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Dysphagia and Exercise Physiology: Clinical Implications of General Adaptation Syndrome, Mitohormesis, and Detraining in Speech-Language Rehabilitation

Disfagia e fisiologia do exercício: implicações clínicas da Síndrome da Adaptação Geral, mitohormese e destreino na reabilitação fonoaudiológica

Disfagia y fisiología del ejercicio: implicaciones clínicas del Síndrome General de Adaptación, la mitohormesis y el desentrenamiento en la rehabilitación fonoaudiológica

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Abstract

Introduction: Speech-language pathology has widely employed muscle exercises in dysphagia rehabilitation for more than 30 years; however, these interventions are not always grounded in consolidated principles of exercise physiology. This study aims to examine and integrate core concepts

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from this field in order to support evidence-based practices in swallowing rehabilitation, with emphasis on mechanisms of muscle adaptation at both physiological and molecular levels, including the General Adaptation Syndrome (GAS), hormesis/mitohormesis, and detraining. **Description:** This is a narrative, exploratory, and conceptual review based on searches conducted in PubMed/MEDLINE, Embase, Web of Science, LILACS, SciELO, and Google Scholar. The analysis revealed a scarcity of studies directly integrating exercise physiology principles, GAS, hormesis, and detraining into speech-language pathology approaches to dysphagia rehabilitation. In light of this gap, the manuscript articulates evidence from exercise physiology and related fields to discuss how repeated therapeutic stimuli may transiently disrupt homeostasis and trigger adaptive responses in the muscles involved in swallowing. The alarm, resistance, and exhaustion phases of GAS are addressed, as well as the effects of controlled stressors on protective and supercompensatory cellular mechanisms, the role of reactive oxygen species and mitochondrial biogenesis, and the repercussions of detraining. In addition, the principles of biological individuality, specificity, progressive overload, and reversibility are discussed as applied to therapeutic dosing. **Conclusion:** Incorporating these concepts strengthens clinical reasoning in speech-language pathology, improves exercise dosing and progression, and supports safer, more effective, and more sustainable interventions, especially in patients with low functional reserve.

Keywords: Dysphagia; General Adaptation Syndrome; Hormesis; Rehabilitation of Speech and Language Disorders; Rehabilitation Research.

Resumo

Introdução: A fonoaudiologia utiliza amplamente exercícios musculares na reabilitação da disfagia há mais de 30 anos; contudo, essas intervenções nem sempre se apoiam em fundamentos consolidados da fisiologia do exercício. Este estudo objetiva compreender e integrar conceitos centrais dessa área para sustentar práticas baseadas em evidências na reabilitação da deglutição, com ênfase nos mecanismos de adaptação muscular em seus aspectos fisiológicos e moleculares, incluindo a Síndrome da Adaptação Geral (SAG), a hormese/mitohormese e o destreino. **Descrição:** Trata-se de uma revisão narrativa, exploratória e conceitual nas bases PubMed/MEDLINE, Embase, Web of Science, LILACS, SciELO e Google Scholar. A análise revelou escassez de estudos que integrem diretamente os princípios da fisiologia do exercício, a SAG, a hormese e o destreino à reabilitação fonoaudiológica da disfagia. Diante dessa lacuna, o manuscrito articula evidências da fisiologia do exercício e de áreas correlatas para discutir como estímulos terapêuticos repetidos podem romper transitoriamente a homeostase e desencadear respostas adaptativas nos músculos envolvidos na deglutição. São abordadas as fases de alarme, resistência e exaustão da SAG, os efeitos de estressores controlados sobre mecanismos celulares protetores e supercompensatórios, o papel das espécies reativas de oxigênio e da biogênese mitocondrial, bem como as repercussões do destreino. Além disso, são discutidos os princípios de individualidade biológica, especificidade, sobrecarga progressiva e reversibilidade aplicados à dosagem terapêutica. **Conclusão:** A incorporação desses conceitos fortalece o raciocínio clínico fonoaudiológico, qualifica a dosagem e a progressão dos exercícios e favorece intervenções mais seguras, eficazes e sustentáveis, especialmente em pacientes com baixa reserva funcional.

