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Resilience and Disaster: Flexible Adaptation in the Face of Uncertain Threat

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Abstract

Disasters cause sweeping damage, hardship, and loss of life. In this article, we first consider the dominant psychological approach to disasters and its narrow focus on psychopathology (e.g., posttraumatic stress disorder). We then review research on a broader approach that has identified heterogeneous, highly replicable trajectories of outcome, the most common being stable mental health or resilience. We review trajectory research for different types of disasters, including the COVID-19 pandemic. Next, we consider correlates of the resilience trajectory and note their paradoxically limited ability to predict future resilient outcomes. Research using machine learning algorithms improved prediction but has not yet illuminated the mechanism behind resilient adaptation. To that end, we propose a more direct psychological explanation for resilience based on research on the motivational and mechanistic components of regulatory flexibility. Finally, we consider how future research might leverage new computational approaches to better capture regulatory flexibility in real time.

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INTRODUCTION

Disasters can strike swiftly and cause shocking levels of damage. They can also emerge more gradually due to spreading events or causes that ultimately affect huge portions of a population. The high level of uncertainty that characterizes disasters, coupled with their sweeping impacts, can produce a range of mental health consequences, from general distress to depression, anxiety, grief, suicide, or psychological trauma. Although much of the research on disasters has focused on extreme psychological harm, an important and growing body of work has also documented abundant resilience (Bonanno et al. 2010).

Resilience paradox: the paradoxically weak ability of correlates of resilient outcomes to predict future resilient outcomes

In this article, we consider the unique stressors associated with disasters and compare these with the larger literature on aversive and potentially traumatic events in general. We note that the tendency within the mental health literature to underestimate resilient outcomes, often observed in the context of potential trauma, is especially pronounced in the aftermath of disaster. We then consider the relatively recent literature that attempts to map the broader heterogeneity in outcomes following these events, including the recent impacts of the COVID-19 pandemic. This approach highlights the diversity of long-term outcomes as well as the previously underappreciated prevalence of resilient outcomes. Next, we review correlates of resilient outcomes and note that these correlates show surprisingly limited ability to accurately predict future resilient outcomes, a phenomenon dubbed the resilience paradox (Bonanno 2021a,b). We review several possible explanations for the paradox and propose a likely resolution derived from recent theory and research on flexible self-regulation, or regulatory flexibility. Finally, we consider how regulatory flexibility during disaster might be captured in real time using combinations of momentary assessment, machine learning (ML), and other computational methods.

Machine learning (ML): the development of algorithms that learn from data to develop reproducible predictive models, classification models, and clustering models

Potentially traumatic event (PTE): a highly aversive, violent, or life-threatening event that may lead to a prolonged trauma reaction

THE UNIQUE STRESS OF DISASTER

Disasters share many features with other potentially traumatic events (PTEs). For example, they are highly distressing and pose violent or life-threatening challenges. However, owing to their sweeping scale, the threats posed by disasters are typically more extreme and enduring than other PTEs. Moreover, the uncertainty of disasters is often compounded by chaotic circumstances and a lack of critical survival information (Son et al. 2019), which exacerbates the already difficult task of sourcing possible solutions and prescribing recovery plans. Disasters also cast a wider net than PTEs. They vary greatly in magnitude (i.e., size, strength, and duration), the nature of the causal event, and timing, which generate both short- and long-term consequences that can simultaneously impact individuals, their families, and the broader geographic regions in which they live (Bonanno et al. 2010, Chen et al. 2020). These consequences in turn can ripple through a multitude of psychosocial and systemic impacts, ranging from disruptions in daily routine to economic fallout, physical health, psychological and emotional impacts, and loss of life.

Disaster Type, Duration, and Timing

The mental health impact of disasters tends to vary across types of disasters. Natural disasters are often experienced as unpreventable, with no clear source of blame, and can result in pervasive feelings of helplessness and loss of control. Although human-made disasters are commonly perceived as more preventable, disasters caused by negligence or premeditation can result in heightened anger and desires for retribution. Conversely, public health emergencies, such as pandemics or acts of bioterrorism, can produce high levels of fear and anxiety due to uncertainty of impact and long-term effect. This distress is often compounded by feelings of isolation and loneliness resulting from accompanying quarantine mandates.

A comparative study across earthquakes, floods, landslides, fires, environmental pollution, and disease epidemics revealed statistically meaningful variation in risk perception across disaster types, which also depended on whether survivors experienced the disaster directly, indirectly, or from a distance (Ho et al. 2008). Of note, however, the categorization of disaster type is often ambiguous, encompassing multiple forms. For example, the 2011 Tōhoku earthquake created a tsunami that led to the meltdown of the Fukushima nuclear power plant, resulting in highly dangerous radiation leakage (McFarlane & Williams 2012). Similarly, while Hurricane Katrina was devastating in its natural course, the flooding in the surrounding areas was worsened by the failure of the levees, which was seen as caused by human neglect and error (Travis 2005).

The duration and timing of a disaster can also vary greatly. Acute-impact disasters, such as hurricanes, earthquakes, or large-scale terrorist attacks, strike suddenly and intensely but often produce rippling consequences that endure beyond the event itself, taxing both personal and community coping resources and weakening the capacity to manage ongoing tasks and challenges. For example, in the aftermath of Hurricane Katrina, displaced students evidenced ongoing lower levels of educational performance (Pfefferbaum et al. 2016).

In comparison, chronic-impact disasters, such as droughts or disease pandemics, are characterized by a gradual onset and offset. For example, pandemics occur in relatively focused geographic locations, slowly gather momentum, and spread until they reach full pandemic status. These events cause stress through ambiguity and uncertainty, as gradual-onset disasters force people to determine the personal health risks of daily activities based on minimal information. During the COVID-19 pandemic, for example, levels of fear, worry, and loneliness increased gradually over the initial months, peaked, and subsequently gradually declined (Varga et al. 2021). Interestingly, although government actions in response to the COVID pandemic may have reduced confusion, they appear to have had little impact on population-level subjective worry and stress (Varga et al. 2021). The offset of chronic disasters can be equally ambiguous, which creates a challenge to interpreting when it is safe to act freely again. Although the economic impact of chronic disasters can be more directly measurable using standard economic indicators, these too are subject to some ambiguity owing to the extended timeframe and the possible confounding influence of additional events that independently inform economic well-being.

Other features of disasters also influence levels of threat, risk, and psychopathology. In a now classic review, Norris et al. (2002) found that the overall level of impairment in exposed populations varied by disaster type, characteristics of the region in which the disaster occurred, and age range. Specifically, the greatest level of impairment was documented in disasters involving mass violence, in less economically developed regions, and among younger people.

MULTI-LEVEL PSYCHOLOGICAL CONSEQUENCES

Although the ways individuals experience and react to disaster are well documented, considerably less research has examined the psychological consequences at broader levels. The available evidence, however, shows that disasters can fundamentally change family dynamics and structure. Families that experience greater levels of impact, such as financial difficulties, loss of property, and changes in their social support network, often report greater levels of family conflict and lower levels of family functioning and cohesion (Cao et al. 2013, Uttervall et al. 2014). Although the empirical evidence is largely cross-sectional and somewhat mixed, overall, children exposed to disaster appear to be at greater risk of mental health problems in homes with high levels of conflict, hostile/anxious parenting styles, caregiver distress, low family connectedness, a downward change in family functioning, and either excessive or inadequate information about the disaster (Cobham et al. 2016). Several studies have assessed these factors using longitudinal (Bountress et al. 2020) or prospective (e.g., Bokszczanin 2008) designs. Structural equation modeling indicates complex and often reciprocal relationships between parental distress, child distress, and parent-child conflict and communication. In a study of families exposed to a tornado disaster (Bountress et al. 2020), the level of direct experience of a tornado disaster predicted both parental distress and adolescent traumatic stress 8 months after the tornado. Importantly, 8-month adolescent traumatic stress also predicted increased parental distress at 12 months, and, reciprocally, 8-month parental distress predicted increased adolescent traumatic stress at 12 months. Additionally, 8- and 12-month parent–child conflict/communication contributed to adolescent traumatic stress at 12- and 24-month follow ups.

