first step, context sensitivity, pertains to the ability to evaluate situational demands and challenges and set a goal that guides adaptation.

Next, repertoire involves the selection of a specific strategy to meet that goal from one's personal set of effective strategies, and its implementation. Finally, feedback involves monitoring the efficacy of the implemented strategy and modifying or replacing it if needed. Self-talk (self-directed silent or spoken speech, illustrated by speech bubbles) can enhance both the flexibility mindset and the flexibility sequence. Figure adapted with permission from ref. 17, copyright G.A.B. & C. L. Burton.

the predator¹⁰⁰. Although approaching a predator can incur obvious costs, it can also bring somewhat counterintuitive benefits, such as informing the predator they have been detected, alerting other gazelles to danger and influencing the predator's hunting strategy. The efficacy of this strategy is, in turn, moderated by situational variations such as age, amount of vegetation and group size. Although the approach strategy might be a useful evasion technique for the gazelle, the animals that hunt them are formidable and often catch and kill them. If the success of the approach strategy was averaged across a large number of encounters with predators, the overall effect of this behaviour would likely be modest^{102,103}.

A comparable mix of situational variation and cost–benefit trade-offs also characterizes human behaviours. However, these considerations have frequently been ignored. For example, researchers looking at coping and emotion regulation have, for decades, succumbed to the fallacy of uniform efficacy¹⁷; that is, they routinely assume that some regulatory strategies are almost always effective regardless of their possible costs or the various constraints and challenges presented by differing situations^{17,104}. A growing body of studies using a contextualized approach has demonstrated more variable outcomes. For example, behaviours thought to be uniformly adaptive (such as positive emotions, cognitive reappraisal and seeking social support) have proved beneficial in many contexts, yet have also been shown to be less adaptive or even maladaptive in others^{105–108}. Conversely, behaviours assumed to be generally maladaptive (such as emotional suppression, avoidance and distraction) have been associated with meaningful costs, but have also been found to be highly adaptive in some contexts^{91,109}. Many factors might influence the cost–benefit trade-off of a given strategy or resource, such as the timing of its use, a person's ability to use it¹¹⁰, its rigid application across varying situations and the moderating influence of other proximal strategies¹¹¹. Consequently, when the efficacy of any given strategy or resource is averaged across situations, it will contribute relatively little to the overall prediction of a resilient outcome.

One promising approach to understanding how people who show resilient outcomes negotiate this challenging mix of situational variation and cost–benefit trade-offs leverages machine learning and its capacity to increase both predictive capabilities and the range of variables considered^{112–115}. Several studies using the machine learning

approach have demonstrated improved prediction of the resilience trajectory^{87–89}. Yet, despite its computational sophistication, machine learning has still not been able to illuminate the mechanism by which resilient individuals adapt to such complexity¹⁶. Another promising computational approach has emerged out of network analysis. Standard network analysis illuminates how interacting symptoms can be driven by stressors into stable, psychopathological states⁷¹³. A dynamic network analysis¹¹⁶ can include risk and resilience factors within the network of factors that can potentially interfere with or foster the emerging connections between symptoms¹¹⁶. Although network analysis nicely accommodates cost–benefit trade-offs, it takes a generic perspective on stressor events and does not easily incorporate situational variation. To find a versatile approach that can accommodate both situational variation and cost–benefit trade-offs, we next turn to a behavioural framework known as regulatory flexibility.

Regulatory flexibility

The concept of regulatory flexibility describes a process of dynamic behavioural adjustment and change in the face of high stress and situational demands. Regulatory flexibility seeks to explain how people assess the nuances of a situational stressor, select a strategy from their repertoire that seems likely to meet the demands of that stressor^{17,104,117–122}, and then monitor and revise that strategy as needed¹⁷. The flexibility framework encompasses several related concepts, including coping flexibility, emotion regulation flexibility and psychological flexibility. Although these concepts differ somewhat in measurement, aim and scope^{17,104,117–122}, they tend to coalesce around the assumption that flexible behavioural adaptation requires both a motivational component that provides the thrust needed to adjust behaviour and a mechanistic component that provides the tools to bring about those behavioural adjustments. The motivational and mechanistic components of regulatory flexibility have been described as the flexibility mindset^{10,16} and the flexibility sequence^{10,16,17}, respectively (Fig. 4).

