Functional neuroimaging of resilience to trauma: convergent evidence and challenges for future research

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Conflict of Interest

Dr Feder is named co-inventor on a patent application in the US, and several issued patents outside the US filed by the Icahn School of Medicine at Mount Sinai related to the use of ketamine for the treatment of PTSD. This intellectual property has not been licensed. Dr. Perez-Rodriguez has received research grant funding from Neurocrine Biosciences, Inc, Millennium Pharmaceuticals, Takeda, and AI Cure. She is a consultant for Neurocrine Biosciences, Inc. and Alkermes. She has served on an advisory board for Neurocrine Biosciences Inc. Drs. Norbury and Seeley have no conflicts of interest to declare.

Abstract

Resilience is broadly defined as the ability to adapt successfully following stressful life events. Here, we review functional MRI studies that investigated key psychological factors that have been consistently linked to resilience to severe adversity and trauma exposure. These domains include emotion regulation (including cognitive reappraisal), reward responsivity, and cognitive control. Further, we briefly review functional imaging evidence related to emerging areas of study that may potentially facilitate resilience: namely social cognition, active coping, and successful fear extinction. Finally, we also touch upon ongoing issues in neuroimaging study design that will need to be addressed to enable us to harness insight from such studies to improve treatments for – or, ideally, guard against the development of – debilitating post-traumatic stress syndromes.

Introduction

Trauma exposure does not invariably result in adverse psychiatric outcomes. Epidemiological estimates for clinically significant posttraumatic stress symptoms range from 5-22% after exposure to natural disasters, severe injuries, or assault, to 46-65% after sexual violence ((Bromet, Karam, Koenen, & Stein, 2018; Shalev, Liberzon, & Marmar, 2017; Watson, 2019). Similarly, 10-25% of those exposed to significant childhood maltreatment show better-than-expected functioning (Walsh, Dawson, & Mattingly, 2010).

Broadly, resilience is defined as successful adaptation following trauma, adversity, or stressful life events (Feder, Fred-Torres, Southwick, & Charney, 2019; Kalisch et al., 2017; Southwick, Charney, & DePierro, 2023). Beyond vulnerability or risk for psychiatric disorders, resilience requires having experienced adversity or trauma (Yehuda & Flory, 2007) (**Box 1: Quantifying trauma**). Resilience research aims to identify mechanisms to improve prevention and treatment of posttraumatic stress and trauma-related disorders. In neuroimaging studies, resilience is typically defined as absence of psychopathology despite exposure to adversity or trauma, but in some studies *alternatively* as high scores on measures of trait resilience, e.g., the Connor-Davidson Resilience Scale (CD-RISC) (Connor & Davidson, 2003a) (**Box 2: Quantifying resilience**), notwithstanding significant variation in its operationalization and measurement (Denckla et al., 2020; Feder et al., 2019; Kalisch et al., 2017; Southwick et al., 2023).

Resilience-related psychological factors

Despite these definitional differences, decades of research have identified psychological factors that promote resilience to trauma and severe adversity. Some widely replicated and potentially modifiable factors include effective emotion regulation, positive emotionality, cognitive flexibility and control, facing fears and active coping, and ability to harness social support (reviewed in (Seeley, Boukezzi, DePierro, Charney, & Feder, In press; Southwick et al., 2023)). Effective emotion regulation is associated with higher executive control and supports adaptive coping. Facing fears, likely facilitated by successful fear extinction plus cognitive flexibility, allows for critical appraisal of threats and active coping via tackling stressors or

problem solving. Positive emotions and related reward system function also promote resilience by supporting positive reframing and the ability to harness social support, which in turn serves as a safety net and facilitates stress recovery. The ability to harness social support draws partly on competent social cognition – capacity to accurately 'read' and respond to others' intentions of others – making social cognition a potential resilience-linked factor.

The current review: neural correlates of psychological factors in resilience

Building on work identifying core psychological factors associated with resilience (Feder et al., 2019; Seeley et al., In press; Southwick et al., 2023) and previous neuroimaging resilience reviews in adults and/or youth (Méndez Leal & Silvers, 2021; Moreno-López et al., 2020; van der Werff, van den Berg, Pannekoek, Elzinga, & Van Der Wee, 2013), our narrative review covers human fMRI studies of neural circuitry underlying psychological factors associated with resilience to trauma and severe adversity. We organize fMRI studies around *emotion regulation*, *reward responsivity*, and *cognitive control*, e.g., (Dennison et al., 2016; Holz, Tost, & Meyer-Lindenberg, 2020; Kaldewaij et al., 2021; van der Werff et al., 2013). As described above, *active coping*, *facing fears* (and related fear extinction) (Careaga, Girardi, & Suchecki, 2016), and the ability to harness *social support* (including competent *social cognition*) (Lepore & Kliewer, 2019; Stevens & Jovanovic, 2019) have also been linked to resilience, yet there are fewer resilience neuroimaging studies of them as resilience-related psychological factors. Here, we include these factors as "emerging areas", as they might illuminate additional pathways to resilience and underlying neural circuitry.

Cross-sectional fMRI studies of resilient individuals typically focus on *(1)* youth and adults who have experienced childhood maltreatment or *(2)* adults exposed to trauma in adulthood including severe accidents, assaults, or occupation-related incidents (e.g., first-responders, military). In this narrative review, we only discuss cross-sectional studies with a key comparison group of healthy, non-trauma-exposed participants (in addition to resilient and symptomatic groups), because this allows researchers to disentangle effects of trauma exposure and psychopathology (see van der Werff et al., 2013). Also included are several studies of neural correlates of high trait resilience.

We focus on literature published after van der Werff and colleagues' 2013 review. Due to recent large cohort studies and improved reporting standards for neuroimaging, this allows us to focus on better powered work. Within each section, we first cover cross-sectional findings in resilient trauma survivors (children; adults) and high trait resilience (when available). Additionally, we discuss longitudinal studies and a few available interventional studies that contribute new insights on the neural correlates of resilience. Although most studies reviewed here focus on task-based regional brain activity, we also include relevant functional connectivity findings, including resting state fMRI.

[Box 1 around here]

[Box 2 around here]

Functional neuroimaging of resilience mechanisms

Emotion regulation

Successful emotion regulation is key in resilience (Troy & Mauss, 2011). Resilient individuals downregulate neural responses to stress or threat via medial prefrontal cortex (mPFC) inhibition of emotional reactivity in a network of brain regions, including the amygdala and anterior cingulate cortex (ACC); conversely, absent or low resilience is associated with hyperreactivity to emotional stimuli, both trauma-related and -unrelated (Patel, Spreng, Shin, & Girard, 2012; Whittle et al., 2013). In an earlier review, resilient adults (exposed to trauma in childhood and/or adulthood) showed greater mPFC engagement, including rostral ACC, and lesser activity in the dorsal ACC and amygdala, compared to symptomatic trauma-exposed adults across several studies (van der Werff et al., 2013).

Cross-sectional studies in youth with a history of childhood maltreatment show increased frontolimbic connectivity in resilient youth (Demers et al., 2018; Moreno-López et al., 2020); for example greater down-regulation of amygdala activity during emotion regulation (Schweizer et al., 2016). Higher-trait resilience youth living in adverse environments spent more time than lower-trait resilience peers in a dynamic resting state functional connectivity pattern of less salience network connectivity with both the central executive and default mode networks. This

could suggest lesser influence of emotional reactivity during unconstrained thought (Iadipaolo et al., 2018).

Cross-sectional findings are bolstered by several recent longitudinal studies of early adversity. Among adopted children who experienced early institutional care, self-reported anxiety at three-year follow-up decreased more in children who showed reduced amygdala responses to images of their adoptive parents (versus strangers) at baseline (Callaghan et al., 2019). Similarly, previously-institutionalized youth showing stronger ventromedial (vm)PFC-hippocampal functional connectivity during an aversive learning task reported lower anxiety at two-year follow-up (Silvers et al., 2016). A longitudinal study of internalizing symptoms in older adolescents and youth with a childhood maltreatment history compared to propensity-matched controls found that greater baseline amygdala threat reactivity predicted later internalizing symptoms – independently of stressful life events and factors such as socioeconomic status, suggesting that lesser limbic reactivity may be a unique predictor of resilience to childhood maltreatment (Gerin et al., 2019).

Cross-sectional findings in adults are similar to those in youth. Healthy adults with a childhood maltreatment history demonstrated greater frontal inhibition of emotional distractors (Demers et al., 2021). In another study of resilient adults with a childhood maltreatment history, blunted amygdala response correlated with higher depression symptoms (Yamamoto et al., 2017). However, in Yamamoto and colleagues' sample of healthy individuals without clinically significant symptoms, it is notable that higher amygdala reactivity was accompanied by a compensatory increase in prefrontal functional connectivity, linked to top-down emotion regulation. Studies of adulthood trauma exposure similarly suggest lesser amygdala reactivity and greater mPFC regulation in resilient adults. Lower baseline amygdala reactivity to fearful faces at 2-3 weeks post-incident was associated with lower self-reported PTSD symptoms at one-year follow-up, in individuals recruited from a hospital emergency department (Stevens et al., 2017). Another study, using Granger causality analysis, revealed more resting state mPFC inhibition of the amygdala in resilient typhoon survivors, compared to both symptomatic survivors and non-trauma-exposed controls (Chen et al., 2018a).

Longitudinal work in adults links pre-exposure neural functioning to later outcomes. In a large prospective sample of police trainees, pre-exposure anterior PFC activity during an

emotional action control task predicted lower PTSD symptoms at follow-up. Anterior PFC activity moderated the positive relationship between previous trauma load (a risk factor for PTSD) and PTSD symptom levels at follow-up, such that cumulative number of lifetime trauma exposures was not linked to higher PTSD symptoms in trainees with higher anterior PFC activity (Kaldewaij et al., 2021). In another cohort of police trainees scanned pre- and post-trauma exposure, those with higher post-traumatic intrusion symptoms showed increased salience network resting state connectivity after stress induction (Zhang et al., 2022). Together, these studies suggest that prefrontal regulation of limbic reactivity to emotional threat cues may predict resilience to posttraumatic stress and anxiety symptoms. In Kaldewaij et al. (2021), amygdala reactivity appeared to be acquired, rather than a prospective marker of PTSD vulnerability. However, previous longitudinal studies linked stress vulnerability to higher baseline amygdala reactivity (Admon et al., 2009; Swartz, Knodt, Radtke, & Hariri, 2015). Longitudinal prospective cohort studies, such as the ongoing Advancing Understanding of Recovery After Trauma (AURORA) study (McLean et al., 2020), which follows patients scanned 2-3 weeks after visiting the emergency department post-trauma, hold promise for a more granular understanding of emotional responding in resilience. Notably, there may be multiple pathways to risk/resilience: cross-task cluster analysis in an AURORA cohort, replicated in a different cohort with a wider range of trauma exposures, identified two vulnerability-related "biotypes" characterized by heightened emotional reactivity to threat, but differential reactivity to reward, detailed in a later section (Stevens et al., 2021).

From an interventional perspective, a pilot trial of fMRI-guided real-time neurofeedback training decreased amygdala activation and increased amygdala-vmPFC connectivity in combat veterans, but was not superior to sham in reducing PTSD symptoms (Zotev et al., 2018). However, training a pre-deployment military sample to downregulate EEG-derived amygdala signal successfully decreased amygdala BOLD signal and increased amygdala-mPFC functional connectivity at follow-up (Keynan et al., 2019). Active training improved experimental emotional regulation indices, but had no effect on self-reported anxiety (Keynan et al., 2019). Neurofeedback training represents a step towards developing new interventions for at-risk individuals. However, whether this approach will be effective in preventing or mitigating post-traumatic distress requires further study.

Cognitive reappraisal. Cognitive reappraisal is a deliberate form of emotion regulation that buffers risk for adverse outcomes following trauma exposure (Rodman, Jenness, Weissman, Pine, & McLaughlin, 2019). The ability to re-evaluate the meaning of experiences promotes adaptation after trauma, and represents a core part of psychological interventions (Hofmann, Asmundson, & Beck, 2013). For example, in an ecological momentary assessment study in individuals remitted from depression, positive appraisal (ability to "*focus on positive meaning*") and feelings of resilience were mutually reinforcing. Positive reappraisal was also associated with lower incidence of residual depressive symptoms (Hoorelbeke, Van den Bergh, Wichers, & Koster, 2019). Neuroimaging meta-analyses highlight ventrolateral (vl)PFC and dorsolateral (dl)PFC, dorsal ACC, and amygdala function in effortful emotional regulation in heathy individuals – and highlight functional differences in healthy vs. symptomatic participants (Zilverstand, Parvaz, & Goldstein, 2017).

