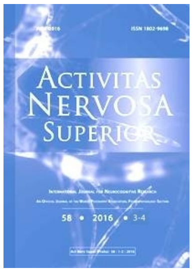

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MINI REVIEW

MECHANISMS OF STRESS IN HUMANS

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Abstract

The purpose of this literature review is to summarize stress-related research to better understand the mechanisms of stress. The connections between stress and environmental, physiological, as well as neurological factors were examined. Research has shown that stress exposure was related to cognitive dysfunctions, altered attention strategies, reduced capacity to experience pleasure, and higher risk-taking tendency in achieving gains. A high level of stress was associated with greater hippocampal volume loss and was found to hinder memory retrieval while enhancing memory consolidation process. Physiologically, high stress levels were linked to shortened telomeres, elevated levels of circulating inflammatory markers, as well as hypoactivation of electrodermal activity and diurnal cortisol in response to stressors. Moreover, prenatal stress exposure was found to be a risk factor that can make an individual vulnerable to develop later stress-related physical and psychological problems. Researchers have also identified protective factors that can buffer individuals from the negative impact of stress.

Key words: *Stress; Trauma; Memory; Reward; Attention*

1. INTRODUCTION

Numerous research studies have been conducted to investigate the mechanisms of stress and the impact of stress on health and wellbeing. Stress responses are designed to maximize the chance of survival when encountering stressors. However, when the stress system becomes dysregulated, it can exert negative effects on people's psychological and physiological health. Some reported studies examining stress mechanisms from environmental, physiological, and neurological perspectives were summarized below to better understand the role of stress in an individual's health and well-being.

2. ENVIRONMENTAL FACTORS IN STRESS

Many environmental factors contribute to the physical and psychological expressions of stress. Researchers have found that a stressful prenatal environment can impact the development of an offspring's hypothalamic-pituitary-adrenal (HPA) system (Lupien, McEwen, Gunnar, & Heim, 2009; Sandman, Davis, Buss, & Glynn, 2012; Welberg & Seckl, 2001) through exposures to elevated maternal cortisol levels, and resulted in the offspring's slower recovery from stress (e.g., Sandman et al., 2012). The altered stress system is likely to be further activated in the

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stressful environment that has triggered the elevated maternal cortisol levels at the first place (e.g., Thompson, 2014).

2.1. Chronic Stressors and Allostatic Load

To highlight the impact of stress before actual symptoms of illness appear, Katz, Sprang, and Cooke (2012) introduced the concept of allostatic load, defined as "the failure or exhaustion of normal physiologic processes that occurs in response to severe, frequent, or chronic stressors" (p.469), in assessing the negative impact of chronic stress on physiological health. According to Katz et al. (2012), allostatic load consists of multiple physiological indicators, such as norepinephrine and blood pressure, to evaluate the risk of developing disorders such as hypertension and diabetes. The goal of taking allostatic load into account is to enable professionals to assess the vulnerability of current healthy individuals in developing physical health problems later on (Katz et al., 2012).

2.2. Stress and Stressor Diversity

Aside from the influence of stress exposures early in life, the pattern of stressors can play a role in individuals' affective responses. The concept of stressor diversity was discussed by Koffer, Ram, Conroy, Pincus, and Almeida (2016) in understanding the effect of chronic stress on health. Stressor diversity expresses the degree to which the total stressors are spread out across different stressor types. Among other research interests, Koffer et al. examined the relationship between stressor diversity and daily affect to address the contradictory predictions generated by two different hypotheses. From the perspective of the uncertainty of stressor hypothesis, high stressor diversity is more likely to be associated with low positive affect and high negative affect as individuals with stressors spreading throughout more areas tend to experience more uncertainties as compared to those with stressors limiting to a few areas (e.g., Koffer et al, 2016). On the other hand, from the chronicity of stressor perspective, low stressor diversity is more likely to be associated with low positive affect and high negative affect as individuals with stressors concentrating on a few areas have less coping options as compared to those with stressors spreading throughout more areas (e.g., Koffer et al., 2016).

Koffer et al. (2016) extracted and analyzed data from two independent studies, National Study of Daily Experiences (2,022 adults) and The Intraindividual Study of Affect, Health, and Interpersonal Behavior (150 adults). Both studies collected self-report data on daily stressors and daily affect. Among other findings, researchers found that high stressor exposure and low stressor diversity combined was associated with high negative affect and low positive affect, a result that was in accordance with the chronicity of stressor hypothesis.

In summary this research shows that individual stress reactions and responses are related to their prior, including prenatal, stress exposures, as well as the diversity of their current stressors. When experiencing stress, individuals undergo several physiological and neurological changes.