At the community level, disaster events can exert a collective impact that alters not only individual and family experiences of the event but also the context in which post-disaster recovery occurs (Tierney & Oliver-Smith 2012). Disasters often permanently reshape communities, with potential impacts on the infrastructure and organizational ecology of the community that ripple through and alter socioeconomic and sociopolitical patterns (Arcaya et al. 2020). Individual and community impacts are intricately interwoven and often reciprocally interacting with each other. For example, traditional sources of support that individuals may have previously relied upon can shift as other individuals and groups of the community concordantly adjust to the events. One study found that the extent of community cohesion was mediated by the severity of the disaster. Although cohesion was high initially, as severity increased survivors tended to shift focus to individual interests, resulting in an overall decrease in community cohesion (Chang 2010). Similarly, a disaster event can create economic pressures that undermine individuals' capacity to engage with their communities, restrict social interactions, or result in mass relocation. These consequences, in turn, can increase social conflict and undermine social connectedness and other crucial resources for recovery (Kaniasty 2020, Xu et al. 2016).

TRAUMA, POSTTRAUMATIC STRESS DISORDER, AND THE RESILIENCE TRAJECTORY

With the advent of posttraumatic stress disorder (PTSD) as a formal diagnostic category in 1980, violent or life-threatening events, including disasters, were routinely understood through a narrow binary lens that focuses on either PTSD or its absence. Although the dominance of a binary approach was initially useful in advancing research and treatment of trauma-related psychopathology, it has until recently stifled other crucial avenues of research. For one, it tends to ignore the failings of psychiatric diagnoses (Bonanno et al. 2010, Conway et al. 2021, Frances & Widiger 2012). The complexity of the diagnostic algorithm for PTSD, for example, produces surprisingly heterogeneous symptom presentations that likely exacerbate both measurement error and diagnostic uncertainty (Galatzer-Levy & Bryant 2013). Even more problematic, a binary model says almost nothing about other possible trauma outcomes, including stable healthy adaptation or resilience, and is essentially mute on how these diverse outcomes might come about.

Skewed and Heterogeneous Distributions

It is well established that most people exposed to PTEs do not develop PTSD or other psychological disorders (Hoppen & Morina 2019, Kessler et al. 2017). This can be seen in the skewed distribution histograms of PTSD and other types of symptoms depicted in **Figure 1**. Each of these distributions was measured in the early months after exposure to a loss or PTE. In a binary approach, the data of interest lie in the elongated tail of each distribution, where individuals with PTSD and other forms of psychopathology might be diagnosable. All remaining individuals, the bulk of the sample, are then simply lumped together into a larger category of those who did not develop psychopathology. Bonanno (2004) challenged this view, arguing that responses to PTEs

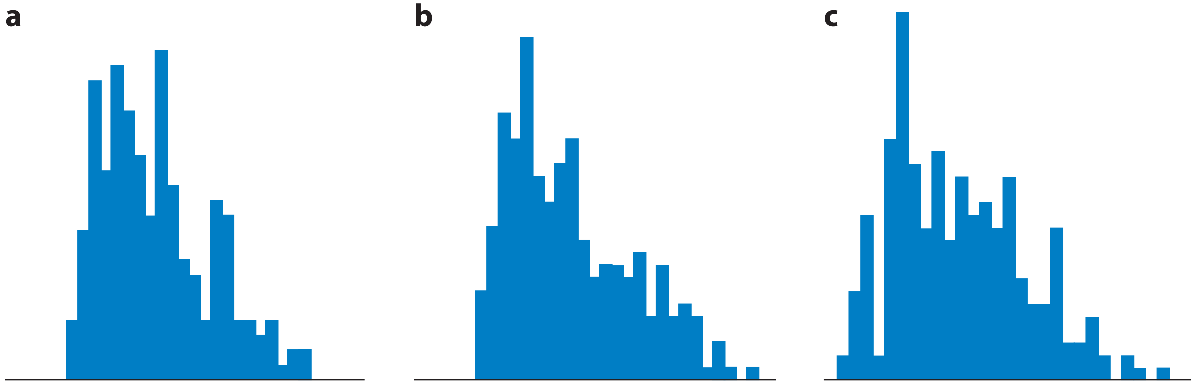

Figure 1

Cross-sectional distributions of (*a*) depression symptoms following a spinal cord injury, (*b*) posttraumatic stress disorder symptoms following traumatic injury, and (*c*) grief symptoms following spousal loss. Panel *a* adapted with permission from Bonanno et al. (2012); panel *b* adapted with permission from DeRoon-Cassini et al. (2010); panel *c* adapted with permission from Bonanno et al. (2002).

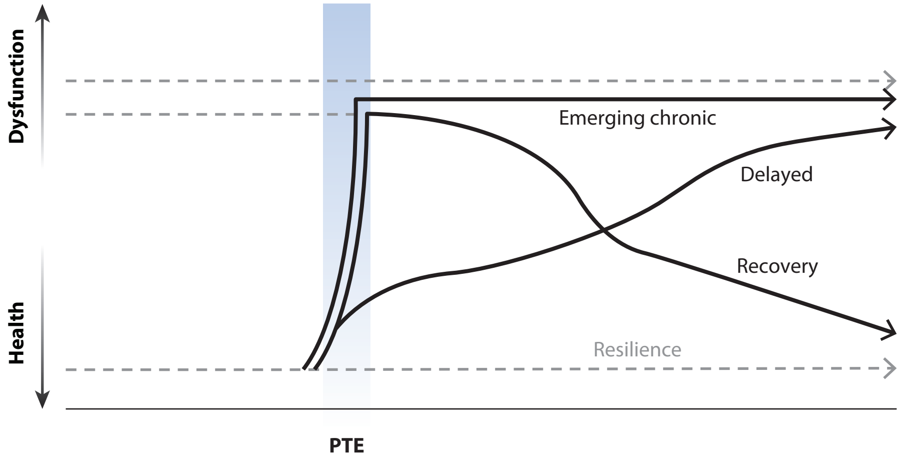

Figure 2

Prototypical outcome trajectories in relation to a potentially traumatic event (PTE). Figure adapted with permission from Bonanno (2004).

are heterogeneous and can be characterized by several distinct, prototypical trajectories of outcome. These include emerging chronic symptom elevations, a gradual recovery pattern, delayed symptom elevations, and the most common pattern of resilience, defined as a "stable trajectory of healthy functioning across time" (Bonanno 2004, p. 21). The histograms in **Figure 1** suggest that even at a cross-section, there are clues to the existence of such diverse patterns. Specifically, the distributions are not smooth but rather suggest multiple latent clusters or subgroups—i.e., a multimodal distribution—that might underlie divergent trajectories (Bonanno 2004). Each of the distribution histograms in **Figure 1** was, in fact, derived from longitudinal investigations (Bonanno et al. 2002, 2012; deRoon-Cassini et al. 2010) that observed distinct trajectories of symptoms.

Highly Replicable Outcome Trajectories

Initial attempts to identify trajectories of change following PTEs relied on simple decision algorithms (e.g., Bonanno et al. 2002). Later, it became possible to identify latent trajectories using unsupervised ML tools, such as Latent Growth Mixture Modeling (LGMM), that discovered previously unidentified groups of individuals who shared similar trajectories over time and, importantly, differed substantively from one other (Grimm et al. 2017, Muthén 2004) (see **Figure 2**). It is important to note that LGMM is not a diagnostic tool that classifies observed change behavior. Rather, this approach first characterizes latent distributions of change in a data set and then probabilistically determines which distribution (i.e., trajectory) each individual in the data set most likely belongs to. Due to the probabilistic approach, some interpretive caution is warranted, as factors other than those favored by a researcher (e.g., sampling bias) could plausibly inform a given trajectory solution (Bauer & Curran 2003). For this reason, replication of trajectory patterns becomes imperative (Grimm et al. 2017).

