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The Evolution of Swallowing Rehabilitation and Emergence of Biofeedback Modalities

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Abstract

Purpose of Review The purpose of this review is to consolidate evidence related to the use of biofeedback in swallowing rehabilitation. Rather than a comprehensive review, we provide a historical and conceptual justification for integration of biofeedback modalities in the treatment of dysphagia.

Recent Findings Although biofeedback has been used for decades in/as an adjunct to muscle strengthening rehabilitation programmes, advances in our understanding of swallowing neural control provide potential for new applications of technology to facilitate swallowing recovery. New research highlights the emergence of skill-based swallowing training, which focuses on adaptation of specific components of timing and coordination in the swallowing motor plan. This research suggests positive clinical outcomes using feedback that is impairment specific and is designed with principles of neuroplasticity in mind.

Summary The emerging emphasis on motor control, rather than muscle strength, implicates a critical role for the use of biofeedback modalities to allow conscious insights into specific aspects of the generally obscure swallowing process.

Keywords Dysphagia · Biofeedback · Rehabilitation · Neuromodulation · Neural control · Motor control

Introduction

In the broadest of terms, our current practice for behavioural management of swallowing impairment covers a wide range of interventions contained within two overarching categories: compensatory approaches, including diet modification, postural and behavioural adaptations, and rehabilitation approaches, categorised by some into direct and indirect modalities [1]. Compensatory approaches are used quite widely in clinical practice and by definition are focused on either intrinsic or extrinsic adaptations that alter bolus or biomechanics to produce a typically transient effect on efficiency or safety of swallowing [2]. Rehabilitation approaches are designed to alter the underlying substrates of swallowing, producing long-term changes in swallowing dynamics [3], but are perhaps somewhat less well integrated into routine clinical care [4]. In this manuscript, we will turn a lens specifically to rehabilitation strategies for dysphagia. Rather than a comprehensive review, we will focus more specifically on a conceptual justification for integration of biofeedback modalities as an adjunct to rehabilitation programmes.

An Evolutionary Timeline of Our Conceptualisation of Swallowing

> "You can't connect the dots looking forward, you can only connect them looking backwards" (Steve Jobs, 2005)

The purpose of this review is to consolidate evidence related to the use of biofeedback in swallowing therapy. In keeping with the wisdom of Steve Jobs, we will reflect on the past and review the evolving evidence that underlies past, current, and hopefully future dysphagia management

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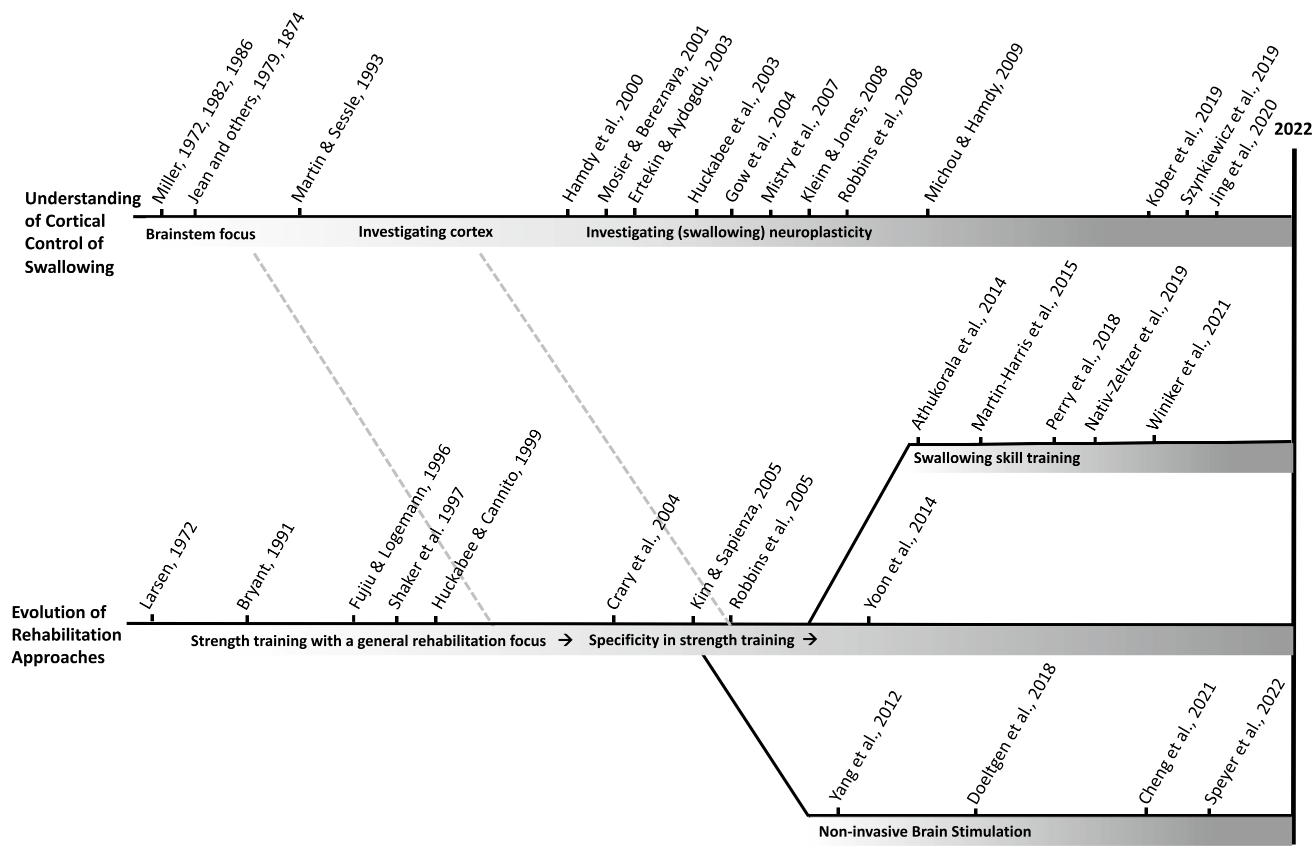