Palavras-chave: Disfagia; Síndrome de Adaptação Geral; Hormese; Reabilitação da Fala e da Linguagem; Pesquisa em Reabilitação.

Resumen

Introducción: La fonoaudiología ha utilizado ampliamente ejercicios musculares en la rehabilitación de la disfagia durante más de 30 años; sin embargo, estas intervenciones no siempre se sustentan en principios consolidados de la fisiología del ejercicio. Este estudio tiene como objetivo examinar e integrar conceptos centrales de esta área para sustentar prácticas basadas en la evidencia en la rehabilitación de la deglución, con énfasis en los mecanismos de adaptación muscular en sus dimensiones fisiológicas y moleculares, incluyendo el Síndrome General de Adaptación (SGA), la hormesis/mitohormesis y el desentrenamiento. **Descripción:** Se trata de una revisión narrativa, exploratoria y conceptual, basada

en búsquedas realizadas en PubMed/MEDLINE, Embase, Web of Science, LILACS, SciELO y Google Scholar. El análisis reveló escasez de estudios que integren directamente los principios de la fisiología del ejercicio, el SGA, la hormesis y el desentrenamiento en la rehabilitación fonoaudiológica de la disfagia. Ante esta laguna, el manuscrito articula evidencias de la fisiología del ejercicio y de áreas afines para discutir cómo los estímulos terapéuticos repetidos pueden alterar transitoriamente la homeostasis y desencadenar respuestas adaptativas en los músculos implicados en la deglución. Se abordan las fases de alarma, resistencia y agotamiento del SGA, los efectos de estresores controlados sobre mecanismos celulares protectores y de supercompensación, el papel de las especies reactivas de oxígeno y de la biogénesis mitocondrial, así como las repercusiones del desentrenamiento. Además, se discuten los principios de individualidad biológica, especificidad, sobrecarga progresiva y reversibilidad aplicados a la dosificación terapéutica. **Conclusión:** La incorporación de estos conceptos fortalece el razonamiento clínico en fonoaudiología, cualifica la dosificación y la progresión de los ejercicios, y favorece intervenciones más seguras, eficaces y sostenibles, especialmente en pacientes con baja reserva funcional.

Palabras clave: Disfagia; Síndrome de Adaptación General; Hormesis; Rehabilitación del Habla y del Lenguaje; Investigación en Rehabilitación.

Introduction

Biological adaptation is a dynamic and continuous process triggered by the organism's exposure to stimuli capable of disrupting its basal state of physiological equilibrium. This transient disruption of homeostasis constitutes the central principle of the General Adaptation Syndrome (GAS), proposed by Hans Selye, which describes the organism's nonspecific physiological response to different stressors[1,2]. Initially formulated within the context of endocrinology and systemic stress, GAS was subsequently incorporated into exercise sciences as an explanatory model for adaptations induced by controlled physical stimuli[3].

In the field of physical exercise, GAS has become one of the main theoretical foundations for understanding how mechanical, metabolic, and neuromuscular stimuli elicit functional and structural adaptations in skeletal muscle. These adaptations include changes in contractile capacity, fatigue resistance, metabolic efficiency, and neuromotor organization, all of which depend on the magnitude, duration, and frequency of the applied stimulus[3].

In Speech-Language Pathology, particularly in dysphagia rehabilitation, the prescription of muscle exercises is a well-established and widely used practice. Tongue resistance exercises, swallowing facilitation maneuvers, postural strategies, and respiratory interventions are used to improve the biomechanical efficiency and safety of swallowing[4]. However, although these approaches are technically described and functionally validated, they are not always supported by an in-depth understanding of exercise physiology. Aspects such as stimulus dosage, therapeutic progression, identification of muscle fatigue, and maintenance of functional gains remain poorly systematized in clinical speech-language pathology practice.

Considering that the muscles involved in swallowing are subjected during therapy to repetitive, intentional, and potentially stressful stimuli, it is essential to understand how these tissues respond to the imposed stress, which adaptations may be expected, and which physiological limits must be respected. In this context, the incorporation of the concepts of GAS, hormesis, and detraining provides a robust theoretical framework to refine clinical reasoning, support educational material development, and encourage further research, thereby favoring safer, more effective, and more sustainable speech-language pathology interventions.