Over the past decade, research on trajectories following PTEs has met the replication criterion many times over. Not all data sets share the same properties or level of methodological rigor, of course, and in some cases trajectory models fail to produce interpretable solutions. However, a recent comprehensive review of 54 studies that evaluated 67 trajectory analyses of potential responses to PTEs (Galatzer-Levy et al. 2018a) demonstrated common trajectories across diverse contexts and metrics (**Figure 2**) as well as common proportions for these trajectories that varied meaningfully based on individual and population parameters. Specifically, the large number of studies included in the review made it possible to derive parameter estimates for distinct trajectories that were agnostic to modeling approach, study design (e.g., prospective, longitudinal), type of outcome scale (e.g., PTSD, depression, anxiety, grief), or type of PTE (e.g., combat, traumatic injury, loss, life-threatening medical events).

The modal outcome across these diverse studies was again the resilience trajectory of stable, low symptom levels. The resilience trajectory was almost always the majority response, observed on average in two-thirds (66%) of a study's participants. The next most prevalent trajectory, recovery (23.4%), was characterized by initially elevated symptoms that steadily abated, followed by a chronic high-symptom trajectory (11.7%) and a delayed symptom increase trajectory (9.7%). These trajectories were derived using LGMM and related modeling approaches and encompassed both longitudinal and prospective data sets. Sources of heterogeneity in these estimates resulted primarily from population differences across studies rather than from sampling bias. Of note, the prevalence of resilience and other trajectories was comparable to the findings of earlier studies that used less computationally sophisticated trajectory modeling approaches (e.g., Bonanno et al. 2002), suggesting broad replication across methods.

Resilience trajectory: a stable trajectory of good mental health following a highly potentially traumatic event or disaster

Resilience blind spot: the tendency to misinterpret initial distress following a potentially traumatic event or disaster as long-term trauma with minimal possibility of resilience

The Resilience Blind Spot

When couched in terms of the broad and sweeping impacts of disaster, the idea of psychological resilience might seem improbable if not impossible. The anguish and anxiety experienced by individuals directly impacted by disaster spread easily across broad swaths of a population through the mechanism of emotional contagion, such that even those not directly affected may feel heightened distress (Perrin et al. 2009). Anxiety and emotional contagion are further accentuated by continuous media attention and the steady stream of provocative images, on-the-spot interviews, analyses, and regularly updated outcome metrics it produces (Looi et al. 2020, Neria & Sullivan 2011). Together, these factors tend to focus public attention on only the direst psychological outcomes, while simultaneously obscuring awareness of the prevalence of psychological resilience. This phenomenon has been referred to metaphorically as a resilience blind spot (Bonanno 2021a,b).

The underestimation of resilient outcomes is often reinforced in early pronouncements from the mental health community. In the aftermath of the 9/11 terrorist disaster, for example, New York city health officials anticipated a looming "mental health crisis" and "began making preparations to train an army of volunteer therapists" (Goode & Eakin 2002), while the Federal Emergency Management Agency (FEMA) earmarked well over a hundred million dollars (the equivalent of hundreds of millions today) to provide the city with free counseling to all those who might seek it. Although many suffered enduring trauma symptoms from the event, the forecasted widespread mental health crisis never materialized (Bonanno 2021a). Nearly the same sequence occurred at the onset of the more recent COVID-19 pandemic. Early on, mental health experts warned of "a historic wave of mental health problems" that would likely overwhelm the country's mental health system (Wan 2020). Again, although there were some people with lasting psychological difficulties, the sweeping mental health crisis did not materialize. Indeed, as we discuss below for both the 9/11 attacks and the COVID-19 pandemic, resilience, and not lasting psychopathology, was the dominant response.

TRAJECTORY STUDIES OF DISASTER OUTCOMES

Disaster studies have typically relied on cross-sectional and sometimes longitudinal-correlational research. Although these studies provide basic information regarding psychological distress in the aftermath of disaster, they are inherently limited, at best capturing a snapshot of immediate sequelae or overall group change but failing to consider more diverse variations in the psychological adjustment over time. While it is important to consider the overall impact of disasters, these limitations have often led to exaggerated ranges of prevalence (Bonanno et al. 2010, Chen et al. 2020). Moreover, because these studies typically assess outcomes unidimensionally, as symptom levels or psychiatric disorders, they have tended to neglect assessments of optimal functioning.

To more robustly interrogate the psychological responses following disasters, longitudinal and prospective studies have increasingly modeled evolving trajectories of psychological outcomes. The four prototypical trajectories repeatedly observed in the aftermath of PTEs, discussed above, have also been observed in the context of disaster. As in research with PTEs broadly, the most common pattern was the stable trajectory of low symptoms and distress—that is, resilience.

Natural and Human-Made Disasters

In the aftermath of natural disasters such as hurricanes and tsunamis, most individuals evidenced a resilient trajectory, regardless of age and time elapsed since the disaster (Johannesson et al. 2015, Pietrzak et al. 2013, Self-Brown et al. 2013). Among older adults residing in areas heavily impacted by Hurricane Ike, for example, 79% were resilient, exhibiting low or no PTSD symptoms across assessments at 3, 6, and 15 months after the disaster, while only 16% and 5% of the participants fell under chronic and delayed-onset trajectories, respectively (Pietrzak et al. 2013). Two years following Hurricane Katrina, similar findings emerged for youth and their mothers (Self-Brown et al. 2013). Specifically, 66% of mothers impacted by Katrina exhibited little or no PTSD symptoms (i.e., resilience), a percentage far exceeding those with chronic (4%) and recovery (30%) trajectories (Self-Brown et al. 2013). Another study examining PTSD symptoms among youth impacted by Katrina identified the same three trajectories, with resilience as the predominant pattern (70%), followed by recovery (27%) and chronic (4%) trajectories (Self-Brown et al. 2013), while another study found that in the aftermath of the Wenchuan earthquake, 81.6% adolescents exhibited low PTSD symptoms (Zhou et al. 2018) and 68% had low to no sleep problems (Zhou et al. 2019). A study that examined posttraumatic stress in Swedish tourists exposed to the 2004 Indian Ocean tsunami 1, 3, and 6 years after the disaster found that 72.3% of the sample remained resilient (Johannesson et al. 2015).

Although a few studies have reported lower resilience rates, these studies typically identified an additional trajectory with a low number of symptoms that never exceeded clinical level. For example, in a study of posttraumatic stress symptoms in children following Hurricane Andrew (La Greca et al. 2013, Lai et al. 2015), 37% of the children showed a low-symptom resilient trajectory, while another 43% showed initially moderate, subthreshold symptoms that dissipated to low levels within the first 10 months of the study. When combined, these two patterns captured 80% of the sample. Another study examined depression trajectories among mothers impacted by Hurricane Katrina (Lai et al. 2015) and found that 29% evidenced a resilience trajectory while another 61% participants fell into a "low" trajectory with mild levels of symptoms over time. Again, when combining these two groups, it is more than evident that most mothers in this study exhibited few to almost no symptoms over time.

Some natural disaster studies have also reported additional trajectories besides the four prototypical patterns. However, these trajectories are often of very low frequency. For example, in a study examining sleep problems following the Wenchuan earthquake, a U-shaped trajectory was identified (Zhou et al. 2019) that was evident in only 3.8% of the sample. However, given the imperative need to replicate these trajectories, classes comprising less than 5% of a sample are typically unreliable in comparison to the more likely replication of trajectories with higher prevalence rate across samples (Nylund-Gibson & Choi 2018).