The flexibility mindset

Adapting one's behaviour to mitigate stressful circumstances requires effort, and therefore motivation. Within the psychotherapy literature, a related concept known as psychological flexibility has been broadly conceptualized as motivated adaptation through the pursuit

of valued goals¹²³, particularly in the context of challenging or distressing situations¹²⁴. Research on psychological flexibility has suffered from methodological limitations, most notably operationalization along a single flexibility–inflexibility questionnaire dimension^{125,126}, which fails to capture the hypothesized motivational component, and validity problems, such as the scale's high correlation (for example, $r = 0.71$) with distress^{124,127–129}. An alternative questionnaire that was developed in response to these limitations¹³⁰ includes the motivational component as a separate dimension, and therefore might have better validity.

Researchers from the field of stress, coping and emotion regulation have emphasized the role of goal satisfaction in flexibility, broadly defined^{17,117} as, for example, the willingness to explore alternative strategies (low need for closure)¹³¹, the courage and motivation to adapt to stressful circumstances (hardiness)¹³² and shifting the valuation of stress from 'is bad for me' to 'can be good for me'¹³³. These diverse motivational strands (typically measured by self-report questionnaire) can be summarized as a flexibility mindset^{10,16} (Fig. 4a). Although the specific content of a flexibility mindset varies idiosyncratically across individuals, the available evidence suggests that it is likely to include optimism (which motivates people to work for the expected positive future)¹³⁴, confidence in coping or coping self-efficacy (which motivates the willingness to try different strategies)¹³⁵ and the appraisal of aversive events as challenges (which motivates a shift in focus beyond threat and towards the goal of adaptation)¹³⁶. Each of these beliefs has evidenced modest ($r = 0.06–0.19$; $\eta^2 = 0.02$) and often non-significant associations with resilient outcomes^{37,40,42,43,137,138}. Importantly, however, these beliefs have been shown to mutually reinforce each other and, consistent with their hypothesized role as motivators, to exert their influence on resilient outcomes indirectly¹³⁴ as mediators of the relationships between stress and flexibility^{139–144}.

The flexibility sequence

Research on regulatory flexibility has implicated several interrelated mechanistic elements (measured by experimental tasks and/or questionnaires) that unfold serially in a three-step process referred to as the flexibility sequence^{10,16,17} (Fig. 4b). The first step in the sequence, context sensitivity^{145–147} (see also discriminative facility¹⁴⁸), involves the ability to decode a situation's unique demands and challenges and to determine the goal for subsequent behavioural adaptation. Goals are often proximal (for example, reducing distress) but can also refer to longer-term aims and values (for example, meeting future needs)^{117,119,130}.

The next step in the sequence, repertoire, involves implementing a strategy from the set of possible strategies that a person has at least some skill in applying to meet that goal^{17,131,149}. This might include coping and emotion regulation strategies, use of social and economic resources, exercise, seeking out close friends or even temporarily engaging in strategies not normally considered healthy (such as getting drunk, finding comfort in food or sex, or joking about a bad situation)^{10,16,22}. The specific individual strategies or resources chosen are less important than the fit between the choice of strategy or resource and the specific situational challenges^{118–120,122}.

Last, the third step in the sequence involves monitoring internal and external feedback regarding the efficacy of the implemented strategy or resource and its modification or replacement when needed^{17,150–152}. Choosing an optimal regulatory response can be thought of as a probability estimate that will succeed in some cases and fail or even interfere with goal pursuit in others. In some models of flexibility, a failed regulatory response is considered an example

of maladaptive flexibility¹¹⁷. However, as experimental studies have demonstrated, the fit between any estimate and goal-driven expectations can be improved with corrective feedback^{153,154}. Inclusion of a feedback step in the flexibility sequence thereby surpasses the adaptive–maladaptive distinction by incorporating self-correction as part of the flexibility process itself. Moreover, when challenges are especially difficult, as is often the case with potentially traumatic events, it becomes necessary to cycle through the flexibility sequence repeatedly, adjusting or replacing strategies and resources until goal adaptation can be reasonably achieved.

Although research on the flexibility sequence has focused largely on the individual steps, researchers have begun directly interrogating the sequence's role in promoting resilience. For example, it is assumed that because most people show resilient outcomes, then most people should also be able to utilize all three steps in the sequence^{10,16}. Consistent with this assumption, latent profile analyses of data from two independent samples¹⁵⁵ revealed that a majority of participants had at least a moderate level of skill in all three steps of the sequence and those skills, in turn, were associated with better mental health. Another study tested the presumed serial pathway through the flexibility sequence using sequential mediation modelling with a sample of individuals exposed to trauma¹⁵⁶. Although performance at each individual step of the sequence showed some relationship to adjustment, the only consistent pathway to depression, anxiety and PTSD symptoms was the pathway from context sensitivity to repertoire to feedback.