Description

A narrative literature review of an exploratory and conceptual nature was conducted by two speech-language pathologists, both PhD professors with clinical and scientific experience in swallowing, and by one PhD professor in Physical Education with expertise in exercise physiology. Based on a search strategy conducted in English, Portuguese, and Spanish, followed by critical reading of the identified publications, an absence of studies was observed within the field of Speech-Language

Pathology that directly and integratively address General Adaptation Syndrome, hormesis, with emphasis on mitohormesis and sarcohormesis, and detraining as applied to dysphagia rehabilitation.

In view of this gap, an integrative and interprofessional synthesis was conducted using evidence from exercise physiology and related fields. This synthesis articulated explanatory models, biological mechanisms, and key references with clinical implications for speech-language pathology practice, with the purpose of supporting safer, more consistent, and physiologically oriented decision-making, as well as interventions with greater potential for effectiveness and maintenance of functional gains.

The narrative review was conducted using a search strategy in English, Portuguese, and Spanish, designed to maximize sensitivity, that is, to retrieve the largest possible number of potentially relevant studies, while maintaining specificity for the three conceptual axes of the manuscript: (1) dysphagia/swallowing, (2) exercise physiology and exercise prescription, and (3) stress adaptation, hormesis/mitohormesis, and detraining/reversibility. Searches were performed in PubMed/MEDLINE, Embase, Web of Science, LILACS, SciELO, and Google Scholar, as these databases provide complementary coverage of biomedical journals, rehabilitation, exercise sciences, and Latin American literature.

In PubMed/MEDLINE, free-text terms and controlled descriptors (MeSH) related to dysphagia and rehabilitation were combined, such as: "Dysphagia", "Deglutition Disorders", "Swallowing", "Deglutition", "Rehabilitation", "Speech-Language Pathology", as well as intervention/training terms such as "Exercise", "Resistance Training", "Strength Training", "Muscle Training", "Tongue Strength", "Isometric", "Isotonic", and theoretical terms including "General Adaptation Syndrome", "Stress, Physiological", "Hormesis", "Mitochondrial Biogenesis", "Reactive Oxygen Species", "Oxidative Stress", and "Detraining"/"Reversibility".

In Embase, the strategy was adapted using Emtree descriptors and their natural-language equivalents, expanding the retrieval of studies indexed outside MEDLINE and of European literature, particularly in areas related to exercise physiology and rehabilitation medicine. In Web of Science, the search prioritized free-text terms in titles, abstracts, and keywords, with emphasis on tracking interface studies and identifying relevant citations through citation tracking, given the conceptual nature of the topic.

To include Ibero-Latin American scientific production, searches in LILACS and SciELO used descriptors and synonyms in Portuguese and Spanish, with terminological variations frequently employed in Speech-Language Pathology and exercise physiology, such as: dysphagia, swallowing, swallowing disorders, speech-language pathology rehabilitation, myofunctional therapy, tongue exercises, tongue strengthening, swallowing maneuvers, exercise physiology, training adaptation, General Adaptation Syndrome, hormesis, mitohormesis, oxidative stress, reactive oxygen species, and detraining.

Finally, Google Scholar was used as a complementary source to identify potentially relevant literature not indexed in traditional databases, including gray literature such as book chapters, conference proceedings, preprints, theses, and articles published in journals with irregular indexing.

In practical terms, the search structure was organized into blocks using Boolean operators (AND/OR) and truncation variations when available (for example: train*, rehab*, swallow*), following the pattern below:

- **Block 1 (dysphagia/swallowing):** (dysphagia OR swallowing OR deglutition OR "deglutition disorders" OR disfagia OR deglutição OR deglución)
- **Block 2 (exercise/muscle training):** (exercise OR "resistance training" OR "strength training" OR training OR "muscle training" OR isometric OR isotonic OR "tongue strengthening" OR exercício OR treinamento OR fortalecimento OR resistência OR isométrico OR isotônico OR "força lingual")
- **Block 3 (adaptive models and mechanisms):** ("general adaptation syndrome" OR stress OR hormesis OR mitohormesis OR "oxidative stress" OR "reactive oxygen species" OR detraining OR reversibility OR "síndrome da adaptação geral" OR estresse OR hormese OR mitohormese OR "estresse oxidativo" OR "espécies reativas de oxigênio" OR destreino OR reversibilidade)