Human-made disasters, such as terrorist attacks and mass shootings, have also evidenced a high prevalence for the resilience trajectory (Maslow et al. 2015, Nandi et al. 2009, Orcutt et al. 2014, Pietrzak et al. 2014). The resilience trajectory was identified as the modal response in the aftermath of the 9/11 terrorist attacks among police officers (78%; Pietrzak et al. 2014) and rescue and recovery workers (53.3%; Maslow et al. 2015). Among residents of the New York City metropolitan area after the 9/11 terrorist attack, Nandi et al. (2009) reported two low depression symptoms trajectories: one with a mean near zero (39%) and another, falling well below the subclinical level, with a mean of fewer than two depression symptoms (34%). When combined, these two groups indicate that a clear majority of the sample exhibited a resilience trajectory of little or no depression.

Trajectory Studies Based on Prospective Data

The resilience trajectory has been consistently shown to capture a majority of individuals, following both natural and human-made disasters. Yet, these proportions likely underestimate the true prevalence of resilience. Disasters are unpredictable, and psychological data on disaster reactions are commonly obtained retrospectively in the months and years after the disaster's onset. Critically, however, retrospect sampling has been shown to bias trajectory estimates in the direction of greater psychopathology and reduced resilience (Galatzer-Levy et al. 2018a).

A ready antidote to this problem is prospective trajectory research (i.e., mapping trajectories from before to after a major event). Although prospective studies are more difficult to carry out, a growing body of research has leveraged this approach. One study, for example, followed college women prior to a campus mass shooting disaster and continued to do so through 6 assessments across 30 months post-shooting (Orcutt et al. 2014). The majority (61%) were classified in a resilient trajectory of minimal posttraumatic stress symptoms across all time points. Another 29% of this sample showed a recovery trajectory, with a dramatic increase in PTSD after the shooting that returned to a minimal level by 6 months, while a third small group (8%) also had initial symptom elevations but experienced a more gradual recovery. Another prospective study, examining low-income women before and after Hurricane Katrina, classified 62% as resilient and another 22% as showing a recovery trajectory (Lowe & Rhodes 2013). Although prospective studies typically examine a single PTE, one disaster study managed to map depression trajectories from repeated assessments beginning prior to the 2008 economic crisis and culminating after Hurricane Sandy in 2012 (Mandavia & Bonanno 2019). A robust majority (84%) of the sample evidenced a resilient trajectory of low depressive symptoms throughout. This study also identified a novel trajectory of incremental chronic depression characterized by an increase in depression after the 2008 economic crisis and a further increase in symptoms, among the same participants, following Hurricane Sandy. The incremental depression pattern was also the only trajectory linked to significant PTSD symptoms following the hurricane.

COVID-19 AND OTHER PANDEMICS

Pandemics are health-related disaster events that encompass a wide geographic area, include multiple countries or continents, and typically affect large numbers of people (Kelly 2011). As a result of the pandemics' evolving nature, the psychological challenges pandemics present tend to vary markedly over time. For example, the global outbreak of the novel coronavirus disease in late 2019 (COVID-19) was declared a pandemic by the World Health Organization in 2020 and eventually spread across the globe, infecting hundreds of millions and causing millions of deaths. The initial spread of the virus was accompanied by predictable spikes in distress and psychopathology symptoms (Han et al. 2021). These initial responses were characterized by a multifaceted network of related symptoms, with COVID-19 danger and contamination fears at the core (Taylor et al. 2020). Over time, other potentially deleterious secondary consequences cascaded across multiple dimensions (Zhang et al. 2022), including economic loss (Lei et al. 2020), unemployment (Achdut & Refaeli 2020), forced social isolation, and inadequate physical space (Pancani et al. 2021).

The initial psychological cost of the pandemic, coupled with the possibility of cascading waves of secondary impacts, prompted urgent predictions of an unprecedented global mental health epidemic that would likely overwhelm health service resources (Hisham et al. 2021). Despite this dire prognosis, longer-term research on COVID-19, when it became available, revealed a pattern of findings broadly consistent with the literature on disaster resilience. A meta-analysis of prospective and longitudinal COVID-19 studies, for example, indicated that the experience of lockdowns, which many feared would cause significant psychological damage, resulted in only minor overall effects on mental health and no significant effects on positive aspects of psychological functioning, such as well-being and life satisfaction (Prati & Mancini 2021). Complementarily, despite predictions of dramatic increases in suicide (Weems et al. 2020), a time-series analysis comparing data from 21 countries on suicide rates before and during COVID-19 found that suicide prevalence had remained essentially unchanged during the pandemic, and in some countries had even declined (Pirkis et al. 2021).

Trajectory studies bring the prevalence of resilience during pandemics into even greater relief. One of the first applications of the trajectory approach examined hospitalized survivors of the 2003 severe acute respiratory syndrome (SARS) pandemic in Hong Kong (Bonanno et al. 2008). SARS was highly virulent and resulted in alarmingly high mortality rates, especially in the Hong Kong region. Nonetheless, although a large portion of hospitalized SARS survivors from Hong Kong experienced chronically poor mental health, another sizeable portion evidenced a resilience trajectory of stable mental health. Similar findings emerged during the COVID-19 pandemic in trajectory studies conducted across the globe. The resilience trajectory was observed in the majority of individuals assessed during the pandemic in, for example, the United Kingdom (Hyland et al. 2021, Pearce et al. 2021, Shevlin et al. 2023), Poland (Gambin et al. 2023), Israel (Kimhi et al. 2021), the United States (Shilton et al. 2021), Germany (Ahrens et al. 2021), France (Pellerin et al. 2022), Australia (Batterham et al. 2022), China (Chen et al. 2022), and Argentina (Fernández et al. 2022). A recent review of 28 trajectory studies conducted during COVID-19 indicated a striking level of similarity with trajectory studies conducted prior to the pandemic (Schäfer et al. 2022). The resilience trajectory was, in fact, observed at essentially an identical prevalence, 66% on average across studies, as in pre-pandemic studies (Galatzer-Levy et al. 2018a). The chronic symptom and delayed symptom trajectories were also observed at a similar frequency. However, there were two meaningful exceptions. The recovery trajectory was less prevalent during COVID-19 (13%) than in pre-pandemic studies (21%). Additionally, a trajectory of mild/moderate distress, relatively uncommon in pre-pandemic analyses (15%; Galatzer-Levy et al. 2018a), was observed almost twice as frequently (27%) in pandemic studies, likely the result of the more extended course of the pandemic.

CORRELATES OF RESILIENCE IN THE AFTERMATH OF DISASTER

Trajectory models of disaster outcome afford researchers a valuable opportunity to interrogate predictive correlates of long-term mental health patterns. A surprisingly large number of factors have been shown to correlate with resilience outcomes (for reviews, see Bonanno et al. 2010, Chen et al. 2020, Newnham et al. 2022, Schäfer et al. 2022). For example, among individuals experiencing the Indian Ocean tsunami, the number of stressors—an index often used to quantify exposure severity—was associated with decreased likelihood of being in a resilience trajectory

(Johannesson et al. 2015). The nature of a specific stressor, another way to conceptualize exposure severity, has also been identified as a correlate of disaster trajectories. For example, initial loss, daily disruptions, and community violence differentiated between chronic and resilience trajectories of PTSD symptoms among youth impacted by Hurricane Katrina (Self-Brown et al. 2013). The subjective perception of threat appears to be especially crucial. For example, perceptions of danger during the 9/11 terrorist attacks were associated with decreased likelihood of resilience regardless of objective levels of exposure (Bonanno et al. 2005).

