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Physiological Stress Responses in Fish: Mechanisms, Impact, and Adaptation

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Abstract

Stress is a physiological response to factors that disrupt an organism's homeostasis and plays a significant role in acclimation, adaptation, and evolution. In fish, environmental stressors such as pollutants, predators, and changes in habitat can impair physiological functions and threaten long-term survival. Stress initiates a rapid response mediated by two hormonal axes: the brain-sympathetic-chromaffin cell axis, which triggers the release of catecholamines (adrenaline and noradrenaline), and the brain-pituitary-interrenal tissue axis, leading to cortisol production. The stress response can be categorized into primary, secondary, and tertiary stages. Primary responses include hormonal activation, while secondary responses involve changes in blood chemistry, respiration, and immune functions. Tertiary responses, which result from chronic stress, can affect growth, reproduction, and immunity, potentially leading to mortality or adaptation. Acute and chronic stress differ in their duration and physiological effects, with chronic stress being particularly damaging due to the energetic cost of prolonged stress responses. The General Adaptation Syndrome (GAS) outlines three phases of the stress response: alarm, resistance, and exhaustion. Homeostasis, maintained through feedback mechanisms, is critical for survival. Understanding the impact of stress on fish is essential for assessing their health and resilience in changing environmental conditions, highlighting the need for effective management strategies in aquaculture and conservation.

Keywords: Stress response, fish physiology, homeostasis, hormonal axis, General Adaptation Syndrome (GAS)

Introduction

Stress is the sum of all physiological responses that occur when animals attempt to establish or maintain homeostasis (Wedemeyer and Mcleay, 1981). In biology, stress is the driving force behind the process of acclimation- adaptation and evolution. Many environmental factors can lead to stress and dysfunction in the fish if they are encountered at levels approaching or beyond the normal tolerance capacity of fish. The alteration of one or more physiological variables to the point that long term survival may be impaired (Bayne, 1985). Stress is a state caused by a

stress factor, or stressor, that deviates from a normal resting or homeostatic state (Barton and Iwama, 1991). a stress response is initiated almost immediately following the perception of a stressor. Mildly stressful situations can have beneficial or positive effects (eustress), while higher severities induce adaptive responses but also can have maladaptive or negative consequences (distress). The stress response is initiated and controlled by two hormonal systems, those leading to the production of corticosteroids (mainly cortisol) and catecholamines (such as adrenaline and noradrenaline and their precursor dopamine). If fish can resist death due to a stressor, they recover to a similar or somewhat similar homeostatic norm. Long-term consequences of repeated or prolonged exposures to stress are maladaptive by negatively affecting other necessary life functions (growth, development, disease resistance, behavior, and reproduction), in large part because of the energetic cost associated with mounting the stress response (allostatic load).

Acute and Chronic Stress

Stressors can range anywhere from very brief (acute)—for example, being caught in a net or escaping a predator—to those that are prolonged and even more or less permanent (chronic)—for example, being overcrowded in a tank or at the bottom of a social hierarchy. When considering whether something results in acute or chronic stress, it should not be based on the duration of the stressor but rather on "y the duration of its consequences on the physiology of the animal" (Boonstra, 2013).

Stressors

1. Chemicals - Industrial waste, pesticides, fertilizers
2. Biological -
3. Environmental
4. Physical

Type of Stress Responses

1. **Primary response**

   Primary response in fish involves the activation of two neuroendocrine axes. The first is the brain-sympathetic-chromaffin cell (BPC) axis, which stimulates the chromaffin cells to produce catecholamines, including adrenaline and noradrenaline. The second is the brain-pituitary-interrenal tissue (BPI) axis, which leads to the production of cortisol from the interrenal tissue. These axes work together to mediate the physiological responses to stress.

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2. **Secondary response**

The activation of various metabolic pathways leads to changes in blood chemistry, hematology, respiration, and acid-base disturbances, along with ion losses at the gills. It also affects hydrothermal balance, cellular responses, and immune function. These physiological alterations help the fish cope with stress, although they can also impact overall health if prolonged.

3. **Tertiary response**

tertiary responses, which involve changes in the whole organism and are associated with chronic stress. These responses include inhibitory effects on fish reproduction, immunity, and growth. Prolonged stress may lead to either mortality or adaptation, depending on the severity and duration of the stressor.