These search blocks were combined according to the objective of each search round. When

the complete combination excessively reduced the number of results, particularly for GAS and mitohormesis associated with dysphagia, two-step searches were performed. First, robust evidence on mechanisms of exercise adaptation was retrieved, particularly regarding GAS, hormesis, and detraining. Subsequently, these findings were connected to the literature on dysphagia rehabilitation and training of the tongue and oropharyngeal structures. This strategy revealed a scarcity of studies directly and integratively addressing these concepts within the specific scope of Speech-Language Pathology, thereby justifying the integrative and interprofessional synthesis presented in the manuscript.

Databases searched and records retrieved (n = 1,247)

- **PubMed/MEDLINE:** 312
- **Embase:** 428
- **Web of Science:** 176
- **LILACS:** 41
- **SciELO:** 22
- **Google Scholar:** 268

Duplicate removal

- Duplicates identified and removed: n = 402
- Unique records for title/abstract screening: n = 845

Title and abstract screening

- Records excluded during screening: n = 742
- Reasons for exclusion by the researchers: studies did not address dysphagia/swallowing, focusing only on general exercise, performance, or basic physiology; addressed dysphagia without an exercise/muscle training component; or examined "stress"/"adaptation" without any relationship to therapeutic exercise.
- Records selected for full-text reading: n = 103

Full-text assessment

- Full texts excluded: n = 79
- Main reasons: intervention not related to muscle exercises applicable to rehabilitation; population/objective incompatible with the focus of the study; outcomes unrelated to swallowing function or without connection to adaptation/detraining; or articles considered redundant for the theoretical discussion.

Chart 1. Studies included in the narrative and integrative synthesis distributed by thematic axis; thematic axes may include overlapping articles (n = 24)

Thematic axis	n	Studies (short citation + reference number)
1) Dysphagia rehabilitation and oropharyngeal training (maneuvers/exercises + respiratory muscle training)	9	Logemann, 2008;[4] Hutcheson et al., 2013;[13] Fujiu et al., 1996;[14] Kahrilas et al., 1993;[15] Robbins et al., 2007;[16] Shaker et al., 1997;[17] Zhang et al., 2022;[18] Clark et al., 2009;[19] Zica et al., 2025a;[3]
2) Hormesis/mitohormesis, oxidative stress, and adaptive signaling in response to exercise	9	Merry et al., 2016;[5] Cheng et al., 2023;[6] Peake et al., 2015;[7] Dutra et al., 2018;[8] Schoenfeld, 2012;[9] Vikne et al., 2006;[12] Selye, 1936a;[1] Selye, 1936b;[2] Zica et al., 2025b;[11]
3) Detraining, reversibility, and post-stimulus interruption effects	6	Jespersen et al., 2011;[10] Oh, 2015;[20] Van den Steen et al., 2018;[21] Van den Steen et al., 2019;[22] Van den Steen et al., 2021;[23] Hsiao et al., 2022;[24]

General Adaptation Syndrome and Muscle Response to Exercise

GAS describes three sequential phases of the organism's response to stress: alarm, resistance, and exhaustion[1,2]. In the alarm phase, an acute disturbance of homeostasis occurs, characterized by the activation of cellular, metabolic, and neuromuscular mechanisms in response to the stimulus. In skeletal muscle, this phase involves transient changes in energy metabolism, activation of intracellular signaling pathways, and increased neuromotor recruitment[3].

In the resistance phase, provided that adequate recovery occurs, the organism adapts to the previously imposed stimulus, thereby increasing its functional capacity. In the muscular context, this is expressed as greater contractile efficiency, increased resistance to fatigue, improved motor control, and, in some cases, structural changes. Conversely, when stress is excessive, poorly dosed,

or sustained without sufficient recovery intervals, the exhaustion phase may occur, characterized by reduced performance, increased risk of injury, and functional impairment[1,3].