Laboratory studies of trauma-exposed individuals found inconsistent evidence for a link between psychological symptoms and neural activity during experimental tasks instructing participants to deliberately modulate their emotional response to affective images using cognitive reframing. A longitudinal study in maltreated youth found a relationship between prefrontal recruitment during effortful cognitive reappraisal (and associated downregulation of amygdala reactivity to negative stimuli) and subsequent risk for mood symptoms, but no relation to anxiety symptoms (Rodman et al., 2019). In a small sample of adolescent girls exposed to violent assault, participants who responded better to trauma-focused CBT demonstrated decreased functional connectivity between the amygdala and mid-posterior insula cortex during reappraisal of negative images following treatment (Cisler et al., 2016). However, in a larger sample of adults with PTSD, regional BOLD signal during a cognitive reappraisal task was not associated with exposure-based psychotherapy outcomes (Fonzo et al., 2017). In conclusion, individual differences in ability to successfully engage active emotion regulation strategies like reappraisal may buffer against the deleterious effects of trauma exposure on mood, but are not necessarily related to changes in anxiety and PTSD symptom levels.

Reward responsivity

Responsivity to reward underlies key psychological factors linked to resilience such as optimism and positive emotionality (Feder et al., 2019). Resilient individuals show comparatively preserved ventral striatum response both when anticipating and receiving rewards, whereas PTSD and history of childhood maltreatment have been linked to anhedonia and blunted reward responses – particularly to social reward cues (Dillon et al., 2009; Hanson, Hariri, & Williamson, 2015; Hanson et al., 2016; Sailer et al., 2008; Elman et al., 2009; Nawijn et al., 2015). In a cross-sectional community-based sample of adolescents (a substantial proportion of whom had a history of severe childhood maltreatment), greater pallidal activation in response to positive images was associated with lower depression symptoms, and higher putamen activation was associated with lesser increase in depression two years later (Dennison et al., 2016). Among a large sample of university students (*n* = 820) in the Duke Neurogenetics Study cohort, increased ventral striatal activation to both anticipatory and consummatory reward during a card guessing game significantly weakened the relationship between childhood trauma exposure and adult anhedonia – including when controlling for other depression symptoms and recent life stress (Corral-Frías et al., 2015).

In a cross-sectional study, trauma-exposed adults without PTSD had greater ventral striatal responses to happy faces compared to those with PTSD (Felmingham et al., 2014). Amongst individuals who felt negatively affected by the outcome of the 2016 US presidential election (and belonged to historically marginalized groups), higher nucleus accumbens BOLD signal and higher mPFC-accumbens connectivity during reward receipt attenuated the relationship between election-related distress and depression symptoms (Tashjian & Galván, 2018). In a longitudinal assessment of combat-exposed paramedics, decreased reward response in the nucleus accumbens post-, but not pre-exposure, was found to be related to self-reported PTSD symptoms – suggesting that preserved reward responses may be a marker of resilience, rather than a prospective indicator (Admon et al., 2013).

While greater reactivity to rewarding social/environmental cues could promote resilience, the resilience-reward responsivity association may be more complex. The longitudinal AURORA biotypes study (Stevens et al., 2021) identified two clusters associated with resilience in adults

scanned 2-3 weeks after seeking emergency department care for a serious injury or medical condition. One (a “high reward reactivity” cluster with low threat reactivity and low inhibitory control) did not replicate in the test cohort. The other, replicable, cluster had low reactivity to both threat and reward, with higher hippocampal and vmPFC engagement during the inhibitory control task, suggesting that resilience is associated with better inhibition of emotional reactivity broadly. The association between resilience and lower general reactivity echoes an earlier small cross-sectional study in Special Forces soldiers – considered highly resilient individuals –, who showed lower differential nucleus accumbens and subgenual PFC responses to monetary reward versus no-reward, compared to non-trauma-exposed civilians (Vythilingam et al., 2009). These findings illustrate challenges for resilience research when trying to synthesize findings across different populations – e.g., repeated occupational trauma exposures may differ from a singular exposure, and certain occupations (like first responders) may select for traits like higher sensation-seeking and higher reactivity threshold. For example, a recent, rigorous attempt to replicate Stevens et al. (2021) AURORA biotypes identified threat- and reward-related clusters in their cohort, but these were not identical to those in AURORA and not related to PTSD vulnerability (Ben-Zion et al., 2023), potentially due to some differences in sample composition and methods.

Cognitive flexibility and cognitive control

Resilient individuals engage prefrontal and hippocampal regions during executive function tasks e.g., (Ben-Zion et al., 2018). Conversely, deficits in inhibition, working memory, attentional control, and cognitive flexibility are observed in both adults with a history of childhood maltreatment and individuals with a diagnosis of PTSD, not accounted for by comorbid psychopathology, substance use, or history of traumatic brain injury (Gould et al., 2012; Scott et al., 2015) (although the relationship between PTSD symptom severity and cognitive function may be bidirectional; Jacob et al., 2019). In an early study, both resilient and non-trauma-exposed healthy adults showed greater vlPFC, mPFC, and dlPFC activation during an inhibitory control task, vs. those with PTSD (Falconer et al., 2008). Resilient individuals have also shown greater dlPFC and superior frontal gyrus activation during an attentional control task with emotional distractors, compared to both adults with PTSD and non-trauma-exposed controls (Blair et al., 2013). Recently, both resilient and non-trauma-exposed adults (but not adults with

PTSD) exhibited significant decoupling between prefrontal regions and subcortical structures when attempting to suppress experimentally-induced memories (Mary et al., 2020): top-down prefrontal modulation of subcortical memory structures (hippocampus, parahippocampal gyrus, and precuneus) was associated with successful memory suppression, whereas the PTSD group showed bottom-up modulation of information flow. Indeed, greater whole-brain resting state hippocampal functional connectivity was a significant predictor of PTSD symptoms at six months in a prospective study in traumatically-injured adults recruited from the emergency department (Fitzgerald et al., 2022). Optimal prefrontal-subcortical cognitive control network function may facilitate resilience.

A longitudinal study in the Duke Neurogenetics Study cohort (*n*=120) identified that greater neural responses to threat and reward predicted future increases in anxiety in university students with average or low but not *high* prefrontal activity during a working memory task, controlling for childhood maltreatment and stressful life events (Scult, Knodt, Radtke, Brigidi, & Hariri, 2019). These findings echo (Stevens et al., 2021) in suggesting that lower general reactivity and higher prefrontal inhibitory control could protect against adverse outcomes post-trauma exposure. Further, a longitudinal assessment of recently trauma-exposed adults found that increased inhibitory control-related hippocampal activation (at 1-2 months post-trauma) predicted decreased PTSD symptom severity at three and six months, and this finding was replicable (van Rooij et al., 2018). The hippocampus links cognition, memory and emotion (Speer & Delgado, 2017), thus is likely relevant to resilience to PTSD symptoms like alterations in mood, cognitive function, and intrusive thoughts and memories.

Finally, NCANDA cohort (*n*=392) resting state fMRI showed that the association between childhood trauma severity and executive function difficulties in adolescents was mediated by lower functional connectivity between a network of the postcentral and precentral gyri, dorsal ACC, intraparietal sulcus, and anterior insula cortex – hub regions implicated in cognitive/behavioral control and sensorimotor integration. Preserved interconnectivity between the postcentral gyrus and dorsal ACC was related to lower reported executive dysfunction at baseline, and predicted lower likelihood of high-risk drinking 1-4 years later (Silveira et al., 2020). In addition to protecting against PTSD symptoms, preserved prefrontal function may reduce vulnerability to maladaptive coping strategies like substance use.

Emerging areas of interest for resilience neuroimaging research

Social support and social cognition. Social support is vital for resilience to trauma exposure in both childhood and adulthood (van Harmelen et al., 2016; van Harmelen et al., 2017; Fritz, de Graaff, et al., 2018; Yule et al., 2019). Conversely, non-supportive social contexts like discrimination and rejection, impact emotion-responsive regions including the amygdala, insula, and ACC, even in the absence of (or after controlling for) associated psychological symptoms (Akdeniz et al., 2014; Clark, Miller, & Hegde, 2018). Supportive social environments may converge with resilience-promoting traits to upregulate perigenual ACC and other PFC regions during acute social (and non-social) threats (Holz et al., 2020). Social support also has a protective effect against prolonged stressors. For example, supportive parenting during childhood attenuates the link between childhood adversity (e.g., maltreatment, poverty) and neural responses to negative emotional faces in childhood (Wymbs et al., 2020), and resting state functional connectivity by adulthood within executive and emotion regulation networks (Brody et al., 2019). However, a longitudinal study in adolescents found no association between childhood adversity resilience (no DSM Axis-1 disorder diagnosis following significant family discord) and neural responses to rejection, although the authors suggest that the null finding might be due to low frequency of abuse and higher socioeconomic status of the sample (Fritz et al., 2019).

Higher levels of social cognitive function (ability to infer the thoughts of others and navigate the social world) may help foster adaptive outcomes following trauma, by conferring ability to recruit and maintain social ties (Stevens & Jovanovic, 2019; Lepore & Kliewer, 2019). Hudson et al. (2018) administered a theory-of-mind task to women with childhood maltreatment exposure and unexposed controls. Women with history of childhood maltreatment without sub-clinical or clinical PTSD symptoms in adulthood showed greater functional connectivity between dorsomedial (dm)PFC and right temporoparietal junction (TPJ) during implicit theory of mind, whereas unexposed controls vs. women with PTSD symptoms showed similar dmPFC-right TPJ functional connectivity. Those with PTSD symptoms also demonstrated right TPJ *hypo*activation during theory of mind, vs. unexposed controls. The TPJ and dmPFC represent nodes in the default network dorsomedial subsystem, involved in mentalizing and social processing (Spreng

& Andrews-Hanna, 2015). In summary, we need further research on proximal neural mechanisms underlying social support and social cognitive functioning in resilience. Considering the broader social environment would improve our understanding of mechanisms underlying resilience (**Box 2**; Biglan et al., 2012).

Active coping. Active coping focuses on approach-oriented behaviors for managing stressors, such as "*I take additional actions to get rid of the problem*" or "*I concentrate my effort on doing something about it*"), and is associated with lower cross-sectional PTSD symptoms (e.g., Stratta et al., 2015; Bistricky et al., 2019; Getnet et al., 2019). Further, there is preliminary evidence that a switch toward active coping accompanies response to cognitive-behavioral therapy for PTSD (Bourdon, El-Baalbaki, Girard, Lapointe-Blackburn, & Guay, 2019). mPFC function in resilience to prolonged stressors is implicated in individual differences in coping styles: healthy men with high early life stress but low trait rumination decreased amygdala and increased vmPFC perfusion during a mental arithmetic stress task, whereas men with high early life stress and high trait rumination showed the opposite (Wang, Paul, Stanton, Greeson, & Smoski, 2013). Healthy volunteers undergoing an acute stress paradigm exhibited initial vmPFC deactivation during early task runs, but. vmPFC signal recovery later in the task was correlated with self-reported active coping and anticorrelated with maladaptive coping behaviors (Sinha, Lacadie, Constable, & Seo, 2016). This reactivity-recovery pattern is consistent with preclinical evidence that prefrontal downregulation is adaptive during *acute* stress,, but should change when stress is prolonged (Maier & Watkins, 2010; Sinha et al., 2016). However, a single laboratory session represents a very different timescale than naturalistic prolonged stress, and directionality of the relationship between mPFC recovery during chronic stress and coping style is unclear. Gender roles and social norms can also differentially reinforce active versus avoidant coping styles (McLean and Anderson, 2009; Street and Dardis, 2018; **Box 2**); interrelationships between these factors may warrant attention.