Regulatory flexibility and resilience

The paradoxical complexities of predicting resilient outcomes – cost-benefit trade-offs, evolving challenges, situation-specific strategy use, and trial and error adjustments – suggest that attempts to build resilience directly will, at best, result in only minimal success⁹⁹. A more promising approach would be to promote resilience indirectly by enhancing the components of regulatory flexibility, thereby arming people with the tools needed to adapt to future situational challenges. Although research in this area is still relatively sparse and no studies have yet demonstrated improvement in regulatory flexibility as a comprehensive behaviour, a considerable body of research focused on the individual skills of the flexibility mindset and on the steps of the flexibility sequence suggests that such improvement is plausible (Table 1).

The beliefs that inform a flexibility mindset appear to be trait-like and, therefore, not easily modified. Nonetheless, attempts to improve these dimensions have shown encouraging results. A meta-analysis¹⁵⁷ of 29 randomized controlled behavioural tasks designed to increase optimism indicated effective improvements using an approach known as the Best Possible Self technique¹⁵⁸, in which, over a 2-week period, people repeatedly envision themselves in a future where everything has turned out in the most optimal way. Fewer attempts have been made to improve coping self-efficacy or challenge appraisal. However, the available evidence indicates that these beliefs can be effectively strengthened through in vivo experiential exercises (such as repeatedly writing about successfully coping with stress) conducted in relation to real-world stressors^{159–162}.

It is also plausible that the skills necessary for each step of the flexibility sequence can be enhanced. Improvements in context sensitivity have been demonstrated in clinical samples, such as patients with chronic pain, following basic skills training¹⁶³. Sensitivity to contextual cues has also been shown to improve with repeated exposure to implicit and explicit cues during a cognitive control task¹⁶⁴, with practice in the

Table 1 | Examples of training to enhance components of regulatory flexibility

Component	Example technique	Description	Example study	Sample	Result	Effect size
Flexibility mindset						
Optimism	Best Possible Self technique	People imagine themselves in a future in which everything has turned out optimally	Malouff and Schutte (2017) ¹⁵⁷	<i>n</i> =3,319, meta-analysis, 29 studies	Optimism increased more in the training group than in the control group	Medium (<i>g</i> =0.64)
Coping self-efficacy	Experiential learning sessions	Comprises individual activities, worksheets, case studies and facilitated discussion on coping self-efficacy	Laureano et al. (2014) ¹⁶⁰	Undergraduate student athletes (<i>n</i> =41)	Coping self-efficacy increased in the training group but not in the control group	Large (<i>d</i> =0.89)
Challenge appraisal	Quiet eye training	Aims to facilitate understanding of where and when to focus gaze on a designated target before, during and after a critical movement (for example, hitting or throwing a ball at the target)	Moore et al. (2013) ¹⁶²	Undergraduates (<i>n</i> =30)	Training led to higher challenge appraisal during difficult tasks compared with the controls	Medium ($\eta_p^2=0.10$)
Flexibility sequence						
Context sensitivity	Practising context-sensitive adjustments in real time	Repeated implicit (experiments 1 and 2) and explicit (experiment 3) cues used to facilitate adjustment to dual-task performance	Fischer et al. (2014) ¹⁶⁴	Students (<i>n</i> =20–40)	Practice improved response times (reduced interference from a competing task) for both implicit and explicit cues	Large ($\eta_p^2=0.20–0.83$)
Repertoire	Reappraisal training	Four sessions spaced 2–5 days apart for two kinds of reappraisal (reinterpretation and distancing) and a no regulation control	Denny and Ochsner (2014) ¹⁷⁰	Community sample (<i>n</i> =103)	Distancing training reduced negative affect more than other types of training over the four sessions	Medium (<i>d</i> =0.52)
Feedback	Emotion regulation training with functional magnetic resonance imaging feedback	Training to downregulate negative emotion using reappraisal with visual analogue feedback of amygdala activity	Herwig et al. (2019) ¹⁷⁶	Community sample (<i>n</i> =26)	Feedback training led to a greater reduction in negative emotion relative to passive control	Large (<i>d</i> =1.12)

d, Cohen's *d* value; *g*, Hedge's *g* value; η_p^2 , partial eta squared.

use of if–then implementation plans¹⁶⁵ and when using a skill-based coping flexibility game¹⁶⁶.