3. PHYSIOLOGICAL FACTORS IN STRESS

Researchers have identified several physiological markers that are associated with stress, i.e. mainly, telomeres, circulating inflammatory markers, and electrodermal activity. These studies provide insights into the widespread impact that stress has on the body.

3.1. Telomeres

The shortening of telomeres, whose function is to protect DNA, was found to be associated with stress exposure (e.g., Epel et al, 2004; Price, Kao, Burgers, Carpenter, & Tyrka, 2013;

Shalev et al., 2013). Puterman, Lin, Krauss, Blackburn, and Epel (2015) conducted a study investigating the relationship between stress, health behaviors, and telomere length. In the study, researchers collected blood samples from 263 healthy woman volunteers, ranging from 50 to 60 years old, at the beginning of the study and one year later. Aside from the blood samples (which were used to extract telomere data), information regarding participants' health behaviors (i.e., physical activity, dietary practice, and sleep quality) were collected by self-report method at four month intervals (0-, 4-, 8-, and 12-month). At the end of the year, participants also completed a checklist of 13 major life stressors.

The results of the study have shown that telomeres were shortened along with additional major life stressors. However, this relationship only occurred for women who displayed low and medium level of health behaviors, but not for those with high level of health behaviors. The study findings suggested the possibility that health behavior might moderate the impact of major life stressors on the telomere length (Puterman et al., 2015).

According to a study conducted by Gotlib et al. (2015), a shortened telomere is a risk factor for developing major depressive disorder. The researchers recruited ninety-seven 10- to 14-year-old girls, who had not experienced psychological disorders, to participate in the study. Approximately half of the participants (50) grew up with mothers suffering from recurrent depressive episodes while the rest of the participants (47) were controls, who grew up with mothers without psychological disorders. After a clinical assessment to screen for eligibility, participants who met the selection criteria provided a saliva sample for the assessment of telomere length. These participants, who were fasting one hour prior to the stress-inducing tasks, underwent a serial subtraction math task and an interview about their stressful social experiences. Four saliva samples were collected throughout these tasks to obtain cortisol levels. Among other findings, the results have shown that shorter telomeres were associated with higher cortisol reactivity, not to basal level of cortisol, suggested a vulnerability to develop illnesses later, such as major depressive disorder (Gotlib et al., 2015).

3.2. Circulating Inflammatory Markers

Acute stress can lead to increased levels of circulating inflammatory markers (e.g., Fuligni et al., 2009; Kiecolt-Glaser et al., 2005; Steptoe, Hamer, & Chida, 2007). Gouin, Glaser, Malarkey, and Beversdorf (2012) examined the relationship between daily stressors and the levels of two circulating inflammatory markers, interleukin-6 (IL-6) and C-reactive protein (CRP). High levels of IL-6 and CRP have been found to be associated with health problems. Gouin et al. (2012) collected blood samples from participants and interviewed them regarding stressors that they had experienced within the past 24 hours. Data from 130 participants were analyzed, and results of the analysis revealed that experiencing multiple stressors was associated with elevated levels of inflammatory markers, which in turn, were associated with physical and psychological health problems, such as depression and autoimmune diseases (Gouin, et al., 2012).

3.3. Electrodermal Activity

Electrodermal activity measures arousals in the autonomic nervous system and it has been examined in response to acute stressors (e.g., Lensvelt-Mulders & Hettema, 2001; Moya-Albiol et al., 2001; Svetlak et al., 2013). Ruiz-Robledillo and Moya-Albiol (2015) compared electrodermal activity in caregivers of people with autism spectrum disorder to non-caregiver age-matched controls in investigating the role of chronic stress on body homeostasis. The researchers took a reading of electrodermal activity from the participants and administered a psychological questionnaire, along with other measures, to the participants before and after subjecting them to a psychosocial stressor. There were 64 participants in the study, with 30 caregivers and 34 non-caregivers. The study results have shown that, as compared to non-caregivers, caregivers reported more emotional and somatic difficulties, such as anxiety and depression, as well as displayed lower electrodermal activity when encountering acute stress induced by the researchers. Moreover, caregivers with higher electrodermal activity trended to report more severe emotional and somatic difficulties and such relationship was not found in the non-caregiver group (Ruiz-Robledillo & Moya-Albiol, 2015).

Based on their findings, Ruiz-Robledillo and Moya-Albiol (2015) proposed that the caregivers' hypoactivity of the electrodermal activity in response to acute stress was possibly due to habituation toward stressors. Moreover, they postulated that while such habituation protected caregivers from health problems that were associated with high electrodermal activity, it came at an expense to these caregivers' adaptive response to the acute, daily stressors—as experiencing the stress reaction, biologically and psychologically, is critical to achieve effective coping outcomes.