Fear extinction. It is important to update fear memories when transitioning from threat to safety, in order to respond appropriately to context (Lissek & van Meurs, 2015). vmPFC and hippocampus are key in fear extinction maintenance, in both human and animal studies (Milad et al., 2007; Fullana et al., 2018). Enhanced extinction learning is associated with surprise-related learning signals in the vmPFC, and amygdala connectivity with a ventral mPFC subregion (Dunsmoor et al., 2019); the same circuitry might be critical for extinction learning as

an interventional mechanism (Fullana et al., 2020). Indeed, greater success of prolonged exposure therapy for PTSD – which promotes extinction learning – is linked to pre-treatment neural responses to emotion, including higher vmPFC signal during emotional regulation, greater magnitude of PFC responses while viewing fearful faces, and greater inhibition of the amygdala by lateral PFC transcranial magnetic stimulation (Fonzo et al., 2017). Further, vmPFC activity has been demonstrated to be central to the success of *imagined* fear extinction, which may be particularly relevant to the psychotherapeutic context, as in-vivo exposure is not always feasible (Reddan, Wager, & Schiller, 2018). Thus, vmPFC recruitment during emotional contexts may be important to later success of exposure-based treatment strategies – and may play a role in successful maintenance of extinction learning broadly.

Resting state findings support the relevance of vmPFC recruitment. Occupational trauma-exposed firefighters with greater insula-vmPFC functional connectivity had fewer PTSD symptoms, although firefighters had greater insula functional connectivity with other fear circuitry regions vs. healthy non-firefighter adults, regardless of PTSD symptoms (Jeong et al., 2019). Similarly, typhoon survivors with PTSD showed greater vmPFC connectivity with the basolateral amygdala, relative to trauma-exposed controls. The basolateral amygdala has a central role in fear learning and emotional responding. This latter study illustrates the difficulty in inferring a directional relationship between brain regions from most functional neuroimaging studies. However, a resting state study, using Granger causality, in typhoon survivors and unexposed healthy adults found that both individuals with PTSD and trauma-exposed controls exhibited greater amygdala-to-mPFC effective connectivity vs. unexposed controls, but inhibitory mPFC-to-amygdala connectivity was only observed in trauma-exposed controls. (Chen et al., 2018b).

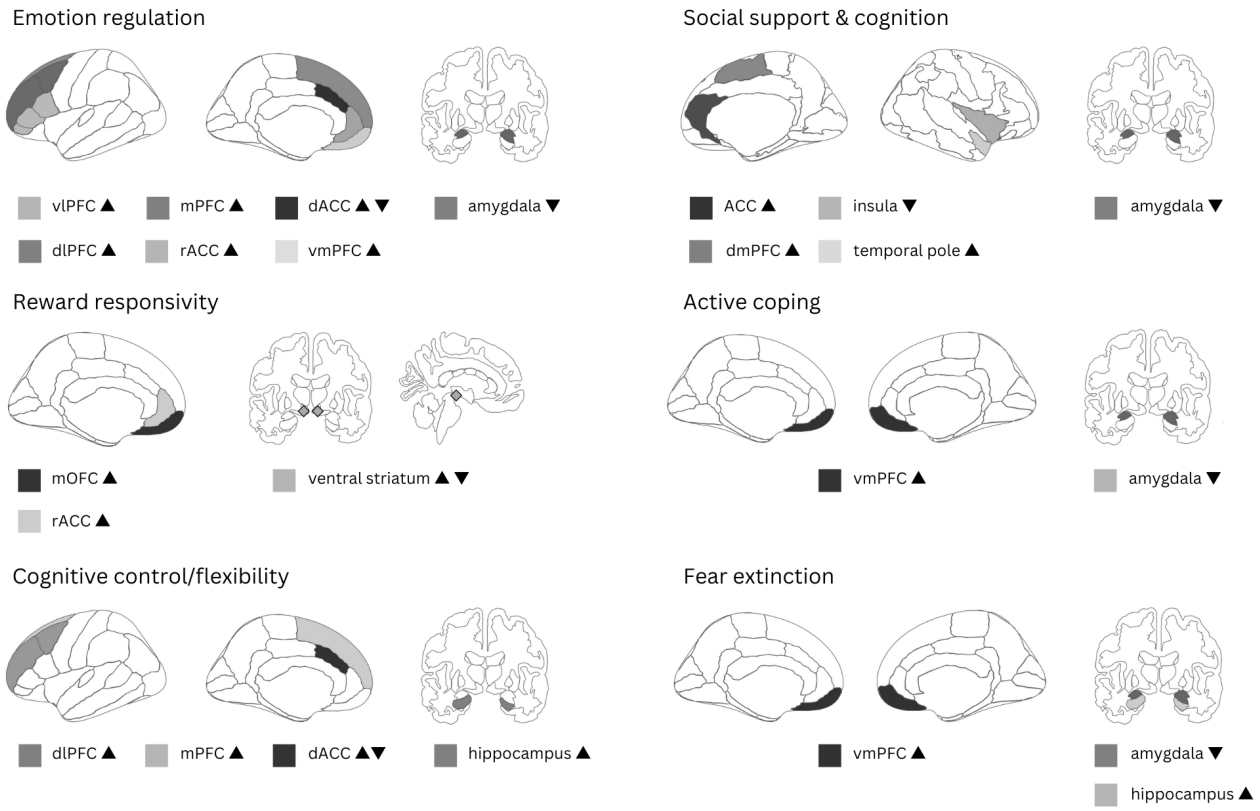

Figure 1. Brain regions most commonly associated with higher resilience to trauma, organized by psychological factor (including emerging areas of interest) and underlying neural circuitry, based on review of fMRI BOLD activation literature.
Note. All figures use parcellations from the Desikan-Killiany Cortical Atlas parcellation or Freesurfer's automatic subcortical segmentation, implemented with ggseg() and ggsegExtra() packages for R (Mowinckel & Vidal-Piñeiro, 2019, n.d.), except for the subcortical Reward Responsivity plot (approximate location of the nucleus accumbens drawn by hand) and the cortical Social Support & Cognition plot (which uses the AAL2 parcellation). ACC = anterior cingulate, PFC = prefrontal cortex, d = dorsal, dl = dorsolateral, m = medial, l = lateral, r = rostral, v = ventral, vm = ventromedial. Upward arrows indicate regions of greater activation in resilient individuals vs. others; downward arrows indicate regions of lower activation in resilient individuals vs. others; and both arrows together indicate mixed findings.

Discussion

Here, we summarized task-based and resting state fMRI studies of resilience to childhood and adulthood trauma, focusing on psychological factors widely linked to resilient responses to severe adversity and trauma: effective emotion regulation, reward responsiveness, and cognitive control. We also reviewed findings related to social cognition, fear extinction, and active coping, as emerging areas of interest in resilience research **(Figure 1)**. Across studies, we found robust evidence for preserved mPFC function in downregulation of limbic responses to emotional stimuli in resilient individuals. This is consistent with evidence from animal and human experimental models implicating mPFC engagement in adaptive coping with prolonged stress (Maier & Watkins, 2010). Chronic social defeat stress-susceptible mice showing social

impairment exhibit selective reductions in vmPFC spike frequencies – suggesting a potential role of preserved vmPFC function in adaptive *social* behaviour following chronic stress (Abe, Okada, Nakayama, Ikegaya, & Sasaki, 2019), in line with emerging human evidence for perigenual cingulate and prefrontal function as mediators of social support's positive effects on responses to stress and pain (Holz et al., 2020). However, we lack knowledge of neural correlates of social functioning and social cognition *in resilient humans* despite their role in fostering positive outcomes (Stevens & Jovanovic, 2019). Considering the broader social environment is also critical for understanding the brain-environment interactions underlying resilience **(Box 2).**

Preserved reward signal processing in the ventral striatum has been linked to resilience to anhedonia and depression symptoms. One possibility is that preserved reward system function promotes participation in social and other rewarding experiences, thereby buffering the impacts of stress. Intact reward circuitry could also contribute to positive prospection – e.g., a hippocampal-midbrain-vmPFC circuit has recently been implicated in imagined future positive outcomes (Iigaya et al., 2019). However, reward system findings have been mixed; resilient people may be less reactive both to reward and threat. Lesser reactivity might allow for greater stability in a changing environment, for example via lower emotional lability or greater ability to remain focused on goals by inhibiting salient yet distracting cues (e.g., Stevens et al., 2021).

Cognitive control-related brain activation predicts positive outcomes following trauma, specifically frontal (dlPFC) and hippocampal. Adult hippocampal neurogenesis plays an important role in cognitive flexibility, which may enable individuals to disengage from trauma-related memories and thoughts, and decrease cardinal PTSD symptoms such as intrusive thoughts and flashbacks (Aupperle, Melrose, Stein, & Paulus, 2012; Anacker & Hen, 2017). Prefrontal-subcortical connectivity (including hippocampal) in cognitive control appears important for suppressing unwanted memories (Mary et al., 2020). Although perhaps not specific to PTSD, activity in this circuit may represent an important factor in vulnerability to PTSD and maladaptive coping mechanisms (e.g., substance use problems) following trauma (Ersche, 2020). Recent work in this area highlights the importance of considering within-person interactions between resilience-relevant factors – specifically, how higher levels of prefrontally-mediated executive function may 'rescue' risk for anxiety in individuals who are more reactive to threat and less responsive to rewards (Scult et al., 2019). We note that the brain regions

highlighted across the resilience-linked psychological factors also broadly correspond to those described in recent models of psychological *vulnerability* to trauma (e.g., Pitman et al., 2012; Patel et al., 2012; Yehuda et al., 2015).

Longitudinal findings

Given that resilience inherently involves a temporal relationship between stressor and response, large longitudinal studies are better able to answer key questions – for example, are the differences between resilient people and those who develop a psychiatric disorder present pre-exposure, or do the differences emerge afterward in a compensatory manner? Can we identify people at greater risk of negative consequences at the time of the event or soon after, and intervene early to prevent PTSD and related disorders? Several of the studies reviewed here illustrate the potential of longitudinal, cohort-based neuroimaging research. Though their samples differ in terms of trauma exposure type and developmental stage, the work by Scult et al. (2019) in the Duke Neurogenetics cohort, Silveira et al. (2020) in the NCANDA cohort, and Stevens et al. (2021) in the AURORA cohort suggest that greater general bottom-up neural reactivity to emotional stimuli – both positive and negative – is linked to poorer outcomes unless accompanied by inhibitory hippocampal and prefrontal engagement.

Limitations

It is important to clarify the scope of inference we can draw from the current data. There are too few studies to differentiate results by developmental stage at the time of the traumatic event and/or the study. In addition to differences in brain development, another difference between studies of adults and youth is that the measures used in adult studies typically focus on symptoms (psychopathology), whereas youth studies tend to operationalize resilience more broadly (**Box 2**). Many studies are retrospective and cross-sectional. Only longitudinal studies can tease out whether differences seen in resilient individuals represent pre-existing vulnerabilities or adaptations. There are also methodological weaknesses, including small sample sizes and low power (Szucs & Ioannidis, 2020). Many older studies used liberal multiple comparison corrections, which increases risk for type 1 errors (Eklund, Nichols, & Knutsson, 2016; Cox, Chen, Glen, Reynolds, & Taylor, 2017). However, some key findings replicate in well-powered samples (e.g., (Corral-Frías et al., 2015; McLean et al., 2020; Silveira et al., 2020) – with the caveat that these findings may not necessarily be robust to cohort and methodological

differences between studies (Ben-Zion et al., 2023). Finally, identifying robust neuroimaging biomarkers requires establishing intrapersonal reliability of fMRI measures (Nord, Gray, Charpentier, Robinson, & Roiser, 2017; Elliott et al., 2019, 2020). Multivariate approaches exploiting the high dimensionality of neuroimaging data may be more appropriate (Dubois & Adolphs, 2016; Finn et al., 2020).

Conclusions and future directions

Real-world settings have started to translate neuroscientific findings to interventions (Greenberg, 2006; Waugh & Koster, 2015; Keynan et al., 2019). Examining neural correlates of treatment response may illuminate neural resilience mechanisms 'activated' by successful treatment. Ongoing and future longitudinal cohort studies with a peritraumatic baseline, such as AURORA (McLean et al., 2020), along with additional consideration of interindividual sociodemographic differences **(Box 3**), will contribute to further understanding resilience to severe adversity and trauma.