Although there is less research on improving regulatory repertoire, numerous studies have shown that it is possible to enhance and expand people's ability to deploy specific coping and emotion regulation strategies¹⁶⁷. A study of affective flexibility (the ability to modulate affect by alternately feeling more or suppressing feelings) demonstrated improvement in the implementation of these strategies over time¹⁶⁸. Similarly, training using reappraisal has led to consistent reductions in negative affect over several days^{169,170}. Relatedly, it is possible to enhance another aspect of repertoire, the availability of supportive resources, through the use of positive relational exercises involving gratitude or kindness¹⁷¹.

The plausibility of enhancing the use of feedback – the key mechanism of the third step of the flexibility sequence – is suggested by research on training with sensory and bodily feedback cues. Work in this area originally took the form of biofeedback training, a method of learned self-regulation in which individuals (typically patients suffering from physical difficulties such as migraines or chronic pain) are trained to gradually exert greater voluntary control over bodily processes through sensory feedback¹⁷². The sensory cue is typically a continuous visual or auditory signal that serves as an analogue representation of sympathetic arousal or some other form of bodily activity. With practice, the individual learns to use feedback to move the sensory cue in a specified direction and, consequently, gains ability to adjust their attempts at self-regulation of bodily activity.

This same basic principle was subsequently adapted for use in neurofeedback training, a process that leverages analogue feedback of brain activity typically assessed using functional magnetic resonance imaging or a combination of magnetic resonance imaging and electroencephalography^{173–175}. For example, in one study participants practised reducing negative emotions to aversive picture stimuli using a simplified form of cognitive reappraisal known as 'reality check' in which they used statements such as 'The stimuli are only pictures' or 'I am participating in an experiment'¹⁷⁶. In some trials, participants also viewed colour-coded feedback representing their amygdala activity. Self-regulation trials with visual feedback resulted in greater amygdala activity reduction compared with trials without visual feedback. Feedback training also resulted in greater task-specific connectivity between the amygdala and areas implicated in emotion regulation, such as the dorsolateral and dorsomedial prefrontal cortices.

A limitation of both biofeedback and neurofeedback training is their reliance on complex and expensive equipment. A far simpler approach with the potential to enhance both the flexibility mindset and sequence is self-talk (a form of self-directed silent or spoken speech)^{177–179}. Self-talk normally emerges spontaneously and can be positive (for example, when people feel pride at an accomplishment and say to themselves 'I did really well') or negative (for example, when people belittle themselves for a failure and say to themselves 'I'm an idiot'). However, self-talk can also be leveraged intentionally in the form of goal-directed self-talk. Goal-directed self-talk has been effectively

harnessed as a learning tool across multiple disciplines, including education, sports and mental health¹⁸⁰.

Although goal-directed self-talk serves myriad functions, its motivational function is of particular relevance to the flexibility mindset¹⁸¹. Motivational self-talk in the form of an affirmative monologue has been shown to increase effort¹⁸², attentional focus¹⁷⁸, executive control¹⁸³ and self-efficacy¹⁸¹, all of which are relevant to the motivational thrust of the flexibility mindset. When applied explicitly to the flexibility mindset (Fig. 4a), motivational self-talk might involve statements such as ‘The future will be okay’ (optimism), ‘I have the skills to get the job done’ (coping self-efficacy) and ‘I will do what is necessary’ (challenge appraisal)¹⁰.

Goal-directed self-talk can also serve an instructional function¹⁸¹ that can be used to train or enhance the steps of the flexibility sequence (Fig. 4b). In this case, self-talk comprises questions a person directs to themselves¹⁸⁴. Instructional self-talk has been used to enhance numerous processes of relevance to the flexibility sequence, such as evaluation and assessment of options, assessment of past actions¹⁸⁴ and emotion regulation¹⁸⁵. When used explicitly for the flexibility sequence, instructional self-talk might involve questions such as ‘What is happening?’ and ‘What do I need to do?’ (context sensitivity), ‘What am I able to do?’ (repertoire) and ‘Is it working?’ (feedback)¹⁰.

A variant of self-talk particularly well suited to the flexibility sequence is distanced self-talk¹⁷⁷. In this form of self-talk, the first-person pronouns normally used (‘I will do this well’) are replaced with the person’s name (‘Tom will do this well’), thereby providing greater psychological distance or a ‘fly-on-the-wall’ perspective. Of relevance to the flexibility mindset, distanced self-talk has been shown to increase challenge appraisal¹⁷⁷ and enhance goal pursuit¹⁸⁶. In terms of the flexibility sequence, distanced self-talk has been shown to enhance emotion regulation effectiveness across a range of circumstances and emotional intensities^{187,188}.