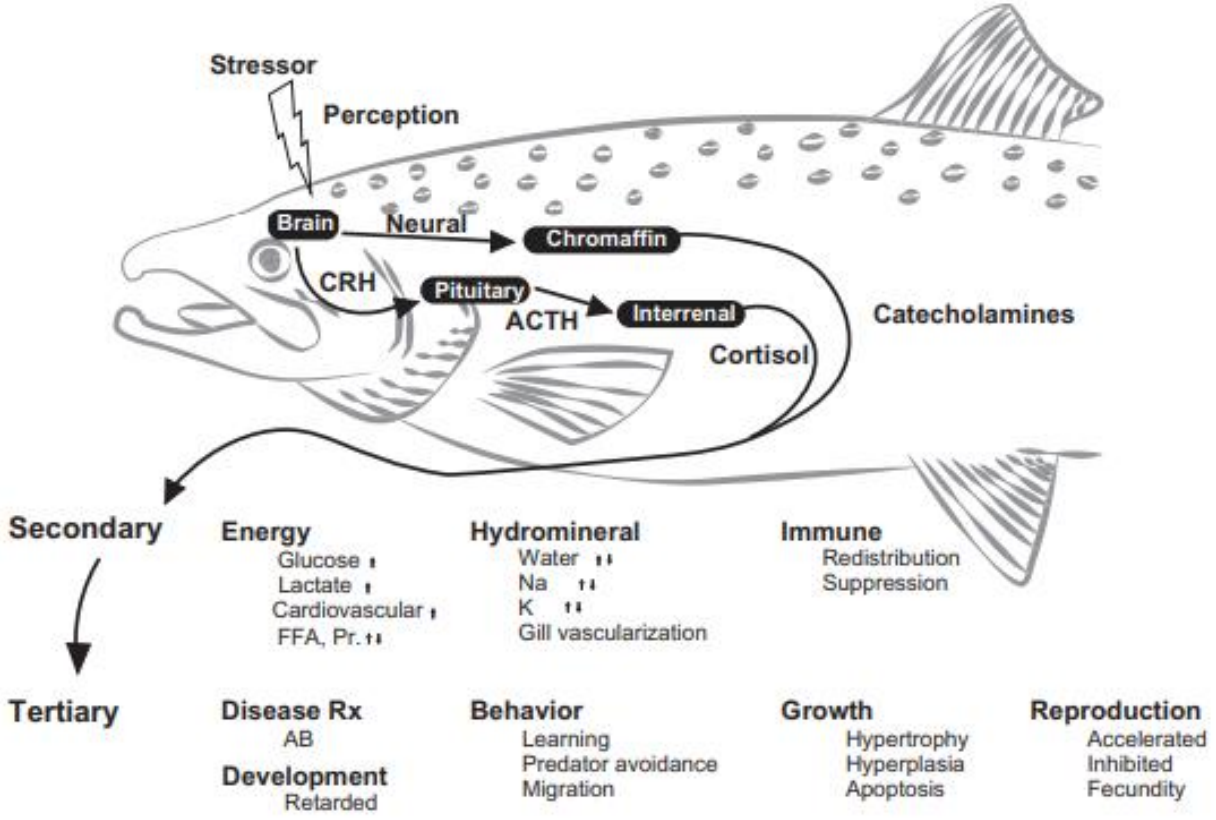

Fig 1: The primary (depicted inside fish), secondary, and tertiary responses of fish during distress. CRH, corticotropin releasing hormone; ACTH, adrenocorticotropic hormone; FFA, free fatty acids; P, proteins; AB, antibodies.