[Box 3 around here]

Box 1: Quantifying trauma

Assessing the severity of different traumatic experiences is not a trivial task. Indeed, to a large extent, the degree to which any event is traumatic is determined by the psychological impact on the person or people involved (Green, 1990). However, such a definition poses some difficulties for studies of resilience, which aim to investigate individual differences in response to similarly adverse events. Studying trauma-exposed samples optimally involves several considerations, including severity of trauma exposure and chronicity, and in the case of childhood maltreatment, developmental stage at the time of trauma exposure (Harpur, Polek, & van Harmelen, 2015; Dunn et al., 2019; Gee, 2020).

Events sufficient to fulfill criteria for a diagnosis of post-traumatic stress disorder (PTSD) have been codified within the American Psychiatric Association's Diagnostic and Statistical Manual (DSM) as 'Category A' events – specifically, in DSM-5, as being "exposed to death, threatened death, actual or threatened serious injury, or actual or threatened sexual violence" (American Psychiatric Association, 2013). In the World Health Organization's International Classification of Diseases (ICD-10), the requirement is simply that a person has experienced an event or situation "of exceptionally threatening or catastrophic nature, which would be likely to cause pervasive distress in almost anyone" (World Health Organization, 1993). Under either scheme, presence of such an event in an individual's history is usually probed using a structured clinical interview (e.g., Weathers et al., 2013).

Experience of childhood trauma in younger research participants may be assessed using developmentally sensitive interviews with a child's primary caregiver (e.g., Goodyer et al., 2010). In comparison, in studies involving adult participants, experience of childhood trauma is often assessed using retrospective questionnaires, such as the Childhood Trauma Questionnaire (Bernstein et al., 1994). Notably, a recent meta-analysis reported poor agreement between prospective and retrospective measures of childhood maltreatment (Baldwin, Reuben, Newbury, & Danese, 2019). Although both prospective and retrospective measures identify groups of at-risk individuals, they appear to highlight largely non-overlapping sets of people – meaning that it may not be valid to assume the same risk mechanisms apply to individuals identified using different methods.

Further, although both intensity and chronicity are important dimensions of trauma, it is not always clear how to combine these different aspects of adverse event exposure in a standardized way. Some studies have addressed this issue by restricting recruitment to individuals exposed to a specific precipitating event, for example in volunteers from the World Trade Center rescue and recovery worker cohort (Pietrzak, Feder, et al., 2014), or individuals with combat trauma (Keane et al., 1989). However, even in such samples, there is likely to be additional lifetime trauma exposure in many participants. One approach to this problem is to use a data reduction technique such as principal components analysis (PCA) to combine several different continuous measures into a single index of trauma exposure severity (e.g., to combine different aspects of childhood family experience; van Harmelen et al., 2017). It is important to bear in mind when synthesizing data in this way that there may also be trauma-specific considerations to take into account during analysis – for example when considering responses to differently gendered angry faces in people exposed to intimate partner violence (Fonzo et al., 2010).

Box 2: Quantifying resilience

In trauma-exposed populations. In neurobiological studies with adult participants, resilience has often been defined based on the absence of a DSM Axis-1 disorder diagnosis following significant trauma exposure. Such categorical analyses may be complemented by dimensional approaches that relate measures to current severity scores for PTSD, depression, or anxiety symptoms. However, it is increasingly acknowledged that symptom sum scores for specific diagnoses are not the only key outcome variable in studies of resilience. Indeed, trauma-related psychopathology is highly heterogenous, and different symptom dimensions may differentially relate to overall burden of disability (e.g., Pietrzak, el-Gabalawy, et al., 2014) – suggesting more nuanced approaches may be warranted. Conversely, studies of the effects of childhood maltreatment have tended to take a more holistic approach towards assessing resilience, including a greater focus on psychosocial outcomes, and examining functioning across multiple domains (McGloin & Widom, 2001; Cicchetti & Rogosch, 2012). Recent examples of this approach across the literature include examining resilience across different functional outcome categories in children (Burt et al., 2016), analysing disruption to work, social, and family life in addition to PTSD symptomatology in trauma-exposed adults (Horn et al., 2016), and the use of PCA-derived cross-domain psychosocial functioning scores in an adolescent cohort (A. L. van Harmelen et al., 2017).

The notion of good functioning invoked by definitions of resilience is *environment-dependent:* adaptive behaviour in violent, volatile, or resource-poor environments may not conform to normative accounts of behaviour in more stable or resource-rich environments (Luthar, Sawyer, & Brown, 2006). Further, psychosocial environments may differ across individuals within a shared wider context – e.g. for individuals who identify as different genders and/or belong to different racial or ethnic groups (Tolin & Foa, 2008; Portnoy et al., 2018; Street & Dardis, 2018; Brondolo, 2015). For example, differences in resilience between men and women have been found to be explained by differences in trauma type exposure across genders (particularly sexual violence; Tolin & Foa, 2008; Portnoy et al., 2018), and socialized gender norms may further contribute to differences in chronic environmental stress exposure and propensity to engage in less adaptive coping strategies (Street & Dardis, 2018). In particular, racism is an additional source of trauma in minoritized people that may be under-recognized by current clinical assessments (Carter, 2007; Williams, Metzger, Leins, & DeLapp, 2018). For example, previous experiences of racial discrimination has recently been shown to add significant risk for PTSD symptom development following traumatic injury (Bird et al., 2021).

Importantly, the expected level of psychosocial functioning for a given individual should take into account their lifetime trauma burden (Karam et al., 2014; Feder et al., 2016). Various researchers have therefore proposed that resilience can best be quantified by regressing metrics of psychosocial functioning against an appropriate measure of trauma exposure severity: such that positive residuals from this model represent better than expected ('resilient') outcomes, and negative residuals represent worse than expected ('vulnerable') outcomes – compared to what would be predicted based on the group as a whole (Amstadter, Myers, & Kendler, 2014; Amstadter, Maes, Sheerin, Myers, & Kendler, 2016; A. L. van Harmelen et al., 2017; Ioannidis, Askelund, Kievit, & van Harmelen, 2020). Resilience-promoting factors can then be described as any resource (biological, psychological, social/socioeconomic) that decreases the risk of poor outcomes following adverse circumstances. Resilience-promoting factors may include both protective factors that help buffer the impact of stress, and resources that are able to foster positive compensatory changes following trauma exposure (Luthar et al., 2006; Schultze-Lutter, Schimmelmann, & Schmidt, 2016). Critically, resilience-promoting factors are not independently additive, but interact in complex ways (Luthar et al., 2006; Fritz, Fried et al., 2018; Liebenberg, 2020). It is therefore vital not to study such factors in isolation, but rather in the context of each other – ideally within the same individuals.

In the general population. Some researchers have also examined population variation in self-reported trait resilience. For example, the Connor-Davidson Resilience Scale (CD-RISC) probes how likely individuals are to endorse statements such as "*I am able to adapt to change*" and "*I tend to bounce back after illness or hardship"* (Connor & Davidson, 2003b). There is somewhat equivocal evidence regarding the relationship between trait resilience and outcomes following trauma exposure (Daniels et al., 2012; Powers et al., 2014). Interestingly, a recent study of emergency department attendees found that a negative association between CD-RISC score close to admission and PTSD symptoms six months in the future was mediated by lower social withdrawal in higher trait resilience individuals – suggesting that the impacts of trait resilience on functional outcome may be via increased ability to maintain or recruit social support (N. J. Thompson, Fiorillo, Rothbaum, Ressler, & Michopoulos, 2018). Further, most questionnaire measures of resilience relate to a specific conceptualisation of resilience that focuses

on individual 'grit' or 'hardiness' and that may not translate well to non-Western cultural settings – particularly those that emphasise the role of communities rather than individuals in fostering resilience (Meili & Maercker, 2019; Mendenhall & Kim, 2019). An alternative approach for studies of resilience in the general population is to study the *mechanisms* underlying resilience based on experimental intervention data – for example as reflected in lower self-reported fear or physiological reactivity during stress induction paradigms.

Box 3: Considerations for future work

Studying multiple potential resilience-promoting factors within the same individual is necessary to tease apart how putative neurobiological resilience factors interact both with each other and with other sociodemographic factors known to affect resilience to trauma-related psychopathology. We would encourage greater consideration of an individual's social, cultural, and socioeconomic environment in future studies of neural mechanisms related to resilience.

The trade-off for high power in large cohort studies is often the selective pressure on study measures (for inclusion, brevity, and ease of administration). However, accurate assessment of both resilience and the sociodemographic factors described above requires in-depth clinical phenotyping and trauma history screening, often by clinical interview with appropriately trained study personnel. To build our understanding of the neural correlates of resilience, future work should aim to hit a sweet spot in this trade-off between appropriate power and depth of individual phenotyping.

An important next step will be to integrate neuroimaging metrics related to resilience with other biological measurements relevant to both individual differences in neural function and environmental exposure. Novel analytic approaches such as the calculation of polygenic risk scores, or quantification of gene co-expression modules may yield sufficient power in (single site) achievable imaging sample sizes to link neural correlates of psychological constructs to underlying biology (Dima & Breen, 2015; Bogdan et al., 2017). Greater integration of neuroimaging data into such pathways should improve our ability to interpret existing findings in terms of underlying molecular mechanisms. The cost of well-powered samples in neuroimaging genetics is typically prohibitively expensive for a single researcher or work group, but large-scale multi-site efforts e.g., the international ENIGMA [Enhancing NeuroImaging Genetics through Meta Analysis] Consortium have been extremely successful in facilitating robust and reproducible research, and will continue to be a tremendous resource (Thompson et al., 2020).

References

Abe, R., Okada, S., Nakayama, R., Ikegaya, Y., & Sasaki, T. (2019). Social defeat stress causes selective attenuation of neuronal activity in the ventromedial prefrontal cortex. *Scientific Reports*, *9*(1), 9447. https://doi.org/10.1038/s41598-019-45833-5

Admon, R., Lubin, G., Rosenblatt, J. D., Stern, O., Kahn, I., Assaf, M., & Hendler, T. (2013). Imbalanced Neural Responsivity to Risk and Reward Indicates Stress Vulnerability in Humans. *Cerebral Cortex*, *23*(1), 28–35. https://doi.org/10.1093/cercor/bhr369

Admon, R., Lubin, G., Stern, O., Rosenberg, K., Sela, L., Ben-Ami, H., & Hendler, T. (2009). Human vulnerability to stress depends on amygdala's predisposition and hippocampal plasticity. *Proceedings of the National Academy of Sciences of the United States of America*, *106*(33), 14120–14125. https://doi.org/10.1073/pnas.0903183106

Akdeniz, C., Tost, H., Streit, F., Haddad, L., Wüst, S., Schäfer, A., … Meyer-Lindenberg, A. (2014). Neuroimaging Evidence for a Role of Neural Social Stress Processing in Ethnic Minority–Associated Environmental Risk. *JAMA Psychiatry*, *71*(6), 672–680. https://doi.org/10.1001/jamapsychiatry.2014.35

American Psychiatric Association. (2013). *Diagnostic and Statistical Manual of Mental Disorders* (Fifth Edition). Washington, DC and London, England: American Psychiatric Association. https://doi.org/10.1176/appi.books.9780890425596

Amstadter, A. B., Maes, H. H., Sheerin, C. M., Myers, J. M., & Kendler, K. S. (2016). The relationship between genetic and environmental influences on resilience and on common internalizing and externalizing psychiatric disorders. *Social Psychiatry and Psychiatric Epidemiology*, *51*(5), 669–678. https://doi.org/10.1007/s00127-015-1163-6

Amstadter, A. B., Myers, J. M., & Kendler, K. S. (2014). Psychiatric resilience: Longitudinal twin study. *The British Journal of Psychiatry: The Journal of Mental Science*, *205*(4), 275–280. https://doi.org/10.1192/bjp.bp.113.130906

Anacker, C., & Hen, R. (2017). Adult hippocampal neurogenesis and cognitive flexibility—Linking memory and mood. *Nature Reviews Neuroscience*, *18*(6), 335–346. https://doi.org/10.1038/nrn.2017.45

Aupperle, R. L., Melrose, A. J., Stein, M. B., & Paulus, M. P. (2012). Executive function and PTSD: Disengaging from trauma. *Neuropharmacology*, *62*(2), 686–694. https://doi.org/10.1016/j.neuropharm.2011.02.008