It is important to stress that resilience is never guaranteed. Rather, as illustrated by the resilience paradox, it is a matter of probability. Although most, but not all, people exposed to potentially traumatic events find their way to resilience, how they achieve this outcome has not been clear. We propose the process of regulatory flexibility, and the empirically derived components it comprises, as the likely pathway^{10,16}. Preliminary research indicates that improving these skills is possible, and therefore suggests a logical means of increasing a person’s probability of a resilient outcome when they are next confronted with a potentially traumatic event.

Summary and future directions

The traditional approach to potentially traumatic events based on the binary distinction of psychopathology (typically PTSD) versus no psychopathology suffers from numerous limitations. Most notably, it fails to account for the heterogeneity of outcomes that follow these events. In particular, the binary approach is mute on the nature and prevalence of resilience, how it comes about, how it might inform more extreme or prolonged outcomes and how it might be improved. Data-driven approaches to potentially traumatic events provide a pivotal antidote to these problems by articulating multiple outcome trajectories and, in particular, by identifying a unique trajectory that captures stable healthy adjustment or resilience. This approach proved highly reliable – the trajectory findings are among the most well replicated in psychology^{30,31} – and opened the door towards a new understanding of the complex interplay of factors that might drive diverse outcomes following exposure to potential trauma or adversity.

Specifically, because correlates of the trajectories, and in particular the resilience trajectory, tend to exert small effects, it became imperative to develop broader models of adaptation to potentially traumatic events that might accommodate the influence of situational variation and cost–benefit trade-offs. This development, in turn, led to an increasing appreciation of the role of regulatory flexibility in the adaptation process.

Because much of this work is nascent, a great deal remains to be understood. One key task for future research will be to clarify more precisely how the components of regulatory flexibility – the flexibility mindset and flexibility sequence – relate to each other and how variations in those relationships influence resilient outcomes. At the same time, it will also be important to untangle how the absence of regulatory flexibility (for example, the rigid use of the same regulatory strategy across varying situations) informs the development of more symptomatic or prolonged outcomes. Prospective studies that measure components of flexibility at baseline prior to the onset of a potentially traumatic event will undoubtedly help clarify the predictive nature of these relationships. More importantly, because regulatory flexibility is conceptualized primarily as a process, capturing that process in real time during real-life challenges will be critical.

By definition, flexibility involves multiple factors interacting in novel and often unanticipated ways over time¹¹⁵. Capturing that complexity will require innovation at both a methodological and a computational level^{113,114,189}. For example, coupling machine learning procedures with intensive longitudinal designs such as ecological momentary assessment, and more thorough situational assessments beyond the limited contextual domains typically investigated (stress controllability and emotional intensity), would improve the measurement of situation-specific responses¹¹⁵. No single flexibility formula applies to all individuals. Thus, leveraging idiographic models with intensive longitudinal data would further advance this enterprise by potentially illuminating situation–behaviour profiles of flexibility and their influence on adaptation to various real-life challenges.

Despite its complexity, it is highly plausible that regulatory flexibility can be enhanced through training¹⁰. For example, research suggests that deficits in the flexibility sequence are usually limited to one step in the sequence¹⁵⁵ and, as reviewed above, methods that might be adapted for improving the skills that underlie individual steps already exist. However, what is lacking is broader training that would strengthen both the flexibility sequence and the flexibility mindset. The development of an easily applied training programme would provide people with the tools they need to sharpen their flexibility skills and, in the process, increase their odds of a resilient outcome when faced with future adverse events. In a similar vein, variants of such training might be developed to help those struggling to recover from an adverse experience or complement treatment for those already suffering more prolonged symptoms. The precise form this kind of training might take is not yet clear. Some evidence suggests that broadly defined flexibility can be inculcated as a by-product of global interventions, such as mindfulness-based stress reduction¹⁹⁰ or acceptance and commitment therapy¹⁹¹. A training programme more explicitly aimed at regulatory flexibility might borrow elements from these approaches or from other established training programmes that target related areas, such as emotional intelligence¹⁹².

Each of these developments offers promising approaches to understanding, informing and, possibly, influencing the various trajectories of response that people experience in the aftermath of highly aversive and potentially traumatic life events. It is unlikely that painful

and prolonged reactions such as PTSD can ever be fully erased. But the possibility of providing new and more versatile tools to assist people in charting their course through turbulent waters and, by doing so, determining for themselves which trajectory they might belong to seems within reach.

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