Individual differences in demographics, economic resources, coping and emotion regulation, and genetics are frequently found to correlate with resilience outcomes. Following 9/11, men, older adults, and Asians were more likely to be resilient, while, conversely, those who experienced income loss were less likely to (Bonanno et al. 2007). When facing natural disasters, resilient outcomes were more likely among individuals with higher levels of educational attainment and more reliable employment (Mandavia & Bonanno 2019, Tang et al. 2014). Unsurprisingly, preexisting mental illness and other psychopathology symptoms have often been identified as predictors for more symptomatic (i.e., nonresilient) trajectories (Heid et al. 2016, Mandavia & Bonanno 2019, Zhou et al. 2019), while higher negative affect (Mandavia & Bonanno 2019), poorer emotion regulation (La Greca et al. 2013), and decreased flexibility (Westphal et al. 2010) have been associated with a reduced likelihood of being in a resilience trajectory. Moving from intrapersonal to interpersonal, social support has been commonly identified as a correlate of resilience following both natural and human-made disasters (Bonanno et al. 2007, Lai et al. 2015, Mandavia & Bonanno 2019). Although relatively few studies have examined resilience at the family and community level, emerging evidence indicates that higher social cohesion (Heid et al. 2016), lower crime rates (Mandavia & Bonanno 2019), and less community exposure to disaster (Gruebner et al. 2016) are associated with resilience outcomes.

THE RESILIENCE PARADOX

How do we make sense of the many factors associated with resilient outcomes? One particularly common explanation is that not all traits and behaviors associated with resilience are important, but only the most meaningful are. By this logic, people who have acquired the key traits and behaviors have a resilience personality that allows them to adapt well in the face of future adversity (Skodol 2010). The idea is intuitively appealing and has the bonus that it can be easily measured by self-report questionnaires.

Unfortunately, there are significant problems with the resilience personality concept. For starters, although several resilience scales have been published (e.g., Connor & Davidson 2003, Gartland et al. 2011), each tends to include different traits. If people are resilient because they possess the key ingredients, as these scales assume, then each scale is necessarily incomplete. Complementarily, these scales fail to explain why so many of the empirically identified correlates of resilient outcomes are not included in the personality, or why these factors may nonetheless still influence resilient outcomes. Most critically, although resilience scales are generally correlated with health and well-being, they do not hold up to their promise when tested in longitudinal or prospective research.

Resilience Scales Do Not Predict Resilience

A true test of a resilience personality scale is whether the scale actually predicts future resilient outcomes. To our knowledge, no such data exist. Alternatively, a less stringent test would examine whether a resilience scale predicted future mental health after the occurrence of a PTE, net of baseline mental health. Although resilience scales have been developed for specific use in the context of disasters, the predictive validity of these scales has not been reported. Five studies have, however, tested the predictive validity of resilience scales across a range of PTEs. Three studies assessed resilience scales prospectively among samples of military peacekeepers prior to deployment (Thomassen et al. 2015), a sample of police trainees prior to active-duty police work (van der Meulen et al. 2018), and a representative sample of the Israeli population prior to the so-called July 2015 wave of terror (Kimhi et al. 2020). A fourth study assessed a resilience scale longitudinally in active-duty police officers (Marchand et al. 2015). In each case, the resilience scale failed to effectively predict post-adversity mental health over and above baseline mental health.

Resilience scales also fail to predict future resilience to stress following adversity. Another prospective study, of relevance for this article, had fortuitously assessed two different types of resilience scales, one measuring trait resilience and another measuring resilience as a process (Engert et al. 2021). The researchers then examined the ability of these scales to predict biological and psychological stress reactivity 8 months later, well into the pandemic. Neither resilience scale showed any predictive effects. Another study tested whether a resilience questionnaire predicted responses to stress in a controlled experimental setting (Roth & Herzberg 2017). In this study, students first completed the resilience personality measure and then participated in a stress test in which they were required to give an oral presentation with minimal time for preparation to a purported panel of experts who would determine their suitability for university study. Students scoring as resilient personalities reported low distress both before and after the stress test, while the supposed nonresilient students reported greater distress after the task. On objective measures, however, such as physiological and nonverbal markers of stress, all students, including the resilient personalities, evidenced increased stress during the presentation task. In summarizing these findings, the authors concluded that the resilience personality may be nothing more than a "self-deception artifact" (Roth & Herzberg 2017).

Small Effects, Situational Variability, and Cost-Benefit Trade-Offs

Why would scales comprised of traits that are generally associated with resilience not actually predict resilience? The most salient reason, hiding in plain sight as it were, is the resilience paradox (Bonanno 2021a,b). The paradox describes the fact that although many purported resilience-promoting factors correlate with resilient outcomes, the size of their associations with actual resilient outcomes is almost always modest. Moreover, because these factors tend to correlate with each other, when combined their individual contributions tend to be even smaller. Thus, the individual correlates of resilient outcomes are at best weak predictors of future resilient outcomes.

It is important to point out here that small effects by themselves are not a fatal problem. Rather, they are an unavoidable, even essential, consideration in psychological science (Funder & Ozer 2019, Götz et al. 2022). The difficulties arise only when we fail to consider the nature of small effects or assume that such effects are more influential than they truly are. This failure is evident in many conceptions of resilience and is especially pernicious in programs designed to build resilience (Chmitorz et al. 2018).

A well-known contributor to small effect sizes is situational variability. Although this consideration is often disregarded when considering resilience, the challenges inherent in PTEs vary markedly across events. Situational variability is even more pronounced in the context of the intense and unpredictable course of disasters. Coping with a hurricane, for instance, is different than coping with a disease pandemic, which in turn presents unique challenges compared to a large-scale terrorist attack. Disasters also produce variability within the same event over time: The challenges a person must confront at the onset of a disaster are likely to change many times over in the days and weeks following the event.

Another underappreciated contributor to small effects is the natural cost-benefit trade-off inherent in virtually all human and animal behaviors (Georgiev et al. 2013, Hubel et al. 2016). A classic example from the animal literature is the peacock's colorful tail. The stunningly beautiful colors of the peacock's tail appear to have evolved for the primary purpose of enticing the peahen to mate. This benefit, however, is counterbalanced by significant costs. For one, the tail is heavy and makes flying much more difficult. Even more crucially, the size and bright colors of the tail are a clear signal to predators of the precise location of a large, meaty bird that cannot easily escape (Darwin 1871, Prum 2017).

Fallacy of uniform efficacy: the assumption that a trait or behavior is uniformly adaptive with little or no cost

Most conceptions of resilience ignore these considerations. These theories propose a small number of essential resilience-promoting factors (Chmitorz et al. 2018) with little or no acknowledgment of their situational variations or possible costs. This oversight is known as the fallacy of uniform efficacy (Bonanno & Burton 2013). The empirical evidence shows clearly that the consequences of different strategies and behaviors are far more equivocal. Research shows, for example, that social support, one of the most commonly identified resilience-promoting factors, is neither universally adaptive across situations nor free of costs (McClure et al. 2014, Southwick et al. 2016). Depending on the cause of their distress, people may feel incapable of social interactions and the reciprocity they require (Bonanno 2021a). Even when support is possible and effectively creates feelings of closeness, it may nonetheless still increase distress (Gleason et al. 2008), particularly if the quality of support is low (Afifi et al. 2013). Social support can also result in the loss of equity in relationships (Gleason et al. 2003) as well as a sense of reduced personal efficacy (Bolger & Amarel 2007). Beyond social support, situational variation and cost-benefit trade-offs have also been shown to characterize other widely touted resilience-promoting factors, such as positive emotions (Gruber et al. 2011, Kalokerinos et al. 2017) and cognitive reappraisal (Troy et al. 2013).