Baldwin, J. R., Reuben, A., Newbury, J. B., & Danese, A. (2019). Agreement Between Prospective and Retrospective Measures of Childhood Maltreatment: A Systematic Review and Meta-analysis. *JAMA Psychiatry*, *76*(6), 584. https://doi.org/10.1001/jamapsychiatry.2019.0097

Ben-Zion, Z., Fine, N. B., Keynan, N. J., Admon, R., Green, N., Halevi, M., … Shalev, A. Y. (2018). Cognitive Flexibility Predicts PTSD Symptoms: Observational and Interventional Studies. *Frontiers in Psychiatry*, *9*, 477. https://doi.org/10.3389/fpsyt.2018.00477

Ben-Zion, Z., Spiller, T. R., Keynan, J. N., Admon, R., Levy, I., Liberzon, I., … Harpaz-Rotem, I. (2023). Evaluating the Evidence for Brain-Based Biotypes of Psychiatric Vulnerability in the Acute Aftermath of Trauma. *American Journal of Psychiatry*, appi.ajp.20220271. https://doi.org/10.1176/appi.ajp.20220271

Bernstein, D. P., Fink, L., Handelsman, L., Foote, J., Lovejoy, M., Wenzel, K., … Ruggiero, J. (1994). Initial reliability and validity of a new retrospective measure of child abuse and neglect. *The American Journal of Psychiatry*, *151*(8), 1132–1136. https://doi.org/10.1176/ajp.151.8.1132

Biglan, A., Flay, B. R., Embry, D. D., & Sandler, I. N. (2012). The Critical Role of Nurturing Environments for Promoting Human Wellbeing. *The American Psychologist*, *67*(4), 257–271. https://doi.org/10.1037/a0026796

Bird, C. M., Webb, E. K., Schramm, A. T., Torres, L., Larson, C., & deRoon-Cassini, T. A. (2021). Racial Discrimination is Associated with Acute Posttraumatic Stress Symptoms and Predicts Future Posttraumatic Stress Disorder Symptom Severity in Trauma-Exposed Black Adults in the United States. *Journal of Traumatic Stress*. https://doi.org/10.1002/jts.22670

Bistricky, S. L., Long, L. J., Lai, B. S., Gallagher, M. W., Kanenberg, H., Elkins, S. R., … Short, M. B. (2019). Surviving the storm: Avoidant coping, helping behavior, resilience and affective symptoms around a major hurricane-flood. *Journal of Affective Disorders*, *257*, 297–306. https://doi.org/10.1016/j.jad.2019.07.044

Blair, K. S., Vythilingam, M., Crowe, S. L., McCaffrey, D. E., Ng, P., Wu, C. C., … Blair, R. J. R. (2013). Cognitive control of attention is differentially affected in trauma-exposed individuals with and without post-traumatic stress disorder. *Psychological Medicine*, *43*(1), 85–95. https://doi.org/10.1017/S0033291712000840

Bogdan, R., Salmeron, B. J., Carey, C. E., Agrawal, A., Calhoun, V. D., Garavan, H., … Goldman, D. (2017). Imaging Genetics and Genomics in Psychiatry: A Critical Review of Progress and Potential. *Biological Psychiatry*, *82*(3), 165–175. https://doi.org/10.1016/j.biopsych.2016.12.030

Bourdon, D.-É., El-Baalbaki, G., Girard, D., Lapointe-Blackburn, É., & Guay, S. (2019). Schemas and coping strategies in cognitive-behavioral therapy for PTSD: A systematic review. *European Journal of Trauma & Dissociation*, *3*(1), 33–47. https://doi.org/10.1016/j.ejtd.2018.09.005

Brody, G. H., Yu, T., Nusslock, R., Barton, A. W., Miller, G. E., Chen, E., … Sweet, L. H. (2019). The Protective Effects of Supportive Parenting on the Relationship Between Adolescent Poverty and Resting-State Functional Brain Connectivity During Adulthood. *Psychological Science*, *30*(7), 1040–1049. https://doi.org/10.1177/0956797619847989

Bromet, E. J., Karam, E. G., Koenen, K. C., & Stein, D. J. (2018). *Trauma and Posttraumatic Stress Disorder: Global Perspectives from the WHO World Mental Health Surveys*. Cambridge University Press.

Brondolo, E. (2015). Racial and Ethnic Disparities in Health: Examining the Contexts That Shape Resilience and Risk. *Psychosomatic Medicine*, *77*(1), 2–5. https://doi.org/10.1097/PSY.0000000000000149

Burt, K. B., Whelan, R., Conrod, P. J., Banaschewski, T., Barker, G. J., Bokde, A. L., … Garavan, H. (2016). Structural brain correlates of adolescent resilience. *Journal of Child Psychology and Psychiatry, and Allied Disciplines*, *57*(11), 1287–1296. https://doi.org/10.1111/jcpp.12552

Callaghan, B. L., Gee, D. G., Gabard-Durnam, L., Telzer, E. H., Humphreys, K. L., Goff, B., … Tottenham, N. (2019). Decreased Amygdala Reactivity to Parent Cues Protects Against Anxiety Following Early Adversity: An Examination Across 3 Years. *Biological Psychiatry: Cognitive Neuroscience and Neuroimaging*, *4*(7), 664–671. https://doi.org/10.1016/j.bpsc.2019.02.001

Careaga, M. B. L., Girardi, C. E. N., & Suchecki, D. (2016). Understanding posttraumatic stress disorder through fear conditioning, extinction and reconsolidation. *Neuroscience and Biobehavioral Reviews*, *71*, 48–57. https://doi.org/10.1016/j.neubiorev.2016.08.023

Carter, R. T. (2007). Racism and Psychological and Emotional Injury: Recognizing and Assessing Race-Based Traumatic Stress. *The Counseling Psychologist*, *35*(1), 13–105. https://doi.org/10.1177/0011000006292033

Chen, F., Ke, J., Qi, R., Xu, Q., Zhong, Y., Liu, T., … Lu, G. (2018a). Increased Inhibition of the Amygdala by the mPFC may Reflect a Resilience Factor in Post-traumatic Stress Disorder: A Resting-State fMRI Granger Causality Analysis. *Frontiers in Psychiatry*, *9*, 516. https://doi.org/10.3389/fpsyt.2018.00516

Chen, F., Ke, J., Qi, R., Xu, Q., Zhong, Y., Liu, T., … Lu, G. (2018b). Increased Inhibition of the Amygdala by the mPFC may Reflect a Resilience Factor in Post-traumatic Stress Disorder: A Resting-State fMRI Granger Causality Analysis. *Frontiers in Psychiatry*, *9*, 516. https://doi.org/10.3389/fpsyt.2018.00516

Cicchetti, D., & Rogosch, F. A. (2012). Gene × Environment interaction and resilience: Effects of child maltreatment and serotonin, corticotropin releasing hormone, dopamine, and oxytocin genes. *Development and Psychopathology*, *24*(2), 411–427. https://doi.org/10.1017/S0954579412000077

Cisler, J. M., Sigel, B. A., Steele, J. S., Smitherman, S., Vanderzee, K., Pemberton, J., … Kilts, C. D. (2016). Changes in functional connectivity of the amygdala during cognitive reappraisal predict symptom reduction during trauma-focused cognitive–behavioral therapy among adolescent girls with post-traumatic stress disorder. *Psychological Medicine*, *46*(14), 3013–3023. https://doi.org/10.1017/S0033291716001847

Clark, U. S., Miller, E. R., & Hegde, R. R. (2018). Experiences of Discrimination Are Associated With Greater Resting Amygdala Activity and Functional Connectivity. *Biological Psychiatry: Cognitive Neuroscience and Neuroimaging*, *3*(4), 367–378. https://doi.org/10.1016/j.bpsc.2017.11.011

Connor, K. M., & Davidson, J. R. T. (2003a). Development of a new resilience scale: The Connor-Davidson Resilience Scale (CD-RISC). *Depression and Anxiety*, *18*(2), 76–82. https://doi.org/10.1002/da.10113

Connor, K. M., & Davidson, J. R. T. (2003b). Development of a new resilience scale: The Connor-Davidson Resilience Scale (CD-RISC). *Depression and Anxiety*, *18*(2), 76–82. https://doi.org/10.1002/da.10113

Corral-Frías, N. S., Nikolova, Y. S., Michalski, L. J., Baranger, D. A. A., Hariri, A. R., & Bogdan, R. (2015). Stress-related anhedonia is associated with ventral striatum reactivity to reward and transdiagnostic psychiatric symptomatology. *Psychological Medicine*, *45*(12), 2605–2617. https://doi.org/10.1017/S0033291715000525

Cox, R. W., Chen, G., Glen, D. R., Reynolds, R. C., & Taylor, P. A. (2017). FMRI Clustering in AFNI: False-Positive Rates Redux. *Brain Connectivity*, *7*(3), 152–171. https://doi.org/10.1089/brain.2016.0475

Daniels, J. K., Hegadoren, K. M., Coupland, N. J., Rowe, B. H., Densmore, M., Neufeld, R. W. J., & Lanius, R. A. (2012). Neural correlates and predictive power of trait resilience in an acutely traumatized sample: A pilot investigation. *The Journal of Clinical Psychiatry*, *73*(3), 327–332. https://doi.org/10.4088/JCP.10m06293

Demers, L. A., Hunt, R. H., Cicchetti, D., Cohen-Gilbert, J. E., Rogosch, F. A., Toth, S. L., & Thomas, K. M. (2021). Impact of childhood maltreatment and resilience on behavioral and neural patterns of inhibitory control during emotional distraction. *Development and Psychopathology*, 1–12. https://doi.org/10.1017/S0954579421000055

Demers, L. A., McKenzie, K. J., Hunt, R. H., Cicchetti, D., Cowell, R. A., Rogosch, F. A., … Thomas, K. M. (2018). Separable Effects of Childhood Maltreatment and Adult Adaptive Functioning on Amygdala Connectivity During Emotion Processing. *Biological Psychiatry: Cognitive Neuroscience and Neuroimaging*, *3*(2), 116–124. https://doi.org/10.1016/j.bpsc.2017.08.010

Denckla, C. A., Cicchetti, D., Kubzansky, L. D., Seedat, S., Teicher, M. H., Williams, D. R., & Koenen, K. C. (2020). Psychological resilience: An update on definitions, a critical appraisal, and research recommendations. *European Journal of Psychotraumatology*, *11*(1), 1822064. https://doi.org/10.1080/20008198.2020.1822064

Dennison, M. J., Sheridan, M. A., Busso, D. S., Jenness, J. L., Peverill, M., Rosen, M. L., & McLaughlin, K. A. (2016). Neurobehavioral markers of resilience to depression amongst adolescents exposed to child abuse. *Journal of Abnormal Psychology*, *125*(8), 1201–1212. https://doi.org/10.1037/abn0000215

Dillon, D. G., Holmes, A. J., Birk, J. L., Brooks, N., Lyons-Ruth, K., & Pizzagalli, D. A. (2009). Childhood Adversity Is Associated with Left Basal Ganglia Dysfunction During Reward Anticipation in Adulthood. *Biological Psychiatry*, *66*(3), 206–213. https://doi.org/10.1016/j.biopsych.2009.02.019

Dima, D., & Breen, G. (2015). Polygenic risk scores in imaging genetics: Usefulness and applications. *Journal of Psychopharmacology*, *29*(8), 867–871. https://doi.org/10.1177/0269881115584470

Dubois, J., & Adolphs, R. (2016). Building a Science of Individual Differences from fMRI. *Trends in Cognitive Sciences*, *20*(6), 425–443. https://doi.org/10.1016/j.tics.2016.03.014

Dunn, E. C., Soare, T. W., Zhu, Y., Simpkin, A. J., Suderman, M. J., Klengel, T., … Relton, C. L. (2019). Sensitive Periods for the Effect of Childhood Adversity on DNA Methylation: Results

From a Prospective, Longitudinal Study. *Biological Psychiatry*, *85*(10), 838–849. https://doi.org/10.1016/j.biopsych.2018.12.023

Dunsmoor, J. E., Kroes, M. C. W., Li, J., Daw, N. D., Simpson, H. B., & Phelps, E. A. (2019). Role of Human Ventromedial Prefrontal Cortex in Learning and Recall of Enhanced Extinction. *Journal of Neuroscience*, *39*(17), 3264–3276. https://doi.org/10.1523/JNEUROSCI.2713-18.2019

