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Brain Reward Circuits Promote Stress Resilience and Health: Implications for Reward-Based Interventions

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Abstract

From the COVID-19 global pandemic to racial injustice and the continued impact of climate change on communities across the globe, the past couple of years have demonstrated the need for a greater understanding of how to protect people from the negative consequences of stress. Here, I outline a perspective on how the brain's reward system might be an important, but often understudied, protective mechanism for stress resilience and stress-related health outcomes. I describe work suggesting that engagement of the reward system inhibits the stress response and is associated with improved health outcomes, including reduced depressive symptomatology and slowed cancer progression. I then highlight important future directions for translational research and illustrate the value of this perspective for improving behavioral interventions in clinical psychology and beyond.

Keywords

reward, stress, health outcomes, resilience

With the rapid, global spread of the COVID-19 virus and ensuing pandemic came uncertainty, social isolation, and stress. However, COVID-19 is just one example of recent events that have increased stress levels for people. Over the past few years, there has been an increase in catastrophic natural disasters and divisive politics, as well as increased attention to rising inequity and racial injustice. These concerns are raising population stress. Stressful life events have been linked to the incidence and exacerbation of physical health concerns (such as cardiovascular disease and viral infection) and mental health concerns (including posttraumatic stress disorder [PTSD] and depression; Cohen et al., 2007). The rise in stress levels and the negative repercussions of stress create a growing need for basic research on stress resilience and more effective stress-management interventions.

Although a rich body of work has explored the effects that stress has on health and well-being, work focused on understanding how to enhance stress resilience is in its infancy. Initial work on stress resilience focused on top-down executive-control processes (i.e., processes that are necessary for the cognitive control of behavior). For example, a review of the literature found that neurocognitive processes, such as problem solving, planning, and goal-directed behavior, are linked to stress regulation (Williams et al., 2009). However, although there is good empirical support for interventions that improve executive functioning among individuals with deficits in executive functioning, there might be other pathways to stress resilience that are modifiable for the general population. Here, I detail an understudied, and perhaps underappreciated, pathway to stress resilience: the brain's reward system. I describe the neural reward system's role in stress reduction and improvements in mental and physical health. I then outline some future directions for research on the relationship between reward and stress resilience. Increased mechanistic and translational research would accelerate the development of interventions for improving stress resilience and health.

The Neurobiology of Reward and Stress

Rewarding stimuli are those that are important for an organism's survival and lead to activation of a network

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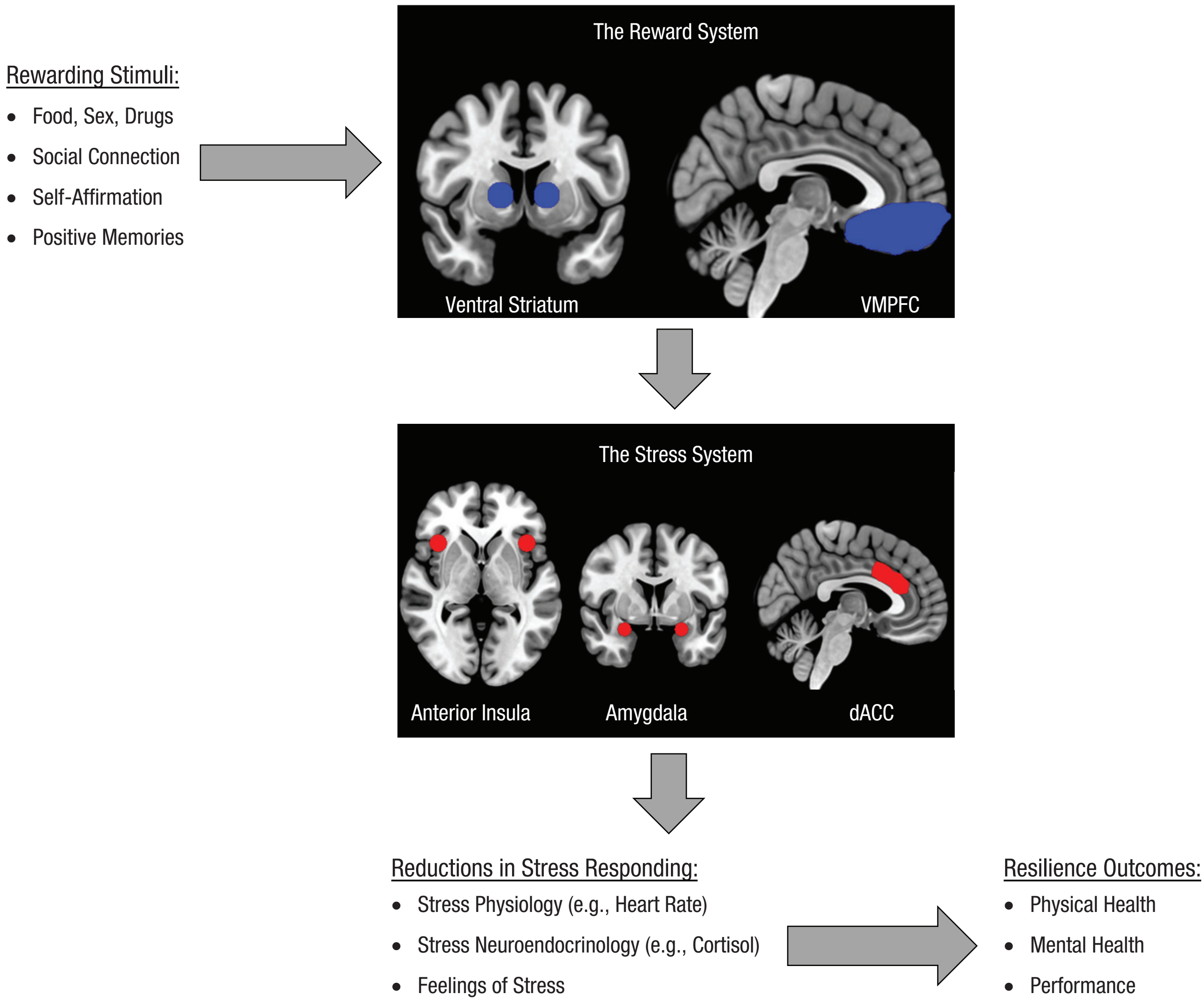