The conclusions of Ruiz-Robledillo and Moya-Albiol (2015) were aligned with the findings of Barker, Greenberg, Seltzer, and Almeida (2012) in comparing stress and cortisol patterns in caregivers of adult children with a serious mental illness to those of the control group. The researchers found that the caregiver group displayed hypoactivation of diurnal cortisol ondays after experiencing high level of stress (Baker et al, 2012). Both studies pointed to system dysregulations that were possibly caused by habituation to chronic stress conditions.

In addition, when encountering a stressful situation, individuals need to focus on the threatening stimuli and reserve energy to prepare for a fight-or-flight response. The stress reaction triggers changes to the nervous system, and in turn, influence people's behaviors and emotion responses.

4. ATTENTION AND MEMORY

4.1. Prefrontal cortex

Stress has negative impact on prefrontal cortex, which is functionally related to attention and working memory (in both animal and human studies, e.g., Arnsten, 2009; Gold, 2015; Mika et al, 2012). A model has been developed to describe the interplay between prefrontal cortex and the amygdala during stress exposure. Psychological stress activates the amygdala which triggers the release of noradrenaline and dopamine, resulting in disruptions of the prefrontal cortex and further activation of amygdala (e.g., Arnsten, 2009; Gold, 2015). Consequently, the attention mechanism shifts from a thoughtful orientation to a more reactive orientation (e.g., Arnsten, 2009). Overtime, chronic stress can alter the structure of prefrontal cortex and lead to prefrontal cortex dysfunctions (e.g., Arnsten, 2009).

Liston, McEwen, and Casey (2009) collected data from 20 healthy adults in the stress exposure group (1-month psychological stress from an upcoming exam) and 20 healthy matching controls in attention-shifting task. Liston et al. analyzed the data on task performances and functional magnetic resonance imaging (fMRI) images scanned while performing the task. The results of the study have shown that exposure to chronic psychological stress disrupted prefrontal cortex function and exerted negative impact selectively on attention control. Moreover, these effects were reversed after a period of stress reduction (Liston, et al, 2009).

4.2. Hippocampus

Stress has been found to associate with reduced hippocampal volume (e.g., Brown et al, 2015; Gerritsen, et al., 2015; Head, Singh, & Bugg, 2012). In a study conducted by Head et al. (2012), researchers examined the role of lifetime stress and exercise on hippocampus, among other variables. They obtained data from two sampling sources, one group of participants was recruited from local communities and another group of participants were recruited from an Alzheimer's Disease Research Center. Ninety-one healthy participants, consisted of middleage and older adults, had a magnetic resonance imaging (MRI) scan and were interviewed by telephone in order to complete a Cumulative Trauma Scale (CTS) as well as provide their exercise engagement levels. Among other findings, Head et al. concluded they found the negative impact of stress on hippocampal volume, as well as the role of exercise in moderating such impact—individuals with low-exercise engagement displayed more hippocampal volume loss as compared to those with high-exercise engagement.

Researchers have found that stress, which triggers the release of glucocorticoids, blocks memory retrieval and enhances memory consolidation (e.g., Roozendaal, Mcewen, &Chattarji, 2009; van Stegeren, 2009; Wolf, 2009)—both are functions of the hippocampus. These effects are strongest with emotional arousing materials, indicating the role of amygdala in memory (e.g., Buchanan, Tranel, & Adolphs, 2006; Roozendaal, et al., 2009; Wolf, 2009). It has been suggested that perhaps memory retrieval was blocked to allow a better focus on the current stressful situation, which is crucial in encoding and consolidation of such information (Wolf, 2009).

5. RISK AND REWARD IN DECISION MAKING

There is evidence from various studies about a key role of decission making in stressful conditions (Admon et al., 2012; Weller et al., 2014; Gold, 2015). For example, in a study conducted by Admon et al. (2012), 24 healthy soldiers underwent stress assessment, as well as functional magnetic resonance imaging (fMRI) scan while playing risk-reward interactive games, before and after serving as combat paramedics. After 18 months on duty, all 24 soldiers displayed symptoms of psychological maladjustment, ranging from post-traumatic stress disorder (PTSD) to mild depression. Among other findings, Admon et al. identified a pattern of dysregulation in response to risk and reward conditions after stress exposure—specifically, increasing PTSD symptoms were associated with lower activation in nucleus accumbens toward reward and greater activation in amygdala toward risk. A possible function for the reduced response to reward in stressful situations is to minimize distractions from the stress response (Gold, 2015).