Fig. 1 Visual representation of two interdependent lines of research that inform the development and iterative refinement of swallowing rehabilitation approaches [5–10, 11–14, 15–17, 18–22, 23, 24, 25, 26, 27–30, 31, 32–40]. The timeline at the top represents selected seminal research expanding our understanding of the cortical control of swallowing. The corresponding timeline at the bottom outlines the corresponding evolution of swallowing rehabilitation approaches. Note that the arrangement of studies in this figure is conceptual in nature and not necessarily to scale. We also acknowledge the many additional seminal papers that have contributed to the progression of swallowing rehabilitation science

practices. Figure 1 illustrates what we perceive as a conceptual timeline across two developing lines of research and how advances in our understanding of swallowing neural control predates, and consequently influences, the evolution of rehabilitation practices. This model will be reflected and elaborated on in the text that follows.

In the Beginning, There Was a Brainstem

The foundations of our developing understanding of swallowing neural control were based on early work by Andre Jean, Art Miller, and other esteemed neuroscientists [5–9], who identified and elaborated on a brainstem-driven central pattern generator (CPG) underlying deglutitive behaviour. Their integrated research proposed a model of neural control consisting of a medullary CPG producing a swallowing reflex. This model was based largely on experimental animal studies, using fictive, or experimentally stimulated, swallowing. Based on research at the time, the cortex was largely excluded from the published models outside its role in the voluntary initiation of swallowing [5–9]. Ensuing research, supporting an ever-increasing understanding of the role of cortical sensorimotor networks, has suggested that man cannot eat by brainstem alone. Ingestive swallowing requires some contribution from cortical structures. Martin and Sessle [10••] were the first to directly challenge that swallowing was confined to brainstem control, supported by a review of cortical lesion studies linked with swallowing dysfunction. Naturally, this paper prompted an expansion of our critical thinking into the importance of cortical input, in particular for volitional swallowing.

Subsequently, the advancement of neuroimaging techniques has seen models of swallowing motor control dramatically evolve to reflect diverse cortical and subcortical input. Ertekin [41] proposed a model with a significantly increased cortical prominence. Included in this work were bidirectional integrations of sensory and motor cortices with the CPG in the medulla, which also extended to include inputs from the limbic and extrapyramidal systems and, infratentorially, into the cerebellum. Ertekin [41], as well as Mosier and Bereznaya [11], were early to acknowledge the differentiation between reflexive and volitional conditions of swallowing, suggesting potential distinction in neural networks for these tasks. Over the past decade, neuroimaging research has led to a redefinition of the concept of swallowing neural control centred around the recognition of the significant cortical modulation of swallowing. This redefinition has led to a change in nomenclature away from a swallow 'reflex' towards what is now commonly referred to as a 'pharyngeal swallowing response'. Further research has resulted in increasingly complex models of swallowing motor control that acknowledge contribution of a broad range of cortical structures with a role in modulation of the pharyngeal response [12–14]. A question that is yet to be clarified: Do cortical networks only modify the motor plan created within the medullary CPG for ingestive swallowing or is there a unique swallowing neural network that utilizes cortical motor planning regions to augment, or differentiate, the reflexive swallowing CPG?