Applied to dysphagia rehabilitation, this rationale allows therapeutic exercises to be understood as controlled mechanical stressors. For example, a tongue resistance exercise performed with adequate load and repetitions initially induces an alarm response, followed by adaptive processes, provided that recovery principles are respected. However, poorly dosed stimuli, whether due to excessive load, number of repetitions, or weekly frequency, may exceed the muscle's adaptive capacity or, conversely, fail to generate sufficient stress. In both cases, the result may be excessive fatigue, reduced performance, or absence of functional effects.

This model shifts clinical understanding from the mere execution of an exercise to the analysis of the organism's adaptive response, reinforcing the need for individualized therapeutic planning and continuous monitoring of muscle response. In exercise physiology, stress represents the selected rehabilitation strategy used to move the muscle away from its basal state.

Hormesis, Mitohormesis, and Sarcohormesis: Cellular and Systemic Mechanisms of Adaptation

The concept of hormesis broadens the foundations of GAS by describing beneficial adaptive responses resulting from exposure to low and controlled doses of potentially harmful stressors[5,6]. Rather than viewing stress linearly as an exclusively deleterious factor, hormesis recognizes that submaximal stimuli can activate cellular mechanisms of protection, repair, and adaptation.

At the cellular level, mitohormesis highlights the role of mitochondria as central regulators of these adaptive responses. During exercise, the moderate production of reactive oxygen species (ROS) does not act merely as a metabolic byproduct, but rather as a molecular signal capable of activating endogenous antioxidant pathways, cellular repair mechanisms, and mitochondrial biogenesis[5-7]. As a result, increased energy efficiency, greater stress tolerance, and improved cellular function may occur.

In skeletal muscle, this phenomenon is described as sarcohormesis, characterizing the structural and functional adaptations induced by exercise[8,9]. These adaptations include improved fatigue resistance, optimized neuromotor coordination, and greater functional stability of muscle tissue. Unlike sports training, the goal in dysphagia rehabilitation is not muscle hypertrophy, but rather the optimization of contractile efficiency, functional endurance, and coordination among the muscles involved in swallowing.

Understanding these mechanisms allows the speech-language pathologist to recognize that insufficient stimuli do not promote meaningful adaptation, whereas excessive stimuli may trigger undesirable inflammatory responses, particularly in populations with reduced functional reserve, such as frail older adults, neurological patients, and individuals with chronic diseases.

Principles of Exercise Physiology and Therapeutic Prescription in Dysphagia

Physical exercise can impose different types of stress on skeletal muscle, including mechanical, metabolic, oxidative, thermal, and hypoxic stress[7]. These stressors do not act in isolation, but rather in an integrated manner, triggering cellular signaling cascades responsible for structural and functional adaptations in muscle tissue. The predominance of each type of stress depends on the pattern of muscle contraction, relative exercise intensity, stimulus duration, total work volume, and recovery intervals[7-9]. Predominantly mechanical stimuli, for example, are associated with deformation of the sarcolemma and myofibrillar proteins, whereas metabolic and oxidative stresses are related to energy depletion, metabolite accumulation, and production of reactive oxygen species (ROS), which act as adaptive molecular signals[5-7].

In clinical dysphagia practice, commonly used therapeutic exercises tend to generate low muscle damage, since they do not involve intense eccentric contractions, high loads, or excessive volumes, which are more typical of hypertrophy-oriented training protocols in Physical Education and Physical Therapy[8,9]. Nevertheless, when prescribed with appropriate load and repetitions, these exercises may trigger relevant adaptive responses and thereby support rehabilitation[10,11].

In specific populations, such as individuals with low functional reserve, bedridden older adults, neurological patients, individuals with sarcopenia, or those with a prolonged history of muscle disuse, it may be inferred that small variations in load, frequency, or number of repetitions may be sufficient to shift muscle tissue from the adaptive threshold

to the fatigue threshold, with direct impact on functional swallowing performance[3,10,11].

