Behavioural Brain Research 282 (2015) 144–154

Contents lists available at ScienceDirect

Behavioural Brain Research

journal homepage: www.elsevier.com/locate/bbr

Review

A systems approach to stress, stressors and resilience in humans

Barry S. Oken [a,b,*], Irina Chamine [a], Wayne Wakeland [c]

[a] Department of Neurology, Oregon Health & Science University, CR-120, 3181 SW Sam Jackson Park Road, Portland, OR 97239, USA
[b] Department of Behavioral Neuroscience & Biomedical Engineering, Oregon Health & Science University, CR-120, 3181 SW Sam Jackson Park Road, Portland, OR 97239, USA
[c] Systems Science, Portland State University, P.O. Box 751, Portland, OR 97207, USA

HIGHLIGHTS

- Stress physiology was reviewed from a systems science perspective.
- Stressors push biological systems from baseline toward lower utility states.
- The system change is based on objective attributes and perceptions of the stressor.
- Allostatic load is utility reduction due to stress-related state changes.
- Resilience affects ability to return to high utility state following perturbations.

ARTICLE INFO

Article history:
Received 25 November 2014
Received in revised form
18 December 2014
Accepted 21 December 2014
Available online 27 December 2014

Keywords:
Psychological stress
Systems science
Allostatic load
Resilience

ABSTRACT

The paper focuses on the biology of stress and resilience and their biomarkers in humans from the system science perspective. A stressor pushes the physiological system away from its baseline state toward a lower utility state. The physiological system may return toward the original state in one attractor basin but may be shifted to a state in another, lower utility attractor basin. While some physiological changes induced by stressors may benefit health, there is often a chronic wear and tear cost due to implementing changes to enable the return of the system to its baseline state and maintain itself in the high utility baseline attractor basin following repeated perturbations. This cost, also called *allostatic load*, is the utility reduction associated with both a change in state and with alterations in the attractor basin that affect system responses following future perturbations. This added cost can increase the time course of the return to baseline or the likelihood of moving into a different attractor basin following a perturbation. Opposite to this is the system's resilience which influences its ability to return to the high utility attractor basin following a perturbation by increasing the likelihood and/or speed of returning to the baseline state following a stressor. This review paper is a qualitative systematic review; it covers areas most relevant for moving the stress and resilience field forward from a more quantitative and neuroscientific perspective.

Contents

1. Introduction 145
2. The human physiologic system: brain structure and network (Fig. 3) 146
3. Stressor 147
4. Measurement of stress 148
   4.1. Peripheral biomarkers 148

Abbreviations: ACTH, adrenocorticotrophic hormone; ANS, autonomic nervous system; DHEA, dehydroepiandrosterone; DHEAS, dehydroepiandrosterone sulfate; EEG, electroencephalogram; fMRI, functional magnetic resonance imaging; HgbA1c, glycosylated hemoglobin A1c; HPA axis, hypothalamo–pituitary–adrenal axis; HRV, heart rate variability; PET, positron emission tomography; PTSD, post-traumatic stress disorder; SSRI, selective serotonin reuptake inhibitor.

* Corresponding author at: Oregon Health & Science University, CR-120, 3181 SW Sam Jackson Park Road, Portland, OR 97239, USA. Tel.: +1 503 494 8873; fax: +1 503 494 9520.
E-mail addresses: oken@ohsu.edu (B.S. Oken), fonareva@ohsu.edu (I. Chamine), wakeland@pdx.edu (W. Wakeland).

http://dx.doi.org/10.1016/j.bbr.2014.12.047

4.2. Brain changes 148
4.2.1. Cognition 148
4.2.2. Structural brain changes 148
4.2.3. Physiological brain changes: EEG, event-related potential, fMRI 148
4.2.4. Genetic changes in brain 148
4.3. Allostatic load 149
4.4. Stress and disease 149
5. Dynamics of stress system – time course of stress-induced physiological changes: state/trait and variables/parameters (Fig. 4) 149
6. Resilience 150
7. Environment and its perception 151
8. Stress and resiliency biomarker changes with treatment 152
9. Utility 152
10. Conclusions 152
Acknowledgements 152
References 152

1. Introduction

Psychological stress is common in our society. A recent survey indicated that 25% of Americans reported high stress and 50% identified a major stressful event during the previous year [1]. Chronic psychological stress increases risk of health problems and contributes to cardiovascular problems [2,3], neurologic and psychiatric diseases such as epilepsy [4], Parkinson's disease [5], multiple sclerosis [6], eating disorders, addictions [7], post-traumatic stress disorder (PTSD), and sleep difficulties. Therefore, it is important to develop evidence-based methods that minimize stress impact. A fuller understanding of stress physiology and psychology can be achieved by approaching this topic from different angles. This work offers a review of stress physiology and psychology from a systems science perspective.