Complementarily, behaviors assumed to be generally maladaptive, such as emotional suppression or focusing on threat, have been found to be highly adaptive in some situations (Bonanno et al. 2004, Galatzer-Levy et al. 2014b, Messman-Moore & Brown 2006). For example, although there is evidence for the short-term costs of suppressing emotional expression, a meta-analysis of over 300 experimental studies indicated that there was considerable variability across studies and experimental contexts, and on balance expressive suppression was moderately effective (Webb et al. 2012). Studies that measured expressive suppression as an ability have linked that ability to positive long-term outcomes. For example, the ability to suppress emotional expression measured after the 9/11 terrorist attacks predicted reduced distress 2 years after the attack, net of initial distress (Bonanno et al. 2004). It is important to note, here as well, that the efficacy of any regulatory strategy will also depend on other possible contextual factors, including the proximal use of other regulatory behaviors and strategies (Chen et al. 2018) and overall regulatory ability (Tull & Aldao 2015).

MODELING COMPLEX TIME-SPECIFIC DATA

How, then, can we predict and promote resilience when resilience is the result of highly individualized, time-specific small effects that interact with contextual factors and even each other (Kalisch et al. 2017)? Traditional statistical approaches, which are designed to test null hypotheses regarding a narrow set of predictors, are not equipped to adequately respond to this question. Increasingly, however, a class of mathematical algorithms that attempt to learn reproducible patterns from data, generally subsumed under the rubric of ML, have been increasingly employed to overcome these limitations (Galatzer-Levy et al. 2018b).

Supervised and Unsupervised Machine Learning

Unsupervised and supervised machine learning (ML): unsupervised ML learns relationships between variables without reference to a defined category, while supervised ML learns to predict defined categories

Two classes of algorithms have most commonly been applied to understand the complex interplay between mechanisms and outcomes following potential trauma. The first, unsupervised ML, aims to learn relationships between variables without reference to an explicit outcome, such as a diagnosis. Unsupervised models reduce data complexity by identifying latent (not directly observable) structures that can be applied to render the information in high-dimensional data more accessible. Examples include principal components analysis, which seeks to extract shared variance components across features, and LGMM, as discussed above, which takes a data-driven approach to identify latent trajectories of responses.

A second class of algorithms, supervised ML, aims to learn and apply a function that accurately predicts a specified outcome, such as trajectories, based on a set of inputs (Mohri et al. 2018). While there are many different types of supervised algorithms, with each operating somewhat differently, generally they follow an initial model-training step in which the algorithms either separate predefined groups (supervised classification) or predict a real number value (supervised regression). Such approaches build on traditional statistical hypothesis testing through model optimization, in which myriad relationships between variables are tested as predictors of outcome. The ultimate aim of supervised ML models, however, is to integrate knowledge into an automated framework that is pragmatically effective in making predictions in new scenarios. For this reason, model testing in supervised ML eschews traditional probability values, which compare relationships in the data against chance, and instead use metrics of accuracy in predicting new cases. Supervised ML algorithms make new predictions by applying weights (akin to beta weights in regression) to predictor inputs that have been learned through the model-training and optimization steps with the goal of reproducing the same accuracy of prediction in new situations (for a basic primer on ML, see James et al. 2021 and the companion website at **https://www.statlearning.com**).

Combining Machine Learning Approaches to Enhance Prediction

ML approaches of various kinds are often combined to model more complex representations of the world. Our team has begun to use supervised models to predict unsupervised trajectories of outcome following aversive life events, a combination that has been shown to increase predictive accuracy over conventional methods (Galatzer-Levy et al. 2014a). Below we review two recent studies that used the combined approach to examine PTEs in general and a third study that recently employed the combined approach in the context of the COVID-19 pandemic disaster.

Schultebraucks et al. (2020) examined a large set of biological and psychological measures, obtained during admission to an Emergency Department following a potential trauma, as predictors of subsequent trajectories of PTSD symptoms, including the low-symptom resilience trajectory. This early window for prediction is appealing to both researchers and clinicians, as multiple assessment measures are obtainable as part of routine care. However, although many of these assessment measures have independently shown associations with posttraumatic stress in previous studies, similar to the resilience paradox their ability to robustly predict longitudinal outcomes has been relatively poor. By utilizing a combined ML classification method, this study showed that the algorithmic combination of early measures was able to more reliably predict resilience and other symptom trajectories over the subsequent 12 months. Moreover, the resulting algorithm demonstrated equivariant accuracy in another, independent population from a different emergency room using data collected by an independent research team.

In another study, Schultebraucks et al. (2021) used the combined approach to model genetic predictors of resilience and depression symptom trajectories in a population-based data set of individuals exposed to diverse PTEs. A conventional genomic analysis tests candidate single nucleotide polymorphisms against a clinical diagnosis. However, this approach has failed to produce robust effects and has proved uninformative about broader patterns of dysfunction and resilience (Border et al. 2019). To address these limitations, Schultebraucks et al. (2021) examined the predictive accuracy of 21 unique polygenic risk and protective scores. Each polygenic score had previously been abstracted from genome-wide association studies of psychiatric disorders, biological mechanisms, psychological characteristics, or health-related cognitive and behavioral indices. Schultebraucks et al. (2021) combined 21 polygenic scores in a deep neural net to predict the overall trajectory patterns and showed clear improvement in discriminatory accuracy.

Recently, we applied the combined ML approach to disaster, specifically to assess the immediate aftermath of the strict COVID-19 lockdown in Hubei, China (Chen et al. 2022). The question of how large urban areas might best manage a major disease outbreak has become an imperative global concern. The Hubei province in China was an ideal location to examine this question as the COVID-19 pandemic first emerged there and, subsequently, the region experienced one of the strictest lockdowns to date. To capture the large range of factors that might influence pandemic outcome, we assessed 59 possible predictors, including both person-level variables, such as optimism, body mass index, COVID-19 worries and fears, and information consumption, and context-level variables, such as housing prices, number of local COVID-19-equipped hospitals, neighborhood socioeconomic status, and urban versus rural residence. Using unsupervised ML, we identified trajectories for three different symptom types: depression, anxiety, and PTSD. Then, we used Least Absolute Shrinkage and Selection Operator (LASSO)—a type of supervised ML—to demonstrate that various combinations of variables effectively predicted the resilience and chronic symptom trajectories.

RESILIENCE THROUGH REGULATORY FLEXIBILITY

Despite their computational sophistication, the combined ML models described above fall short of fully addressing the resilience paradox. On a practical level, for example, at least some of the predictors accommodated in ML models are likely to be unavailable or inaccessible, which is an especially relevant concern in the aftermath of chaotic and unpredictable events like disasters. When this happens, predictive accuracy drops precipitously. In Schultebraucks et al.'s (2020) Emergency Department study, discriminatory accuracy was reduced to a fair level when only biological variables were considered and was even weaker, falling to a poor level, when only psychological variables were considered. A related concern is that, although overall prediction for ML models is generally robust, the predictive accuracy of specific trajectory patterns varies markedly. In Schultebraucks et al.'s (2021) study of polygenic scores, prediction was in the excellent range for the chronic depression trajectory but only in the fair range for the resilience trajectory, while in Chen et al.'s (2022) China lockdown study, this pattern was reversed.

Predictive concerns aside, an even more critical issue is that ML models have not yet illuminated the mechanisms by which individuals facing extreme adversity make sense of and utilize the complex array of behaviors, traits, and resources potentially available to them. Given the well-replicated evidence that most people show resilient outcomes, even in high-uncertainty situations like disasters, it is reasonable to conclude that most people are also able to accomplish this task. But how? It is generally accepted that the human brain rapidly generates goal-based predictions based on prior experience and then adjusts those predictions according to feedback generated through exploratory behavior (Lillicrap et al. 2020). While such processes can be understood in terms of basic computational and neurobiological processes, it remains unclear how they might translate to the task of adapting to complex, unpredictable, and larger-scale scenarios such as disasters.