In this context, understanding the physiological bases that govern adaptation to exercise becomes indispensable for therapeutic prescription in dysphagia. To date, there are no studies in Speech-Language Pathology addressing exercise physiology and its implications specifically contextualized to the swallowing muscles. Therefore, four classic principles of exercise physiology assume a central role in this decision-making process.

Biological individuality refers to the fact that adaptive responses vary widely among individuals and are modulated by factors such as age, sex, muscle composition, clinical condition, nutritional status, previous activity level, and neuromuscular integrity[10,11]. In dysphagia, this principle is particularly relevant, since patients with apparently similar clinical presentations may show different therapeutic responses to the same exercise protocol, requiring continuous and individualized adjustments[11].

The principle of specificity establishes that exercise-induced adaptations are specific to the type of stimulus applied, the muscle group involved, execution speed, range of motion, and pattern of muscle contraction[6,12]. Thus, tongue resistance exercises, for example, promote specific adaptations in the tongue musculature and do not necessarily translate automatically into improved pharyngeal contraction or global improvement in swallowing function. This principle reinforces the need to integrate muscle exercises into the functional context of swallowing, favoring the transfer of gains obtained through training to the target activity.

Progressive overload presupposes that, for new adaptations to occur, the muscle must be exposed to stimuli that are progressively greater than those to which it is already adapted[8,9]. In clinical practice, this means that indefinite repetition of the same protocol, without adjustments in load, duration, or complexity, tends to lead to stagnation of functional gains. In dysphagia, progressive overload must be applied with clinical expertise, respecting individual limits and clinical signs of fatigue, while also recognizing its importance for maintaining and expanding basal functional capacity.

Finally, the principle of reversibility establishes that morphological and functional adaptations acquired through exercise are partially or completely lost when the regular provision of stimuli is interrupted[13]. This principle is directly related to the phenomenon of detraining and has relevant clinical implications in dysphagia, especially for planning discharge from therapy and defining maintenance strategies. Abrupt interruption of exercises may result in functional regression, particularly in patients with reduced neuromuscular reserve, reinforcing the need for longitudinal follow-up and ongoing guidance.

The conscious and critical incorporation of these principles into speech-language pathology clinical reasoning makes it possible to reduce empirical practices, improve the prescription of therapeutic exercises, and support more consistent, safer decisions aligned with the adaptive physiology of skeletal muscle.

Detraining: Evidence, Limits, and Clinical Implications

Detraining refers to the regression of morphological and functional adaptations acquired through exercise after interruption or reduction of the stimulus[13]. Although widely studied in the field of exercise physiology within Physical Education, this phenomenon remains poorly explored in the context of dysphagia rehabilitation.

Initial studies demonstrated that gains in tongue strength obtained through training may begin to decline between two and four weeks after interruption of the stimulus[19]. Other studies observed partial maintenance of these gains after similar detraining periods[20]. More recent studies indicate that the magnitude of maintenance depends on the load, frequency, and specificity of previous training[21–23].

Hsiao et al.[24] introduced the concept of tongue strength reserve, demonstrating that training may increase not only maximum strength but also the functional margin required for safe swallowing, with partial maintenance of these gains after detraining. This finding has relevant clinical implications, suggesting that training may provide a "functional safety zone" even after temporary interruption of exercises.

However, most studies have been conducted with healthy individuals, limiting the generalizability of the results to dysphagic populations. In addition, swallowing is a complex neuromotor process, and maintenance of isolated strength does not necessarily guarantee preservation of function in pathological contexts.

From a clinical perspective, detraining reinforces the need for maintenance strategies, patient education, and longitudinal follow-up, recognizing the adaptive and reversible nature of the neuromuscular system.

Final Considerations

Dysphagia rehabilitation involves the intentional application of stressful stimuli to muscles essential for swallowing function. An in-depth understanding of exercise physiology, including concepts such as General Adaptation Syndrome, hormesis, and detraining, allows speech-language pathologists to ground their practice in solid scientific foundations, moving beyond empirical approaches. The integration of these concepts into clinical reasoning favors safer, more effective, and longer-lasting interventions, contributing to better functional outcomes and to the promotion of patients' quality of life.

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