Systems science is a methodology used to understand complex systems from organizational, structural, and dynamic perspectives [8]. From a systems science viewpoint, stress often corresponds to a state away from optimal in a dynamical system where the optimal location represents a high utility attractor. An attractor basin in a dynamical system corresponds to the conceptual space of locations in which the system resides over time. The state of stress results from a perturbation arising from the internal or external environment (stressor). This stressor could result in the system returning to the baseline optimal attractor or moving into a lower utility attractor basin. The attractor basin is the region of space that shares the same attractor and the whole space may have multiple attractors (Fig. 1).

The attractor in the human system is not a fixed point attractor given the multidimensional nature and, almost inherent, within-subject temporal variability of the physiological measures of state. The noise present in the measurement of the many variables constituting the human system implies the observed human system is stochastic; thus, the attractors are very difficult to describe. In addition, given the varying time frames over which the components of the human physiological system change, the terms *state* and *variable* describing more immediate changes and the terms *trait* or *parameter* describing longer time frame changes represent an artificial separation of the various physiological measures that have different units and widely distributed half-lives. Whatever the attractor, even if the system returns to the baseline high utility attractor, there is often some underlying cost. This cost to the system is a change in the underlying physiology that may: (1) decrease the rate of return to the high utility attractor or (2) decrease the likelihood of returning to the optimal attractor following a future stressor perturbation because the size of the attractor basin is smaller or the attractor has moved closer to a boundary with a non-optimal attractor basin. The movement of the dynamical system into a different attractor basin could also be due to a

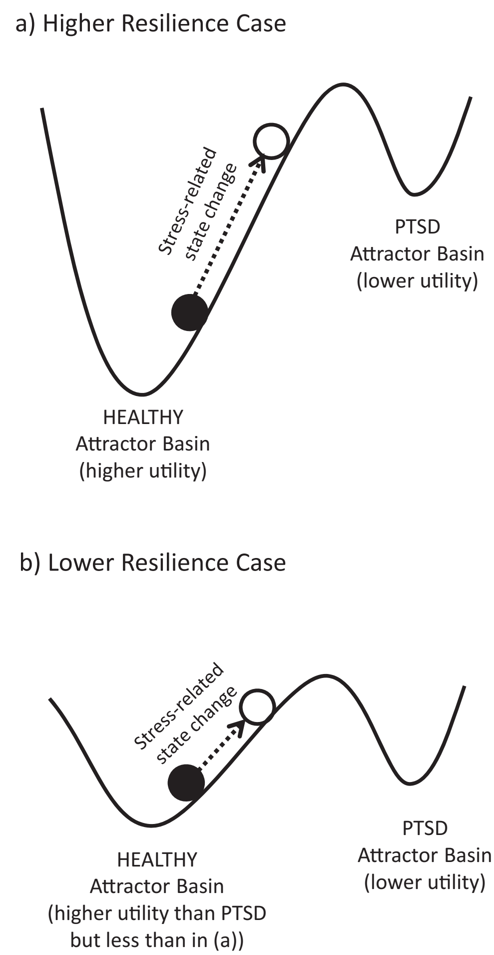

Fig. 1. Attractor basins, utility, and resilience. Hypothetical example of space of possible human physiological states with two attractor basins, one being a healthy higher utility condition and one a lower utility condition state of PTSD (in this figure, higher utility is downward). The attractor basins can tolerate movement of the hypothetical person (solid circle) in the horizontal direction from an external stressor without leaving its basin of attraction. However, with sufficient movement from a stressor, one may go from a higher utility healthy condition basin to a lower utility PTSD basin. The healthy condition in b has lower resilience than in a, with less stress required to shift it to the lower utility basin.

single severe stressor potentially via a dynamical system catastrophe, for example, development of PTSD following a single event (Fig. 2).

Besides negative effects, the stressor can also induce beneficial changes leaving the system more resilient to future perturbations,