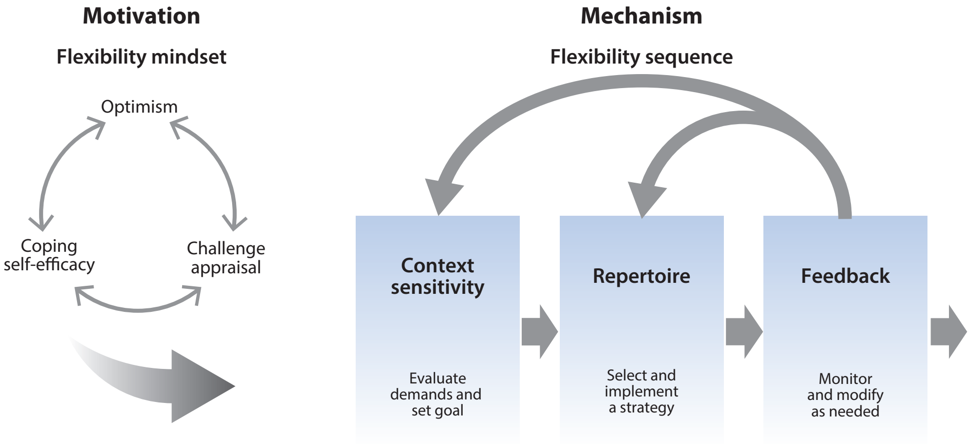

Figure 3

Motivational and mechanistic components of regulatory flexibility. Figure adapted with permission from Bonanno & Burton (2013).

A promising solution is suggested by the burgeoning literature on regulatory flexibility (Bonanno & Burton 2013, Cheng et al. 2014, Kashdan & Rottenberg 2010). Although theoretical conceptions of flexibility vary in scope and focus, they share two fundamental components: a motivational component that propels individuals to adjust their behavior to match situational challenges, and a mechanistic component through which those adjustments come about. These components, which we refer to here as the flexibility mindset and flexibility sequence , respectively, have been proposed as the primary means by which trauma-exposed individuals reach resilient outcomes (Bonanno 2021a,b). We review each component in more detail below and graphically in **Figure 3**.

Motivation: The Flexibility Mindset

Flexibility mindset: interrelated beliefs or attitudes that form a broad motivational conviction that adaptation to adversity is possible

Flexibility sequence: three components of flexible self-regulation—context sensitivity, repertoire, and feedback—that unfold in sequential order

Motivation is intrinsic to flexible adaptation. The processes implicated in both motivation and flexibility show overlapping neural pathways (Keefer et al. 2021) and utilize similar neuromodulators (Jahn et al. 2018). The motivational processes specific to psychological flexibility can be summarized in several interrelated attitudes or beliefs that together form a broad conviction, or flexibility mindset (Bonanno 2021a,b). The beliefs that comprise the flexibility mindset also correlate with resilience, albeit with the same modest effects as other correlates. We argue in this case that their modest effect on resilient outcomes is due to their indirect relationship as motivating factors for the more direct mechanisms of flexibility. One such belief, captured in the tendency toward optimism, serves a motivational function by instilling a willingness to make the adjustments necessary to bring about an expected positive future (Carver & Scheier 2014). Research during the COVID-19 pandemic revealed that the link between stress and mental health was mediated by a path from optimism to flexibility, which, in turn, led to reduced psychological problems and better mental health (Arslan & Yıldırım 2021). Optimism, in turn, has evidenced bidirectional connections with two other motivating factors also associated with both flexibility and resilience (Bonanno 2021a): the belief in one's ability to cope effectively, known as coping self-efficacy (Benight & Cieslak 2011, Zimmer-Gembeck 2021), and the tendency to view threats as challenges, known as challenge appraisal (Delegach & Katz-Navon 2021).

Together, these mutually reinforcing beliefs appear to synergistically create a powerful conviction (Bonanno 2021a,b) that can serve an especially important motivating function in the context of disasters. The high level of distress and uncertainty inherent in disasters renders these events not only difficult to cope with but also difficult to comprehend. Beliefs that there is value in embracing the challenge, and that one is able to, and ultimately will, effectively move forward to a positive future, provide the motivational thrust needed to process these events, both cognitively and emotionally, and to initiate the behavioral adjustments they might require.

There are, of course, other motivations that may come into play, including those that could impede flexibility. For instance, the need for closure, characterized by an intolerance of ambiguity and uncertainty, has been shown to reduced flexibility (Cheng 2003). Individuals high on the need for closure become inflexible when they seize on an immediate solution or habitual regulatory strategy, and then they rigidly fix on that solution without considering other possible alternatives. In the high-uncertainty context of disaster, this propensity would likely exert a strong negative impact on flexible responding.

Mechanism: The Flexibility Sequence

Psychological flexibility was originally operationalized along a single flexibility/inflexibility questionnaire dimension (Bond et al. 2011, Hayes et al. 2004). Although recently expanded (Kashdan et al. 2020), this approach still says little about underlying mechanisms. Experimental research on flexible regulation, on the other hand, implicates several distinct mechanisms (Aldao et al. 2015, Bonanno & Burton 2013, Cheng et al. 2014) that can be summarized in three sequential steps, context sensitivity, repertoire, and feedback, referred to collectively as the flexibility sequence (Bonanno 2021a,b).

The efficacy of regulatory behaviors is heavily dependent on the situational context in which they occur (Aldao 2013). Accordingly, the first step in the flexibility sequence, context sensitivity (Bonanno & Burton 2013; see also Cheng 2003 on discriminative facility), involves decoding a situation's unique challenges and opportunities and then determining a goal for subsequent behavior. Goals are typically proximal (e.g., reducing distress or solving an immediate problem) but may also incorporate longer-term aims and values (e.g., preparing for future difficulties or caring for loved ones) (Aldao et al. 2015, Cheng 2001, Kashdan et al. 2020). The ability to assess and utilize contextual information has been linked to better adjustment to adverse events (Bonanno et al. 2020, Coifman & Bonanno 2010), including disaster (Västfjäll et al. 2014) and, recently, the COVID-19 pandemic (Lenzo et al. 2021).

Once a context-relevant goal is established, the next step of the sequence involves the implementation of a strategy from a person's repertoire of possible strategies that offers the highest probability of meeting that goal (Bonanno & Burton 2013). The scope of a strategy repertoire varies across people and the life span (Zimmermann & Iwanski 2014) and, in general, has been associated with improved adjustment in the face of disaster (Bonanno et al. 2004, Chen et al. 2022, Lenzo et al. 2021). Critically, however, effective regulation depends not so much on using multiple strategies but rather on the fit between the implemented strategy and the specific situational challenges (Bonanno et al. 2004, Cheng 2001, Cheng et al. 2014). Situation–strategy fit has been found to be especially important for adaption to the often-changing conditions of disaster (Cheng et al. 2021, Shabat et al. 2021).

A third, crucial step in the sequence involves monitoring and responding to feedback regarding the efficacy of the implemented strategy (Bonanno & Burton 2013). Choosing an optimal regulatory response is essentially a probability estimate, and sometimes that estimate fails to achieve or may even interfere with goal pursuit. This outcome has been described as maladaptive flexibility

(Aldao et al. 2015). However, the feedback step of the flexibility sequence accommodates the problem of ineffective strategy choice using the built-in, self-corrective mechanism inherent in the flexibility process. As in ML algorithms, the fit between a strategy estimate and goal-driven expectations can be improved with corrective feedback (Harkin et al. 2016, Rieskamp & Otto 2006). Moreover, although the ability to utilize regulatory feedback varies among individuals, people who effectively update their strategy use through feedback evidence better short-term affective and neurobiological adaptation and overall better mental health (Birk & Bonanno 2016, Dorman Ilan et al. 2019).