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Stress Model in Fish

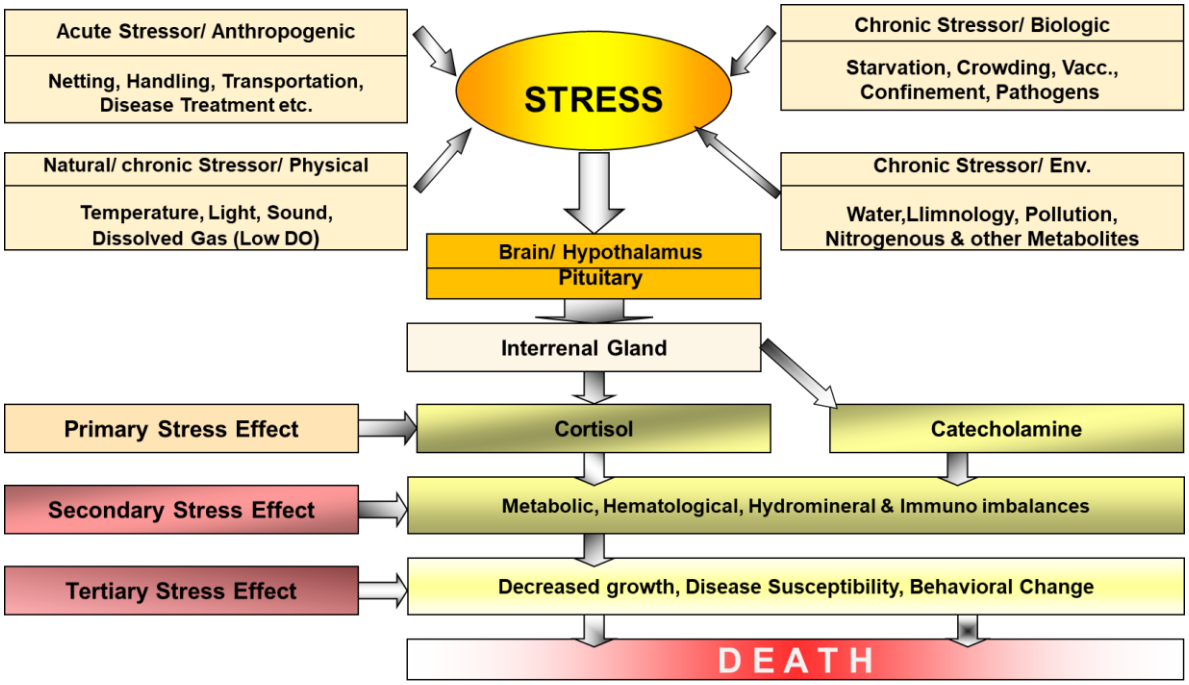

Fig 2: Depicting stress model in fish

General Adaptive Syndrome

The general adaptation syndrome is the sum of all non-specific, systemic reactions of the body which ensue upon long continued exposure to stress. The GAS concept (Selye, 1950) embraced the notion that stress is a generalized response.

Stages of General Adaptive Syndrome

There are three main stages to the stress response: alarm, resistance, and either compensation or exhaustion (death) (Selye, 1950; Schreck, 2000; Schreck and Tort, 2016).

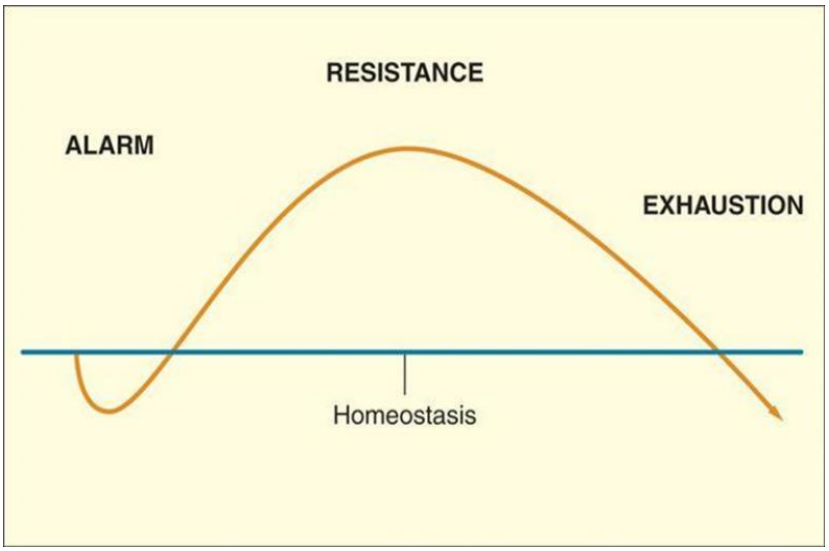

Fig 3: General Adaptation Syndrome generalized response

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Alarm Reaction

The alarm reaction is the sum of all non-specific systemic phenomena elicited by sudden exposure to stimuli to which the organism is quantitatively or qualitatively not adapted. The manifestations of the alarm reaction are the secretion of adrenocorticotropic hormone (ACTH), corticoids and catecholamines, thymicolymphatic involution, eosinopenia, and peptic ulceration. Most of the characteristic manifestations of AR (tissue catabolism, hypoglycaemia, gastro-intestinal erosions, discharge of secretory granules from the adrenal cortex, haemoconcentration, etc.). All of these are nonspecific effects in that they can be elicited by innumerable agents that make an intense demand upon the adaptability of the organism. Some of these phenomena are merely passive and represent signs of damage or "shock," others are signs of active defense against shock. In the case of moderately severe damage, from which recovery is possible, most of the signs of damage become evident before the signs of defense. Alarm reaction may, in turn, be subdivided into two more or less distinct phases: the phase of shock and the phase of counter-shock.