Fig. 1. The proposed pathway by which rewarding stimuli lead to reductions in stress responding and subsequent improvements in health and performance. The blue regions in the brain images show two key regions implicated in the reward system: the ventral striatum (on a coronal slice with the left side of the brain on the left) and the ventromedial prefrontal cortex (VMPFC; on a sagittal slice with the posterior of the brain on the left). The red regions show three key regions implicated in the stress system: the anterior insula (on an axial slice with the front of the brain at the top), the amygdala (on a coronal slice of the brain), and the dorsal anterior cingulate cortex (dACC; on a sagittal slice of the brain).

in the brain that identifies the value of the stimulus (Schultz, 2015). The brain's reward system includes regions in the prefrontal cortex (orbitofrontal cortex, ventromedial prefrontal cortex) and ventral striatum (see Fig. 1) and involves the neurotransmitters dopamine and opioids (Haber & Knutson, 2010). This neurobiological reward system is activated in response to a range of stimuli. Primary rewards are those most typically thought to influence survival, for example, food and sexual activity. However, secondary rewards are those that have been learned to be beneficial to the organism, for example, money and social support. Research suggests that both types of rewarding stimuli lead to activation of the reward system and that they have similar affective consequences (Sescousse et al., 2013). Additionally, there are three key psychological components of reward: (a) learning—the process by which a stimulus or experience is learned to be valuable, (b) liking—the pleasant affective experience of receiving or engaging with a reward, and (c) wanting—the motivation or desire to engage with a reward stimulus (Berridge & Robinson, 2003). A great deal of work in the reward literature has found that these processes rely on both common and dissociable neurobiology (Berridge et al., 2009).

The brain's stress system, on the other hand, includes regions such as the amygdala, dorsal anterior cingulate cortex, and insula (Ulrich-Lai & Herman, 2009). These regions (see Fig. 1) coordinate the physiological stress response. The physiological stress response is marked by increased activity in the hypothalamic-pituitary-adrenal (HPA) axis, a neuroendocrine response leading to a release of the stress hormone cortisol in humans, and by increased activity in the sympathetic nervous system, which leads to changes in blood pressure and heart rate (Ulrich-Lai & Herman, 2009). There is also evidence that stress can affect the immune system, prompting an immune response that is similar to what is seen when the body experiences an infection (Cohen et al., 2007). Following the onset of a stressor, the brain coordinates a cascade of these processes to facilitate a response to the stressor. However, repeated or prolonged stress can result in wear and tear on the physiological systems that support stress responding and can lead to negative health consequences, such as depression or cardiovascular disease (McEwen & Seeman, 1999). Resilience is thought to be the successful coping or adjustment to a stressor and is a pathway for preventing stress-related mental and physical health conditions in the future.