Another example provides study reported by Weller et al. (2014). They examined the relationship between decision making and diurnal cortisol rhythm, a marker of stress reflecting the functions of the hypothalamic-adrenal-pituitary axis. Specifically, a flatter diurnal cortisol (e.g., lower increases and lower falls) after days of experiencing high levels of stress was found in individuals who experienced chronic stress, such as caregivers of adult children with a serious mental illness (Barker et al., 2012). Weller et al. (2014) collected data from 69 adult participants, aged 55 to 88 years old, for their study. In the first phrase of the study, these participants were instructed to collect their saliva samples three times in one day. Participants were on restricted diet one hour prior to the collection of saliva samples, which was later used to measure cortisol levels in assessing the diurnal rhythm of cortisol. The second phase of the study took place one day after the saliva collection. Participants performed the Cup Task, which was designed to measure risk-taking in decision making. One of the study results have shown that a lower diurnal cortisol fall was associated with greater risk-taking behaviors to achieve gains, suggested a possible role of stress in decision-making process (Weller et al., 2014).

In summary, recent findings provide evidence that the neurobiological changes associated with stress have significant implications for memory, cognitive and emotional processing and behavioral responses reflecting the wide ranging specific effects of stress on individuals.

6. CONCLUSION

Stress is a complex process that produces short-term changes, such as physiological and emotional states, as well as long-term alterations on physiological and neuroanatomical levels. Numerous studies have linked chronic stress to several health problems (e.g., Moffitt, 2013), including Parkinson's disease (in animal studies, e.g., Djamshidian & Lees, 2014; Sugama, et al., 2016), depression (e.g., Conway, Rutter & Brown, 2016; Gold, 2015; Swanson, Zeng, Weeks, & Colman, 2013) and pain (e.g., Hannibal & Bishop, 2014; Vachon-Presseau, 2013, Woda, Picard, & Dutheil, 2016). Stress was found to be associated with diminishing capacity to respond to reward (Admon, et al., 2013), declines in cognitive function (Vitaliano, et al., 2005) and disruptions in attentional control of the prefrontal cortex functions (Liston et al., 2009). Stress also plays a role in memory process as manifested by changes in the hippocampus; specifically, stress levels were found to be positively associated with hippocampal volume loss (e.g., Brown et al., 2015; Gerritsenet al., 2015; Head et al., 2012). Moreover, stress has been shown to have negative impact on memory retrieval and positive impact on memory consolidation through the release of glucocorticoids – these effects were strongest when encountering emotional arousing stimuli (e.g., Buchanan et al., 2006; Roozendaal, et al., 2009; Wolf, 2009).

Physiologically, experiencing stress has been associated with shortened telomeres (Gotlib et al., 2015; Puterman et al., 2015) and elevated levels of circulating inflammatory markers (Gouin et al., 2012)— both were connected to psychological and physical health problems. In addition, chronic stress has been associated with hypoactivation of electrodermal activity (Ruiz-Robledillo & Moya-Albiol, 2015) and diurnal cortisol (Barker et al., 2012) in response to stressors. Individuals with low cortisol fall, a manifestation of flat diurnal cortisol rhythm, tended to take more risk in decision-making under gains achieving conditions (Weller et al., 2014).

In addition the physiological alterations associated with stress start out prenatally as fetuses respond biologically to stress experienced by the mother (e.g., Thompson, 2014). Before exhibiting any symptoms of illness, the dysregulation of stress response system can be measured to assess health risks using allostatic load, which consists of a collection of physiological indicators (Katz et al., 2012).

Patterns of stressors may also play a role in the expression of stress reaction. Researchers have found that under high stress exposure, individuals influenced by stressors focused on a few areas tended to experience less positive affect and more negative effect daily as compared to those with stressors spread out to more areas (Koffer et al., 2016).

While stressful life experiences were linked to negative health outcomes, researchers have identified several protective factors that can increase resilience toward stress, including having an adequate attachment to a primary caregiver (e.g., Bernard & Dozier, 2010) and exposure to short-term manageable stress in early life (e.g., Feder, Nestler, & Charney, 2009; Shapero et al, 2015; Thompson, 2014). Other protective factors are engaging in high levels of health behaviors (e.g., Puterman et al., 2015), coping flexibly (e.g., Cheng, Lau, & Chan, 2014), using problem-focus coping instead of avoidant coping strategies (e.g., Chao, 2011; Holahan, 2005), having an optimistic outlook (e.g., Segerstrom, 1998), experiencing positive emotions (e.g., Ong, 2006), engaging in cognitive reappraisal (e.g., Troy, 2010), maintaining social support (e.g., Chao, 2011), and perceiving sense of meaning in life (e.g., Feder, et al., 2009).

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