Eklund, A., Nichols, T. E., & Knutsson, H. (2016). Cluster failure: Why fMRI inferences for spatial extent have inflated false-positive rates. *Proceedings of the National Academy of Sciences*, 201602413. https://doi.org/10.1073/pnas.1602413113

Elliott, M. L., Knodt, A. R., Cooke, M., Kim, M. J., Melzer, T. R., Keenan, R., … Hariri, A. R. (2019). General functional connectivity: Shared features of resting-state and task fMRI drive reliable and heritable individual differences in functional brain networks. *NeuroImage*, *189*, 516–532. https://doi.org/10.1016/j.neuroimage.2019.01.068

Elliott, M. L., Knodt, A. R., Ireland, D., Morris, M. L., Poulton, R., Ramrakha, S., … Hariri, A. R. (2020). What Is the Test-Retest Reliability of Common Task-Functional MRI Measures? New Empirical Evidence and a Meta-Analysis. *Psychological Science*, *31*(7), 792–806. https://doi.org/10.1177/0956797620916786

Elman, I., Lowen, S., Frederick, B. B., Chi, W., Becerra, L., & Pitman, R. K. (2009). Functional Neuroimaging of Reward Circuitry Responsivity to Monetary Gains and Losses in Posttraumatic Stress Disorder. *Biological Psychiatry*, *66*(12), 1083–1090. https://doi.org/10.1016/j.biopsych.2009.06.006

Ersche, K. D. (2020). Resilience to trauma: Just a matter of control? *Science*, *367*(6479), 734–735. https://doi.org/10.1126/science.aaz9451

Falconer, E., Bryant, R., Felmingham, K. L., Kemp, A. H., Gordon, E., Peduto, A., … Williams, L. M. (2008). The neural networks of inhibitory control in posttraumatic stress disorder. *Journal of Psychiatry & Neuroscience : JPN*, *33*(5), 413–422.

Feder, A., Fred-Torres, S., Southwick, S. M., & Charney, D. S. (2019). The Biology of Human Resilience: Opportunities for Enhancing Resilience Across the Life Span. *Biological Psychiatry*, *86*(6), 443–453. https://doi.org/10.1016/j.biopsych.2019.07.012

Feder, A., Mota, N., Salim, R., Rodriguez, J., Singh, R., Schaffer, J., … Pietrzak, R. H. (2016). Risk, coping and PTSD symptom trajectories in World Trade Center responders. *Journal of Psychiatric Research*, *82*, 68–79. https://doi.org/10.1016/j.jpsychires.2016.07.003

Felmingham, K. L., Falconer, E. M., Williams, L., Kemp, A. H., Allen, A., Peduto, A., & Bryant, R. A. (2014). Reduced Amygdala and Ventral Striatal Activity to Happy Faces in PTSD Is Associated with Emotional Numbing. *PLOS ONE*, *9*(9), e103653. https://doi.org/10.1371/journal.pone.0103653

Finn, E. S., Glerean, E., Khojandi, A. Y., Nielson, D., Molfese, P. J., Handwerker, D. A., & Bandettini, P. A. (2020). Idiosynchrony: From shared responses to individual differences during naturalistic neuroimaging. *NeuroImage*, *215*, 116828. https://doi.org/10.1016/j.neuroimage.2020.116828

Fitzgerald, J. M., Webb, E. K., Weis, C. N., Huggins, A. A., Bennett, K. P., Miskovich, T. A., … Larson, C. L. (2022). Hippocampal Resting-State Functional Connectivity Forecasts Individual Posttraumatic Stress Disorder Symptoms: A Data-Driven Approach. *Biological Psychiatry: Cognitive Neuroscience and Neuroimaging*, *7*(2), 139–149. https://doi.org/10.1016/j.bpsc.2021.08.007

Fonzo, G. A., Goodkind, M. S., Oathes, D. J., Zaiko, Y. V., Harvey, M., Peng, K. K., … Etkin, A. (2017). PTSD Psychotherapy Outcome Predicted by Brain Activation During Emotional Reactivity and Regulation. *American Journal of Psychiatry*, *174*(12), 1163–1174. https://doi.org/10.1176/appi.ajp.2017.16091072

Fonzo, G. A., Simmons, A. N., Thorp, S. R., Norman, S. B., Paulus, M. P., & Stein, M. B. (2010). Exaggerated and Disconnected Insular-Amygdalar Blood Oxygenation Level-Dependent Response to Threat-Related Emotional Faces in Women with Intimate-Partner Violence

Posttraumatic Stress Disorder. *Biological Psychiatry*, *68*(5), 433–441. https://doi.org/10.1016/j.biopsych.2010.04.028

Fritz, J., de Graaff, A. M., Caisley, H., van Harmelen, A.-L., & Wilkinson, P. O. (2018). A Systematic Review of Amenable Resilience Factors That Moderate and/or Mediate the Relationship Between Childhood Adversity and Mental Health in Young People. *Frontiers in Psychiatry*, *9*. https://doi.org/10.3389/fpsyt.2018.00230

Fritz, J., Fried, E. I., Goodyer, I. M., Wilkinson, P. O., & van Harmelen, A.-L. (2018). A Network Model of Resilience Factors for Adolescents with and without Exposure to Childhood Adversity. *Scientific Reports*, *8*(1), 15774. https://doi.org/10.1038/s41598-018-34130-2

Fritz, J., Stretton, J., Askelund, A. D., Schweizer, S., Walsh, N. D., Elzinga, B. M., … van Harmelen, A.-L. (2019). Mood and neural responses to social rejection do not seem to be altered in resilient adolescents with a history of adversity. *Development and Psychopathology*, 1–13. https://doi.org/10.1017/S0954579419000178

Fullana, M. A., Albajes-Eizagirre, A., Soriano-Mas, C., Vervliet, B., Cardoner, N., Benet, O., … Harrison, B. J. (2018). Fear extinction in the human brain: A meta-analysis of fMRI studies in healthy participants. *Neuroscience & Biobehavioral Reviews*, *88*, 16–25. https://doi.org/10.1016/j.neubiorev.2018.03.002

Fullana, M. A., Dunsmoor, J. E., Schruers, K. R. J., Savage, H. S., Bach, D. R., & Harrison, B. J. (2020). Human fear conditioning: From neuroscience to the clinic. *Behaviour Research and Therapy*, *124*, 103528. https://doi.org/10.1016/j.brat.2019.103528

Gee, D. G. (2020). Caregiving influences on emotional learning and regulation: Applying a sensitive period model. *Current Opinion in Behavioral Sciences*, *36*, 177–184. https://doi.org/10.1016/j.cobeha.2020.11.003

Gerin, M. I., Viding, E., Pingault, J.-B., Puetz, V. B., Knodt, A. R., Radtke, S. R., … McCrory, E. J. (2019). Heightened amygdala reactivity and increased stress generation predict internalizing

symptoms in adults following childhood maltreatment. *Journal of Child Psychology and Psychiatry*, *60*(7), 752–761. https://doi.org/10.1111/jcpp.13041

Getnet, B., Medhin, G., & Alem, A. (2019). Symptoms of post-traumatic stress disorder and depression among Eritrean refugees in Ethiopia: Identifying direct, meditating and moderating predictors from path analysis. *BMJ Open*, *9*(1), e021142. https://doi.org/10.1136/bmjopen-2017-021142

Goodyer, I. M., Croudace, T., Dunn, V., Herbert, J., & Jones, P. B. (2010). Cohort Profile: Risk patterns and processes for psychopathology emerging during adolescence: the ROOTS project. *International Journal of Epidemiology*, *39*(2), 361–369. https://doi.org/10.1093/ije/dyp173

Gould, F., Clarke, J., Heim, C., Harvey, P. D., Majer, M., & Nemeroff, C. B. (2012). The effects of child abuse and neglect on cognitive functioning in adulthood. *Journal of Psychiatric Research*, *46*(4), 500–506. Scopus. https://doi.org/10.1016/j.jpsychires.2012.01.005

Green, B. L. (1990). Defining Trauma: Terminology and Generic Stressor Dimensions. *Journal of Applied Social Psychology*, *20*(20), 1632–1642. https://doi.org/10.1111/j.1559-1816.1990.tb01498.x

Greenberg, M. T. (2006). Promoting Resilience in Children and Youth. *Annals of the New York Academy of Sciences*, *1094*(1), 139–150. https://doi.org/10.1196/annals.1376.013

Hanson, J. L., Albert, D., Iselin, A.-M. R., Carré, J. M., Dodge, K. A., & Hariri, A. R. (2016). Cumulative stress in childhood is associated with blunted reward-related brain activity in adulthood. *Social Cognitive and Affective Neuroscience*, *11*(3), 405–412. https://doi.org/10.1093/scan/nsv124

Hanson, J. L., Hariri, A. R., & Williamson, D. E. (2015). Blunted Ventral Striatum Development in Adolescence Reflects Emotional Neglect and Predicts Depressive Symptoms. *Biological Psychiatry*, *78*(9), 598–605. https://doi.org/10.1016/j.biopsych.2015.05.010

Harpur, L. J., Polek, E., & van Harmelen, A.-L. (2015). The role of timing of maltreatment and child intelligence in pathways to low symptoms of depression and anxiety in adolescence. *Child Abuse & Neglect*, *47*, 24–37. https://doi.org/10.1016/j.chiabu.2015.05.019

Hofmann, S. G., Asmundson, G. J. G., & Beck, A. T. (2013). The Science of Cognitive Therapy. *Behavior Therapy*, *44*(2), 199–212. https://doi.org/10.1016/j.beth.2009.01.007

Holz, N. E., Tost, H., & Meyer-Lindenberg, A. (2020). Resilience and the brain: A key role for regulatory circuits linked to social stress and support. *Molecular Psychiatry*, *25*(2), 379–396. https://doi.org/10.1038/s41380-019-0551-9

Hoorelbeke, K., Van den Bergh, N., Wichers, M., & Koster, E. H. W. (2019). Between vulnerability and resilience: A network analysis of fluctuations in cognitive risk and protective factors following remission from depression. *Behaviour Research and Therapy*, *116*, 1–9. https://doi.org/10.1016/j.brat.2019.01.007

Horn, S. R., Pietrzak, R. H., Schechter, C., Bromet, E. J., Katz, C. L., Reissman, D. B., … Feder, A. (2016). Latent typologies of posttraumatic stress disorder in World Trade Center responders. *Journal of Psychiatric Research*, *83*, 151–159. https://doi.org/10.1016/j.jpsychires.2016.08.018

Hudson, A., Van Hamme, C., Maeyens, L., Brass, M., & Mueller, S. (2018). *Spontaneous mentalizing after early interpersonal trauma: Evidence for hypoactivation of the temporoparietal junction* [Preprint]. Neuroscience. https://doi.org/10.1101/487363

Iadipaolo, A. S., Marusak, H. A., Paulisin, S. M., Sala-Hamrick, K., Crespo, L. M., Elrahal, F., … Rabinak, C. A. (2018). Distinct neural correlates of trait resilience within core neurocognitive networks in at-risk children and adolescents. *NeuroImage. Clinical*, *20*, 24–34. https://doi.org/10.1016/j.nicl.2018.06.026

Iigaya, K., Hauser, T. U., Kurth-Nelson, Z., O'Doherty, J. P., Dayan, P., & Dolan, R. J. (2019). Hippocampal-midbrain circuit enhances the pleasure of anticipation in the prefrontal cortex. *BioRxiv*, 588699. https://doi.org/10.1101/588699

Ioannidis, K., Askelund, A. D., Kievit, R. A., & van Harmelen, A.-L. (2020). The complex neurobiology of resilient functioning after childhood maltreatment. *BMC Medicine*, *18*(1), 32. https://doi.org/10.1186/s12916-020-1490-7

Jacob, S. N., Dodge, C. P., & Vasterling, J. J. (2019). Posttraumatic stress disorder and neurocognition: A bidirectional relationship? *Clinical Psychology Review*, *72*, 101747. https://doi.org/10.1016/j.cpr.2019.101747