Some initial work has shown that regions in the reward system can inhibit activity in regions in the neural stress system (Eisenberger et al., 2011; Ulrich-Lai & Herman, 2009). This work suggests that the reward system is a biologically plausible mechanism for stress-reduction effects. The dynamics of communication between the reward and stress systems are still being identified, but some work with humans and animals has begun to identify critical components of this process. For example, reward-system neurotransmitters, such as dopamine and opioids, have receptor sites located in regions that coordinate the stress response (Drolet et al., 2001). Furthermore, blocking dopamine or opioids by administering antagonists can result in exaggerated stress responses in animals (Abercrombie & Jacobs, 1988). Increasing opioids, by administering an agonist, can lead to lower cortisol stress responding and lower self-reported stress levels in humans (Bershad et al., 2015). Thus, altering the presence of reward-system neurotransmitters has direct effects on stress responding—evidence of the link between the brain's reward and stress systems.

The Reward System Reduces Stress Reactivity

There is emerging evidence that activating the brain's reward system leads to reductions in stress responding. Experimental work in humans and animals has found that exposure to rewarding stimuli reduces physiological stress reactivity. For example, rats given sweet drinks or access to sexually receptive mates for several days showed decreased neuroendocrine (HPA axis) and cardiovascular (sympathetic system) stress reactivity to restraint stress (Ulrich-Lai et al., 2010). These effects are also seen in humans; for example, viewing rewarding erotic images reduced neuroendocrine cortisol reactivity to a subsequent laboratory task that induces stress (Creswell, Pacilio, et al., 2013). Moreover, this buffering of stress is not observed only with primary rewards. For example, social support activates the reward system in the brain (Eisenberger et al., 2011) and buffers cortisol stress responding (Kirschbaum et al., 1995). Reflecting on an important personal value activates the reward system (Dutcher et al., 2016), reduces neural activity in response to acute stress (Dutcher et al., 2020), and buffers cortisol reactivity to acute stress (Creswell et al., 2005).

Experimental work has also found that exposure to rewarding stimuli reduces behavioral and psychological responses to stress. Indeed, rats who were rewarded demonstrated less anxiety behavior when exposed to a stressor (Ulrich-Lai et al., 2010), and even zebra fish showed less anxious behavior in a stress paradigm when given rewarding food (Manuel et al., 2015). Human infants given a sweet fluid (compared with those given spring water) cried less during a subsequent blood draw (Abad et al., 1996). Similarly, in adults, receiving either primary or secondary rewards (compared with a control condition) has been linked to better performance on stressful math and verbal exams (Creswell, Dutcher, et al., 2013; Creswell, Pacilio, et al., 2013).

These results suggest that rewarding stimuli can reduce acute stress. Indeed, this effect is observed across species, which implicates systems in the brain that are shared across humans and other animals. Although some work in stress reduction points to cortical structures (such as the prefrontal cortex), the animal work described here clearly indicates that those structures are not the only ones involved in stress reduction. Research in this area should further explore how activating these reward systems in the brain affects stress physiology and subsequent behavior, as well as how enduring these effects are.

The Influence of Reward on Health via Stress Resilience

One example of potential enduring effects of reward administration concerns physical and mental health outcomes. Initial studies in rodents highlight relationships between reward-system activation and physical health. For example, experimental activation of the reward system has been shown to improve immunity and limit cancer progression in mice. Specifically, directly stimulating dopamine neurons within the reward system led to enhanced adaptive immune responses following a bacterial challenge (Ben-Shaanan et al., 2016). These effects of reward on health appeared to be driven by stress-resilience pathways, as they were mediated by the sympathetic nervous system's effects on the immune system (Ben-Shaanan et al., 2016). In a separate study, stimulation of the same reward region in the brain led to reductions in tumor weight in mice with tumors, an effect that was mediated by the sympathetic nervous system's effects on immunity in bone marrow (Ben-Shaanan et al., 2018). Taken together, these studies suggest that direct stimulation of the reward system affects physiological stress systems that link stress to poorer health. Links between reward and physical health have been observed in humans, too. Greater engagement in rewarding activities, such as taking vacation time, is associated with lower resting blood pressure, lower body mass index, and decreased risk of metabolic syndrome (Hruska et al., 2020; Pressman et al., 2009). A probable mechanism for these health benefits is activation of the brain's reward system in response to these rewarding activities, which leads to corresponding reductions in stress.