Although much of the research on the flexibility sequence has focused on individual steps, recent studies have tested some of the central predictions about the sequence itself. For example, since most people show resilient outcomes, a key prediction is that most people should also be able to utilize all three steps in the sequence (Bonanno 2021b). Consistent with this prediction, latent profile analyses of data from two independent samples found that a majority in both samples had at least a moderate level of skill in all three steps and that the combination of these skills, in turn, was associated with better mental health (Chen & Bonanno 2021). A second key prediction is that psychological adaptation to aversive events comes about via the pathway specified by the flexibility sequence (i.e., context sensitivity to repertoire to feedback). To test this idea, Robinson et al. (2022) employed a series of sequential mediation models to predict three different outcome measures (depression, anxiety, and PTSD) in a trauma-exposed population. Both skill in the individual steps of the sequence and the various combinations of pairs of steps showed modest but inconsistent prediction of the outcomes. Only the serial pathway through all three steps of the sequence consistently predicted better adjustment on all outcome measures.

CAPTURING REGULATORY FLEXIBILITY IN REAL TIME

We reviewed research and theory supportive of the proposition that resilient outcomes in the aftermath of PTEs, including unpredictable, life-threatening events such as disasters, emerge through the process of regulatory flexibility. As this work indicates, regulatory flexibility is not a singular activity but rather involves two related sets of components: a motivational component, consisting of interrelated beliefs centered on the idea that challenges can be overcome with effort, and a mechanistic component, driven by a sequence of steps involving assessment of a situational challenge, selection of a strategic response from one's repertoire of possible responses, and use of feedback to assess, revise, or replace that response as needed. By extension, this work also indicates that the routine and inflexible reliance on any single response, be it repetitive use of a specific coping or emotion regulation strategy or singular reliance on a specific resource, tend to result in poor adaptation and possibly enduring psychopathology.

We argued that regulatory flexibility involves the rapid, iterative, real-time process of optimizing strategy use in service of adaption to a specific challenge. However, a fair assessment of the existing research on flexible self-regulation can only conclude that this research has yet to fully capture how this process unfolds in real time. Although the literature on the components of regulatory flexibility has led to considerable methodological and conceptual advances, with few exceptions research in support of that literature has been limited to questionnaire or laboratory measures obtained at a single point in time, independent of outcome or as a static predictor of future outcomes.

How, then, could this research be organized to better capture flexibility in action? First, to adequately examine the relationship between a more granular flexibility process and adaptation, these data points will need to be nested within changing patterns of adjustment, as captured for example in individual outcome trajectories. To achieve this, a window of measurement will need to be established, ideally with at least one assessment prior to the PTE to allow for identification of prospective trajectories (Bonanno et al. 2015) and several assessments in the follow-up period to capture variations in outcomes. Interpretation of the resultant trajectories should be couched in comparison to the prototypical trajectories that have been conserved across relevant dimensions of psychological health (e.g., levels of symptoms and distress, sleep quality, and well-being) and commonly exposed populations (e.g., assault victims, first responders, natural disaster survivors).

Second, the concept of flexible adaptation forces us to think beyond main effects and trait predictors and to instead assume interdependent and interacting systems with multiple constituent parts. While behavioral phenomena, such as sleep, are often measured by simple questionnaire items at a cross-section, within this formulation they can instead be recognized for their complex biological, psychological, and social aspects along with how they might change dynamically in response to environmental perturbation. Moderators of interest, in this case, might involve variations in emotion regulation or coping strategies, resource utilization, trait-like propensities, and active or passive social processes and practices.

This approach introduces opportunities across dimensions to assess and triage for risk and possible points of intervention that may influence the trajectory of response. Although the flexibility sequence concept arose out of an empirical tradition, with the bulk of the research aimed at either articulating its components or testing their adaptive influence on long-term adjustment, the concept seems ripe for development as an intervention strategy. Some individuals, for example, have shown clear deficits in specific components of regulatory flexibility that could easily serve as the conceptual basis for specific targeted interventions (Bonanno et al. 2023, Chen & Bonanno 2021). Addressing this issue would be akin to research in the area of treatment selection, which has demonstrated that outcomes can be improved by algorithmically matching a patient's background and current presentation to the treatment that is statistically most likely to result in an optimal response (Cohen & DeRubeis 2018). Because the potential dimensionality of ongoing measurement is so expansive, however, it will be important for researchers to utilize prior knowledge to guide the identification of both the likely systems involved and their most accessible proxy measures.

The regulatory flexibility concept also dictates consideration that a given individual may employ a diversity of behaviors and strategies at any time in any given context. It is already possible to capture dynamic variations of this sort using currently available repeated assessments methodologies, such as ecological momentary assessment (EMA). Although the data produced by EMA are often relatively crude (e.g., they rely primarily on self-report), these procedures nonetheless dramatically increase the accuracy of measurement of real-world activities over more conventional static assessments (Burke et al. 2017). A recent study demonstrated the potential of EMA as a tool for capturing the interplay between the flexibility sequence and adjustment in real time (S. Chen, X. Han, P. Sun & G.A. Bonanno, unpublished observations). Specifically, this study assessed continuous relations between sensitivity to contextual variation, use of strategy repertoire, and maintenance or change of strategy in relation to momentary measures of anxiety, depression and perceived stress captured multiple times daily over a 21-day period. Moreover, these findings, generated in the United States, were replicated in an independent sample in China, demonstrating the generalizability of the approach.

As technological innovations become increasingly available to the scientific community, however, granular assessments of the flexibility process should be able to advance apace. Paradigms developed to directly index stress and flexible regulatory ability in laboratory settings are already moving beyond the laboratory and into daily life. It is becoming increasingly plausible, for example, to capture dynamic, event-linked changes in psychophysiological and behavioral variables using passive data collection from remotely connected devices, such as wearables or smartphones (Konstantinou et al. 2020). As a potential next step, it would be possible, for instance, to better capture the dynamics of flexible self-regulation by combining passive data sources with repeated, brief, event-related self-report data garnered through EMA.

Finally, there is an essential question about how to model and statistically evaluate such rich data sources once they become available. Across research areas advocating for greater resolution in psychological measurement and intervention, there is a unified recognition of the need for advanced data modeling techniques that can integrate large, diverse data sources across time and perturbations caused by discrete events (Hebbrecht et al. 2020, Hitchcock et al. 2022, Lunansky et al. 2022). We outlined above the underlying principles of unsupervised and supervised ML models that are designed to solve classification and probabilistic prediction problems using high-throughput, high-dimensional data. An important step forward once appropriate data sources are generated is to directly model the components of regulatory flexibility. How do people pull from their internal and external resources to make a momentary decision in an attempt to improve their situation when they are under duress and then revise that process when needed? Understanding the interplay of contextual assessment, situation-specific goal setting, decision making, implementation, feedback, and adjustment requires both granular information and models that can update the classification and prediction at a rate consistent with behavior.

To achieve this aim, applied researchers might borrow from new classes of ML that currently have only been utilized in basic science research. These models elaborate on the basic principles outlined above to predict, and even influence, decision making based on dynamic changes in an individual's state and needs (Galatzer-Levy et al. 2018b). For example, analytic approaches used in basic animal neuroscience research, such as reinforcement learning (RL) models, aim to understand how animals explore and learn through real-time feedback so they might optimize their behavioral actions for maximal reward. The RL approach has also been used effectively in human research to capture prototypical emotional responses (Broekens et al. 2015). Given comparable forms of granular data and system perturbation, we suggest that RL, or similar approaches, might also be adapted for research on the components of regulatory flexibility during the course of real-time stressful life events.

Prognostications of future advancements in science, however, are often notoriously inaccurate. We proposed that research and mathematical models that capture the dynamic patterns of response and adaptation are the most probable means of advancing our understanding of how humans optimize for resilience under extreme uncertainty. Whatever form future research takes, our hope is that it will continue to push the bounds of our understanding beyond simple binary models of psychopathology/non-psychopathology and toward more fine-grained insights into how motivated exploration and adjustment drive heterogeneous outcomes, in particular resilience, following high-uncertainty events like disasters.

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