Jeong, H., Park, S., Dager, S. R., Lim, S. M., Lee, S. L., Hong, H., … Lyoo, I. K. (2019). Altered functional connectivity in the fear network of firefighters with repeated traumatic stress. *The British Journal of Psychiatry*, *214*(6), 347–353. https://doi.org/10.1192/bjp.2018.260

Kaldewaij, R., Koch, S. B. J., Hashemi, M. M., Zhang, W., Klumpers, F., & Roelofs, K. (2021). Anterior prefrontal brain activity during emotion control predicts resilience to post-traumatic stress symptoms. *Nature Human Behaviour*. https://doi.org/10.1038/s41562-021-01055-2

Kalisch, R., Baker, D. G., Basten, U., Boks, M. P., Bonanno, G. A., Brummelman, E., … Kleim, B. (2017). The resilience framework as a strategy to combat stress-related disorders. *Nature Human Behaviour*, *1*(11), 784. https://doi.org/10.1038/s41562-017-0200-8

Karam, E. G., Friedman, M. J., Hill, E. D., Kessler, R. C., McLaughlin, K. A., Petukhova, M., … Koenen, K. C. (2014). Cumulative Traumas and Risk Thresholds: 12-Month PTSD in the World Mental Health (WMH) Surveys. *Depression and Anxiety*, *31*(2), 130–142. https://doi.org/10.1002/da.22169

Keane, T. M., Fairbank, J. A., Caddell, J. M., Zimering, R. T., Taylor, K. L., & Mora, C. A. (1989). Clinical evaluation of a measure to assess combat exposure. *Psychological Assessment: A Journal of Consulting and Clinical Psychology*, *1*(1), 53–55. https://doi.org/10.1037/1040-3590.1.1.53

Keynan, J. N., Cohen, A., Jackont, G., Green, N., Goldway, N., Davidov, A., … Hendler, T. (2019). Electrical fingerprint of the amygdala guides neurofeedback training for stress resilience. *Nature Human Behaviour*, *3*(1), 63. https://doi.org/10.1038/s41562-018-0484-3

Lepore, S. J., & Kliewer, W. (2019). Social Intelligence Attenuates Association between Peer Victimization and Depressive Symptoms among Adolescents. *Psychology of Violence*, *9*(6), 644–652. https://doi.org/10.1037/vio0000234

Liebenberg, L. (2020). Reconsidering interactive resilience processes in mental health: Implications for child and youth services. *Journal of Community Psychology*, *48*(5), 1365–1380. https://doi.org/10.1002/jcop.22331

Lissek, S., & van Meurs, B. (2015). Learning models of PTSD: Theoretical accounts and psychobiological evidence. *International Journal of Psychophysiology*, *98*(3, Part 2), 594–605. https://doi.org/10.1016/j.ijpsycho.2014.11.006

Luthar, S. S., Sawyer, J. A., & Brown, P. J. (2006). Conceptual Issues in Studies of Resilience. *Annals of the New York Academy of Sciences*, *1094*(1), 105–115. https://doi.org/10.1196/annals.1376.009

Maier, S. F., & Watkins, L. R. (2010). Role of the medial prefrontal cortex in coping and resilience. *Brain Research*, *1355*, 52–60. https://doi.org/10.1016/j.brainres.2010.08.039

Mary, A., Dayan, J., Leone, G., Postel, C., Fraisse, F., Malle, C., … Gagnepain, P. (2020). Resilience after trauma: The role of memory suppression. *Science*, *367*(6479). https://doi.org/10.1126/science.aay8477

McGloin, J. M., & Widom, C. S. (2001). Resilience among abused and neglected children grown up. *Development and Psychopathology*, *13*(4), 1021–1038.

McLean, C. P., & Anderson, E. R. (2009). Brave men and timid women? A review of the gender differences in fear and anxiety. *Clinical Psychology Review*, *29*(6), 496–505. https://doi.org/10.1016/j.cpr.2009.05.003

McLean, S. A., Ressler, K., Koenen, K. C., Neylan, T., Germine, L., Jovanovic, T., … Kessler, R. (2020). The AURORA Study: A longitudinal, multimodal library of brain biology and function after traumatic stress exposure. *Molecular Psychiatry*, *25*(2), 283–296. https://doi.org/10.1038/s41380-019-0581-3

Meili, I., & Maercker, A. (2019). Cultural perspectives on positive responses to extreme adversity: A playing field for metaphors. *Transcultural Psychiatry*, *56*(5), 1056–1075. https://doi.org/10.1177/1363461519844355

Mendenhall, E., & Kim, A. W. (2019). How to Fail a Scale: Reflections on a Failed Attempt to Assess Resilience. *Culture, Medicine, and Psychiatry*, *43*(2), 315–325. https://doi.org/10.1007/s11013-018-9617-4

Méndez Leal, A. S., & Silvers, J. A. (2021). Neurobiological Markers of Resilience to Early-Life Adversity During Adolescence. *Biological Psychiatry: Cognitive Neuroscience and Neuroimaging*, *6*(2), 238–247. https://doi.org/10.1016/j.bpsc.2020.08.004

Milad, M. R., Wright, C. I., Orr, S. P., Pitman, R. K., Quirk, G. J., & Rauch, S. L. (2007). Recall of Fear Extinction in Humans Activates the Ventromedial Prefrontal Cortex and Hippocampus in Concert. *Biological Psychiatry*, *62*(5), 446–454. https://doi.org/10.1016/j.biopsych.2006.10.011

Moreno-López, L., Ioannidis, K., Askelund, A. D., Smith, A. J., Schueler, K., & van Harmelen, A.-L. (2020). The Resilient Emotional Brain: A Scoping Review of the Medial Prefrontal Cortex and Limbic Structure and Function in Resilient Adults With a History of Childhood Maltreatment. *Biological Psychiatry: Cognitive Neuroscience and Neuroimaging*, *5*(4), 392–402. https://doi.org/10.1016/j.bpsc.2019.12.008

Mowinckel, A. M., & Vidal-Piñeiro, D. (2019, December 17). *Visualisation of Brain Statistics with R-packages ggseg and ggseg3d*. arXiv. https://doi.org/10.48550/arXiv.1912.08200

Mowinckel, A. M., & Vidal-Piñeiro, D. (n.d.). *GgsegExtra* [R]. Retrieved from https://github.com/ggseg/ggsegExtra (Original work published 2019)

Nawijn, L., van Zuiden, M., Frijling, J. L., Koch, S. B. J., Veltman, D. J., & Olff, M. (2015). Reward functioning in PTSD: A systematic review exploring the mechanisms underlying anhedonia. *Neuroscience & Biobehavioral Reviews*, *51*, 189–204. https://doi.org/10.1016/j.neubiorev.2015.01.019

Nord, C. L., Gray, A., Charpentier, C. J., Robinson, O. J., & Roiser, J. P. (2017). Unreliability of putative fMRI biomarkers during emotional face processing. *NeuroImage*, *156*, 119–127. https://doi.org/10.1016/j.neuroimage.2017.05.024

Patel, R., Spreng, R. N., Shin, L. M., & Girard, T. A. (2012). Neurocircuitry models of posttraumatic stress disorder and beyond: A meta-analysis of functional neuroimaging studies. *Neuroscience & Biobehavioral Reviews*, *36*(9), 2130–2142. https://doi.org/10.1016/j.neubiorev.2012.06.003

Phelps, E. A., Delgado, M. R., Nearing, K. I., & LeDoux, J. E. (2004). Extinction Learning in Humans: Role of the Amygdala and vmPFC. *Neuron*, *43*(6), 897–905. https://doi.org/10.1016/j.neuron.2004.08.042

Pietrzak, R. H., el-Gabalawy, R., Tsai, J., Sareen, J., Neumeister, A., & Southwick, S. M. (2014). Typologies of posttraumatic stress disorder in the U.S. adult population. *Journal of Affective Disorders*, *162*, 102–106. https://doi.org/10.1016/j.jad.2014.03.024

Pietrzak, R. H., Feder, A., Singh, R., Schechter, C. B., Bromet, E. J., Katz, C. L., … Southwick, S. M. (2014). Trajectories of PTSD risk and resilience in World Trade Center responders: An 8-year prospective cohort study. *Psychological Medicine*, *44*(1), 205–219. https://doi.org/10.1017/S0033291713000597

Pitman, R. K., Rasmusson, A. M., Koenen, K. C., Shin, L. M., Orr, S. P., Gilbertson, M. W., … Liberzon, I. (2012). Biological studies of post-traumatic stress disorder. *Nature Reviews Neuroscience*, *13*(11), 769–787. https://doi.org/10.1038/nrn3339

Portnoy, G. A., Relyea, M. R., Decker, S., Shamaskin-Garroway, A., Driscoll, M., Brandt, C. A., & Haskell, S. G. (2018). Understanding Gender Differences in Resilience Among Veterans: Trauma History and Social Ecology. *Journal of Traumatic Stress*, *31*(6), 845–855. https://doi.org/10.1002/jts.22341

Powers, M. B., Warren, A. M., Rosenfield, D., Roden-Foreman, K., Bennett, M., Reynolds, M. C., … Smits, J. A. J. (2014). Predictors of PTSD symptoms in adults admitted to a Level I trauma center: A prospective analysis. *Journal of Anxiety Disorders*, *28*(3), 301–309. https://doi.org/10.1016/j.janxdis.2014.01.003

Reddan, M. C., Wager, T. D., & Schiller, D. (2018). Attenuating Neural Threat Expression with Imagination. *Neuron*, *100*(4), 994-1005.e4. https://doi.org/10.1016/j.neuron.2018.10.047

Rodman, A. M., Jenness, J. L., Weissman, D. G., Pine, D. S., & McLaughlin, K. A. (2019). Neurobiological Markers of Resilience to Depression Following Childhood Maltreatment: The Role of Neural Circuits Supporting the Cognitive Control of Emotion. *Biological Psychiatry*, *86*(6), 464–473. https://doi.org/10.1016/j.biopsych.2019.04.033

Sailer, U., Robinson, S., Fischmeister, F. P. S., König, D., Oppenauer, C., Lueger-Schuster, B., … Bauer, H. (2008). Altered reward processing in the nucleus accumbens and mesial prefrontal cortex of patients with posttraumatic stress disorder. *Neuropsychologia*, *46*(11), 2836–2844. https://doi.org/10.1016/j.neuropsychologia.2008.05.022

Schiller, D., & Delgado, M. R. (2010). Overlapping neural systems mediating extinction, reversal and regulation of fear. *Trends in Cognitive Sciences*, *14*(6), 268–276. https://doi.org/10.1016/j.tics.2010.04.002

Schultze-Lutter, F., Schimmelmann, B. G., & Schmidt, S. J. (2016). Resilience, risk, mental health and well-being: Associations and conceptual differences. *European Child & Adolescent Psychiatry*, *25*(5), 459–466. https://doi.org/10.1007/s00787-016-0851-4

Schweizer, S., Walsh, N. D., Stretton, J., Dunn, V. J., Goodyer, I. M., & Dalgleish, T. (2016). Enhanced emotion regulation capacity and its neural substrates in those exposed to moderate childhood adversity. *Social Cognitive and Affective Neuroscience*, *11*(2), 272–281. https://doi.org/10.1093/scan/nsv109

Scott, J. C., Matt, G. E., Wrocklage, K. M., Crnich, C., Jordan, J., Southwick, S. M., … Schweinsburg, B. C. (2015). A quantitative meta-analysis of neurocognitive functioning in posttraumatic stress disorder. *Psychological Bulletin*, *141*(1), 105–140. https://doi.org/10.1037/a0038039

Scult, M. A., Knodt, A. R., Radtke, S. R., Brigidi, B. D., & Hariri, A. R. (2019). Prefrontal Executive Control Rescues Risk for Anxiety Associated with High Threat and Low Reward Brain Function. *Cerebral Cortex*, *29*(1), 70–76. https://doi.org/10.1093/cercor/bhx304

Seeley, S. H., Boukezzi, S., DePierro, J. M., Charney, D. S., & Feder, A. (In press). Biological mechanisms of stress resilience: Human and animal studies. In *Charney and Nestler's*

Neurobiology of Mental Illness (eds. Charney, D.S, Nestler, E.J., Buxbaum, J.D., Binder, E., Gordon, J.A., and Picciotto, M.) (6th ed.). Oxford University Press.