Moreover, greater neural reward reactivity may be protective against the negative effects of stress on mental health. Indeed, taking more vacation time is associated with lower depressive symptoms (Pressman et al., 2009). Greater neural reward reactivity to rewarding tasks has been shown to be associated with longitudinal decreases in depressive symptoms in adolescents (Telzer et al., 2014) and fewer depressive symptoms in young adults reporting high levels of stress related to the 2016 presidential election (Tashjian & Galván, 2018). Individuals with a high degree of recent stress showed lower positive affect when they had low ventral striatum reward reactivity, but higher positive affect when they had high ventral striatum reward reactivity, which suggests a protective effect of reward reactivity on vulnerability to depression (Nikolova et al., 2012). Similarly, reward reactivity or stimulation may have benefits in clinical populations, as well. For example, deep brain stimulation of reward-related regions in the brain led to a lessening of symptoms in patients with refractory major depressive disorder (Bewernick et al., 2010). Research on patients with PTSD also has found that high reward sensitivity might be a buffer against negative behaviors following trauma (Kasparek et al., 2020) and that a biased neural response to reward (compared with punishment) leads to a decrease in PTSD symptoms (Ben-Zion et al., 2022). These initial findings suggest that reward reactivity may provide a buffer against the mental health consequences of stress or distress, and thus that engaging the reward system might have stress-related health benefits.

One of the key challenges and opportunities facing the field is how to best leverage the pathway between reward and stress reduction to improve health. How do acute effects of rewarding stimuli on stress responding link to broader physical and mental health benefits? How do we build reward-activating interventions that support long-term stress resilience in at-risk patient populations?

Building Interventions That Foster Resilience via the Reward System

Although some clinical treatments capitalize on engaging reward pathways (e.g., deep brain stimulation), the field has yet to fully exploit the reward system in behavioral treatments for patients. One notable exception is behavioral activation therapy (Dimidjian et al., 2006), which is recognized as an evidence-based treatment for depression. A core element of this therapy is to have patients schedule more positive, rewarding activities and find more opportunities for reaching valued self-identified goals (Dimidjian et al., 2006). It is not yet clear whether behavioral activation therapy itself directly activates the reward system, but research has found that in patients with major depressive disorder, this treatment results in a recovery of activity in reward structures known to be affected in depression (Dichter et al., 2009). There is also the potential for building more rewarding activities into existing behavioral treatments (e.g., daily rewarding activities, increased leisure time) or training clinicians to reinforce those rewarding activities, to increase the efficacy of psychological and behavioral treatments. For instance, a program combining mindfulness and cognitive behavioral therapy led depressed patients to report greater appreciation of rewarding and positive experiences in their life, which corresponded to decreases in depression symptoms (Geschwind et al., 2011).

Translational research can capitalize on work showing links between reward-system activation and stress resilience to build more powerful and effective stress-reduction interventions. Here, I outline six basic and translational research areas that could help facilitate the creation or improvement of stress-reduction interventions and clinical paradigms:

1. *Basic research should continue to explore the neurobiological mechanisms for the association between reward and stress reduction*: Initial neuroanatomical investigations have identified connections between reward and stress systems in the brain, but less work has tested a mechanistic pathway by which rewarding stimuli can reduce stress responding in the brain and body, and under what circumstances that can provide a buffer against

the negative health consequences of stress. A model that maps reward-system activation to neural stress responding to physiological stress responding and consequently behavioral responding would help researchers home in on the conditions under which intervention could be helpful. One key future direction will be to work toward a greater understanding of the structural connections (e.g., white matter pathways) between stress and reward networks in the brain. Another key direction will be to explore which reward regions and targeted stress-system regions are critical for stress reduction; animal work that has identified a candidate nucleus in the amygdala (Ulrich-Lai et al., 2010) could help future interventions to target the most essential mechanisms for stress-reduction benefits.