Phase of Resistance

The stage of resistance represents the sum of all non-specific systemic reactions elicited by prolonged exposure to stimuli to which the organism has acquired adaptation as a result of continuous exposure. It is characterized by an increased resistance to the particular agent to which the body is exposed and a decreased resistance to other types of stress. Thus, the impression is gained that, during the stage of resistance, adaptation to one agent is acquired "at the expense of" resistance to other agents.

Homeostasis

Homeostasis is a function indispensable for Life that is accomplished through chemical and physical processes (Pennazio, 2009). Homeostasis is a term coined by the physiologist Walter Cannon. Homeostasis, as currently defined, is a self-regulating process by which biological (or mechanical) systems maintain stability while adjusting to changing conditions (Billman, 2012).

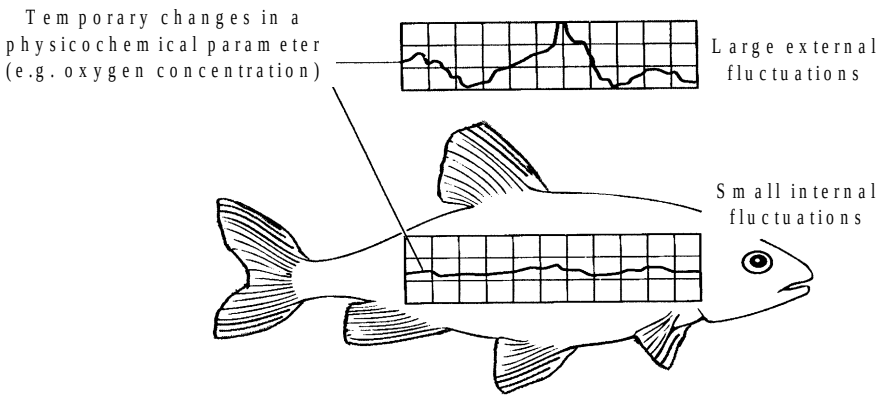

Fig 4: Homeostasis effect

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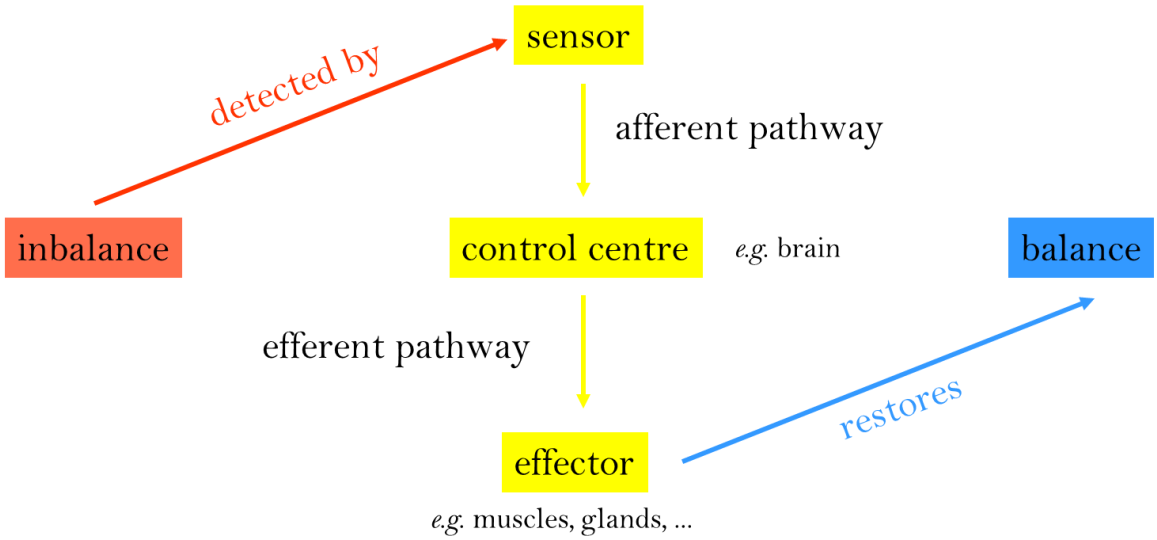

Fig 5: Homeostasis is accomplished via feedback mechanisms

Phase of Exhaustion

Finally, the stage of exhaustion represents the sum of all non-specific systemic reactions which ultimately develop as the result of very prolonged exposure to stimuli to which adaptation had been developed, but could no longer be maintained.

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