Shalev, A., Liberzon, I., & Marmar, C. (2017). Post-Traumatic Stress Disorder. *New England Journal of Medicine*, *376*(25), 2459–2469. https://doi.org/10.1056/NEJMra1612499

Silveira, S., Shah, R., Nooner, K. B., Nagel, B. J., Tapert, S. F., de Bellis, M. D., & Mishra, J. (2020). Impact of Childhood Trauma on Executive Function in Adolescence—Mediating Functional Brain Networks and Prediction of High-Risk Drinking. *Biological Psychiatry: Cognitive Neuroscience and Neuroimaging*, *5*(5), 499–509. https://doi.org/10.1016/j.bpsc.2020.01.011

Silvers, J. A., Lumian, D. S., Gabard-Durnam, L., Gee, D. G., Goff, B., Fareri, D. S., … Tottenham, N. (2016). Previous Institutionalization Is Followed by Broader Amygdala-Hippocampal-PFC Network Connectivity during Aversive Learning in Human Development. *Journal of Neuroscience*, *36*(24), 6420–6430. https://doi.org/10.1523/JNEUROSCI.0038-16.2016

Sinha, R., Lacadie, C. M., Constable, R. T., & Seo, D. (2016). Dynamic neural activity during stress signals resilient coping. *Proceedings of the National Academy of Sciences*, *113*(31), 8837–8842. https://doi.org/10.1073/pnas.1600965113

Southwick, S. M., Charney, D. S., & DePierro, J. M. (2023). *Resilience: The Science of Mastering Life's Greatest Challenges* (3rd ed.). Cambridge University Press.

Speer, M. E., & Delgado, M. R. (2017). Reminiscing about positive memories buffers acute stress responses. *Nature Human Behaviour*, *1*(5), 0093. https://doi.org/10.1038/s41562-017-0093

Spreng, R. N., & Andrews-Hanna, J. (2015). The Default Network and Social Cognition. *Brain Mapping: An Encyclopedic Reference*, *3*, 165–169. https://doi.org/10.1016/B978-0-12-397025-1.00173-1

Stevens, J. S., Harnett, N. G., Lebois, L. A. M., van Rooij, S. J. H., Ely, T. D., Roeckner, A., … Ressler, K. J. (2021). Brain-Based Biotypes of Psychiatric Vulnerability in the Acute Aftermath of Trauma. *American Journal of Psychiatry*, *178*(11), 1037–1049. https://doi.org/10.1176/appi.ajp.2021.20101526

Stevens, J. S., & Jovanovic, T. (2019). Role of social cognition in post-traumatic stress disorder: A review and meta-analysis. *Genes, Brain and Behavior*, *18*(1), e12518. https://doi.org/10.1111/gbb.12518

Stevens, J. S., Kim, Y. J., Galatzer-Levy, I. R., Reddy, R., Ely, T. D., Nemeroff, C. B., … Ressler, K. J. (2017). Amygdala Reactivity and Anterior Cingulate Habituation Predict Posttraumatic Stress Disorder Symptom Maintenance After Acute Civilian Trauma. *Biological Psychiatry*, *81*(12), 1023–1029. https://doi.org/10.1016/j.biopsych.2016.11.015

Stratta, P., Capanna, C., Dell'Osso, L., Carmassi, C., Patriarca, S., Di Emidio, G., … Rossi, A. (2015). Resilience and coping in trauma spectrum symptoms prediction: A structural equation modeling approach. *Personality and Individual Differences*, *77*, 55–61. https://doi.org/10.1016/j.paid.2014.12.035

Street, A. E., & Dardis, C. M. (2018). Using a social construction of gender lens to understand gender differences in posttraumatic stress disorder. *Clinical Psychology Review*, *66*, 97–105. https://doi.org/10.1016/j.cpr.2018.03.001

Swartz, J. R., Knodt, A. R., Radtke, S. R., & Hariri, A. R. (2015). A neural biomarker of psychological vulnerability to future life stress. *Neuron*, *85*(3), 505–511. https://doi.org/10.1016/j.neuron.2014.12.055

Szucs, D., & Ioannidis, J. PA. (2020). Sample size evolution in neuroimaging research: An evaluation of highly-cited studies (1990–2012) and of latest practices (2017–2018) in high-impact journals. *NeuroImage*, *221*, 117164. https://doi.org/10.1016/j.neuroimage.2020.117164

Thompson, N. J., Fiorillo, D., Rothbaum, B. O., Ressler, K. J., & Michopoulos, V. (2018). Coping strategies as mediators in relation to resilience and posttraumatic stress disorder. *Journal of Affective Disorders*, *225*, 153–159. https://doi.org/10.1016/j.jad.2017.08.049

Thompson, P. M., Jahanshad, N., Ching, C. R. K., Salminen, L. E., Thomopoulos, S. I., Bright, J., … Zelman, V. (2020). ENIGMA and global neuroscience: A decade of large-scale studies of the

brain in health and disease across more than 40 countries. *Translational Psychiatry*, *10*(1), 1–28. https://doi.org/10.1038/s41398-020-0705-1

Tolin, D. F., & Foa, E. B. (2008). Sex differences in trauma and posttraumatic stress disorder: A quantitative review of 25 years of research. *Psychological Trauma: Theory, Research, Practice, and Policy*, *S*(1), 37–85. https://doi.org/10.1037/1942-9681.S.1.37

Troy, A. S., & Mauss, I. B. (2011). Resilience in the face of stress: Emotion regulation as a protective factor. In B. T. Litz, D. Charney, M. J. Friedman, & S. M. Southwick (Eds.), *Resilience and Mental Health: Challenges Across the Lifespan* (pp. 30–44). Cambridge: Cambridge University Press. https://doi.org/10.1017/CBO9780511994791.004

van der Werff, S. J. A., van den Berg, S. M., Pannekoek, J. N., Elzinga, B. M., & Van Der Wee, N. J. A. (2013). Neuroimaging resilience to stress: A review. *Frontiers in Behavioral Neuroscience*, *7*. https://doi.org/10.3389/fnbeh.2013.00039

van Harmelen, A. L., Kievit, R. A., Ioannidis, K., Neufeld, S., Jones, P. B., Bullmore, E., … Goodyer, I. (2017). Adolescent friendships predict later resilient functioning across psychosocial domains in a healthy community cohort. *Psychological Medicine*, *47*(13), 2312–2322. https://doi.org/10.1017/S0033291717000836

van Harmelen, A.-L., Gibson, J. L., Clair, M. C. S., Owens, M., Brodbeck, J., Dunn, V., … Goodyer, I. M. (2016). Friendships and Family Support Reduce Subsequent Depressive Symptoms in At-Risk Adolescents. *PLOS ONE*, *11*(5), e0153715. https://doi.org/10.1371/journal.pone.0153715

van Rooij, S. J. H., Stevens, J. S., Ely, T. D., Hinrichs, R., Michopoulos, V., Winters, S. J., … Jovanovic, T. (2018). The Role of the Hippocampus in Predicting Future Posttraumatic Stress Disorder Symptoms in Recently Traumatized Civilians. *Biological Psychiatry*, *84*(2), 106–115. https://doi.org/10.1016/j.biopsych.2017.09.005

Vythilingam, M., Nelson, E. E., Scaramozza, M., Waldeck, T., Hazlett, G., Southwick, S. M., … Ernst, M. (2009). Reward circuitry in resilience to severe trauma: An fMRI investigation of resilient

special forces soldiers. *Psychiatry Research: Neuroimaging*, *172*(1), 75–77. https://doi.org/10.1016/j.pscychresns.2008.06.008

Walsh, W. A., Dawson, J., & Mattingly, M. J. (2010). How Are We Measuring Resilience Following Childhood Maltreatment? Is the Research Adequate and Consistent? What is the Impact on Research, Practice, and Policy? *Trauma, Violence, & Abuse*, *11*(1), 27–41. https://doi.org/10.1177/1524838009358892

Wang, L., Paul, N., Stanton, S. J., Greeson, J. M., & Smoski, M. (2013). Loss of Sustained Activity in the Ventromedial Prefrontal Cortex in Response to Repeated Stress in Individuals with Early-Life Emotional Abuse: Implications for Depression Vulnerability. *Frontiers in Psychology*, *4*. https://doi.org/10.3389/fpsyg.2013.00320

Watson, P. (2019). PTSD as a Public Mental Health Priority. *Current Psychiatry Reports*, *21*(7), 61. https://doi.org/10.1007/s11920-019-1032-1

Waugh, C. E., & Koster, E. H. W. (2015). A resilience framework for promoting stable remission from depression. *Clinical Psychology Review*, *41*, 49–60. https://doi.org/10.1016/j.cpr.2014.05.004

Weathers, F. W., Blake, D. D., Schnurr, P. P., Kaloupek, D. G., Marx, B. P., & Keane, T. M. (2013). Clinician-Administered PTSD Scale for DSM-5 (CAPS-5). Retrieved October 9, 2018, from https://www.ptsd.va.gov/professional/assessment/adult-int/caps.asp

Whittle, S., Dennison, M., Vijayakumar, N., Simmons, J. G., Yücel, M., Lubman, D. I., … Allen, N. B. (2013). Childhood Maltreatment and Psychopathology Affect Brain Development During Adolescence. *Journal of the American Academy of Child & Adolescent Psychiatry*, *52*(9), 940-952.e1. https://doi.org/10.1016/j.jaac.2013.06.007

Williams, M., Metzger, I., Leins, C., & DeLapp, C. (2018). Assessing Racial Trauma Within a DSM–5 Framework: The UConn Racial/Ethnic Stress & Trauma Survey. *Practice Innovations*, *3*(4), 242–260. https://doi.org/10.1037/pri0000076

World Health Organization. (1993). *The ICD-10 Classification of Mental and Behavioural Disorders: Diagnostic Criteria for Research*. World Health Organization.

Wymbs, N. F., Orr, C., Albaugh, M. D., Althoff, R. R., O'Loughlin, K., Holbrook, H., … Kaufman, J. (2020). Social supports moderate the effects of child adversity on neural correlates of threat processing. *Child Abuse & Neglect*, *102*, 104413. https://doi.org/10.1016/j.chiabu.2020.104413

Yamamoto, T., Toki, S., Siegle, G. J., Takamura, M., Takaishi, Y., Yoshimura, S., … Yamawaki, S. (2017). Increased amygdala reactivity following early life stress: A potential resilience enhancer role. *BMC Psychiatry*, *17*(1), 27. https://doi.org/10.1186/s12888-017-1201-x

Yehuda, R., & Flory, J. D. (2007). Differentiating biological correlates of risk, PTSD, and resilience following trauma exposure. *Journal of Traumatic Stress*, *20*(4), 435–447. https://doi.org/10.1002/jts.20260

Yehuda, R., Hoge, C. W., McFarlane, A. C., Vermetten, E., Lanius, R. A., Nievergelt, C. M., … Hyman, S. E. (2015). Post-traumatic stress disorder. *Nature Reviews Disease Primers*, *1*, 15057. https://doi.org/10.1038/nrdp.2015.57

Yule, K., Houston, J., & Grych, J. (2019). Resilience in Children Exposed to Violence: A Meta-analysis of Protective Factors Across Ecological Contexts. *Clinical Child and Family Psychology Review*, *22*(3), 406–431. https://doi.org/10.1007/s10567-019-00293-1

Zhang, W., Kaldewaij, R., Hashemi, M. M., Koch, S. B. J., Smit, A., van Ast, V. A., … Roelofs, K. (2022). Acute-stress-induced change in salience network coupling prospectively predicts post-trauma symptom development. *Translational Psychiatry*, *12*(1), 63. https://doi.org/10.1038/s41398-022-01798-0

Zilverstand, A., Parvaz, M. A., & Goldstein, R. Z. (2017). Neuroimaging cognitive reappraisal in clinical populations to define neural targets for enhancing emotion regulation. A systematic review. *NeuroImage*, *151*, 105–116. https://doi.org/10.1016/j.neuroimage.2016.06.009

Zotev, V., Phillips, R., Misaki, M., Wong, C. K., Wurfel, B. E., Krueger, F., … Bodurka, J. (2018). Real-time fMRI neurofeedback training of the amygdala activity with simultaneous EEG in veterans with combat-related PTSD. *NeuroImage: Clinical*, *19*, 106–121. https://doi.org/10.1016/j.nicl.2018.04.010

1