2. *An important next step in translational research will be to investigate how presentation of a reward stimulus that leads to acute stress reduction can foster long-term stress resilience and health enhancement*: Work focusing on reduction of the acute stress response, as well as effects of lifestyle on health, has been done, but little work has examined a time-course model that would link these intermittent effects to subsequent health. For example, some initial work employed a study design in which presentation of a stressful stimulus followed a reward stimulus, allowing analyses comparing reactivity to stressful events that followed reward with reactivity to stressful events that did not follow reward (Dutcher et al., 2020). This design facilitated a greater understanding of the temporal processes of stress reduction via reward. However, it will be key to further probe the temporal processes that occur when reward leads to reduced stress responding, as well as to explore how these neural processes link to downstream stress physiology.
3. *Research should clarify the structural support of this bidirectional relationship between stress and reward*: Many clinical studies have found that patients with a high stress burden or depression demonstrate reduced reward responsivity (Pizzagalli, 2014). The relationship between stress and reward appears to be bidirectional, and future research should clarify how this bidirectionality is supported in the brain. Neuroimaging studies on functional and structural connectivity could help elucidate the nature of the association between the reward and stress systems in the brain. For example, are the structural connections between reward and stress regions in the brain bidirectional, or do the two directions of the relationship leverage separate pathways? Because this bidirectionality suggests competing processes, clarifying the relationship might help elucidate who might benefit from reward-based interventions and when they might benefit. For example, do these interventions need to occur prior to the onset of a clinical diagnosis? Will a reward intervention be less effective for depressed than for nondepressed individuals because their reward system may demonstrate a blunted response to rewarding stimuli? Furthermore, if stress (or depressive symptoms) reduces reward responsivity, understanding the mechanisms by which a reward can overcome that blunted response pattern will be key for future treatments.
4. *Research should explore whether the effectiveness of specific reward interventions varies across different types of stressors and what type of rewards might be most effective in interventions*: It is possible that the type of reward may be an important detail for this area of research. Previous work has focused on blunted reward responses to money in clinical patients, but money may not be as potent a reward stimulus as social connection for patients with depression. Furthermore, although interventions that offer intermittent primary rewards could have important stress-reduction benefits, they might create practical (or ethical) issues: Giving stressed individuals delicious, rewarding food might increase their obesity risk, and offering opiates might lead to addiction. Interventions that focus on engaging patients with secondary rewards may have greater value. Secondary rewards, such as giving and receiving social support and thinking about positive aspects of the self, have been shown to activate the brain's reward system and buffer against the negative effects of a broad range of stressors (Dutcher & Creswell, 2018). There is a broader potential for secondary rewards and rewarding activities, rather than primary rewards, to be part of standard clinical care for individuals with stress-related conditions.
5. *Each component of reward (learning, wanting, liking) might have differential effects on stress reduction and health enhancement*: Most of the work exploring reward's stress-reduction effects has focused on the liking component of reward or has not separated these reward components. It may be the case that one component is necessary or solely responsible for subsequent stress-dampening effects, and knowing this would be critical for designing effective interventions for

stress reduction. For example, some evidence suggests that the motivational deficits of individuals with depression may be due more to low wanting (low anticipatory pleasure) than to low liking (Sherdell et al., 2012). This could mean that interventions maximizing opportunities for pleasurable feelings associated with reward would be particularly effective for depressed people, even in the absence of the desire to engage with rewards.

6. *Finally, for broader implementation, it will be essential to test reward-based interventions in practice*: Thus far, research suggests that stress reduction achieved through reward could help prevent health problems and other stress-related consequences. But work on behavioral activation therapy also suggests that reward-based therapies could be effective as treatments for stress-related health conditions. Investigating the strengths of reward for prevention as well as for treatment will be critical for implementation of interventions in health-care settings. Similarly, understanding the conditions and disease states for which these therapies might be effective would help build an intervention science that could be widely practiced in mental and physical health settings.

Moving Forward: New Directions for Building a Literature on the Link Between Reward and Stress Resilience

Emerging research paints a compelling portrait of how activating the reward system can foster stress reduction and counteract stress-related effects on health. I believe there are important new directions for advancing translational neuroscience research and intervention science by exploring links among rewards, stress resilience, and health. Over the past couple of years, the COVID-19 crisis has affected billions of people worldwide, and strategies for building stress resilience are more important than ever. We can look to resilient responses to other major events for inspiration. For example, following the disastrous wildfires in the American West over the past 5 years, millions of dollars were donated in fundraisers, survivors formed support groups, and events were planned to celebrate rebuilt homes. It is not a coincidence that the natural tendency after stressful events is to reach out and connect with other people, and to donate to recovery efforts. In fact, I suspect that these behaviors result in activation of the reward system, thereby promoting resilience, adjustment, and health. The science of stress resilience is more important than ever. Research should continue to map out the neurobiology of stress-reduction interventions and their health benefits so that we can build empirically supported, effective ways to help people manage during stressful life events.

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Transparency

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