Rehabilitative Approaches for Dysphagia and Early Adjunctive Biofeedback

In Fig. 1, we also outline a similar timeline for the development of our rehabilitative approaches, with clinical implementation following the exploration, expansion, and documentation of new knowledge. As above, in the early days, our models of swallowing motor control supported a conceptualisation of swallowing as a reflex; therefore, our clinical thinking did not consider this to be a deficit that would be amenable to behavioural rehabilitation. As a consequence, in the early days of dysphagia management, clinical care of the patient with dysphagia focused predominantly on compensatory approaches. These methods included diet modification to facilitate ease and safety of swallowing, or cohesiveness of bolus, postural adaptations to redirect bolus away from the airway, effortful swallowing to generate increased force on the descending bolus to decrease residual, and Mendelsohn manoeuvre to maintain opening of the upper oesophageal sphincter (UES) [42].

Muscle Strengthening Approaches

One of the first clear reports of rehabilitation as a long-term restorative approach was a case study by Bryant in 1991 [15•]. This study documented transition of the effortful swallow and Mendelsohn manoeuvre from the compensatory domain to the rehabilitative domain in a patient with head and neck cancer. Of interest, this was also a first report of the use of surface electromyography (sEMG) as a biofeedback modality in rehabilitation of swallowing.

Over the ensuing years, approaches to dysphagia management continued to extend beyond compensation alone to harness the potential of rehabilitation. Like Bryant [15•], others went on to investigate the transition of established compensatory manoeuvres, known to increase bolus pressure, into the rehabilitative realm [16, 17]. As such, rehabilitative approaches were characterised at this time by repetitive execution of these manoeuvres to strengthen muscular substrates of swallowing. At first, these approaches were largely nonspecific, targeting swallowing musculature at a global level such as in the effortful swallow, which involves several oral and pharyngeal muscle groups [43]. While such approaches may be appropriate for patients with diffuse muscle weakness, they lack the specificity necessary for patients who present with deficits in specific areas. Strengthening exercises then evolved to become more specific. For patients with apparent submental muscle weakness, exercises such as the head-lift manoeuvre [18], chin-tuck against resistance [19], and expiratory muscle strength training (EMST) [20] provided opportunities for strengthening of these muscles specifically. Other exercises, such as the tongue-hold manoeuvre [21], allowed for the musculature of the posterior pharyngeal wall to be the focus of rehabilitation, while isometric lingual exercises provided opportunity for increasing lingual strength [22].

Strengthening exercises such as these have allowed for effective approaches to rehabilitation of dysphagia characterised by peripheral muscle weakness. However, they do not come without limitations. Detraining effects have been identified for strength training approaches, which means additional attention to post-treatment maintenance programs is required [44, 45]. Additionally, growing evidence indicates that weakness is not always the primary cause of dysphagia [46–48], with corroborating research to suggest that muscle strengthening may be contraindicated for some patients [48–50], for example, in inadvertently inhibiting anterior–superior hyoid excursion [48, 51]. There is also the fundamental question of which approach to take if the patient with dysphagia is not weak. Strengthening approaches may not be suitable. For patients who present with dysphagia characterised by other deficits, such as poor swallowing skill [46, 47], strength training may also run the risk of reinforcing deficits such as pharyngeal mis-sequencing [52]. As such, alternative approaches to dysphagia rehabilitation are indicated.

Neural Plasticity and a Shift to Skill-Based Swallowing Approaches

Coinciding with our recognition of cortical contributions to swallowing, there has been an increase in understanding mechanisms of neuroplasticity and how these principles may translate to swallowing management. Neural plasticity has been defined by Kleim and Jones ([23••] p. S225) as ‘the mechanism by which the brain encodes experience and learns new behaviours’. These same mechanisms are involved following damage as the brain ‘relearns lost behaviour in response to rehabilitation’. Most will likely be familiar with their work, which highlighted ten principles of experience dependent plasticity. As outlined by Kleim and Jones [23••], principles 1 and 2 describe how failure to engage a neural system may lead to further degradation, while, conversely, engaging it with increasing competence supports improvement of function. Principle 3 highlights the specific relationship between the training experience and the plastic change that is induced. Principles 4, 5, and 7 stress the importance of delivering appropriate therapy at the correct dosage, with a need for sufficient repetition and intensity of salient training. Time since injury and the age of the individual also influence neural plasticity, as represented by principles 6 and 8, with an apparent tendency for increased plasticity shortly after injury and for younger individuals. The authors also explore the diffuse effects of neural plasticity. These effects can either be positive, as proposed by principle 9, which describes the ability of neural plasticity in one set of neural circuits to promote change in other circuits. They can also be negative, as in principle 10, which describes the potential for neural plasticity to impede expression or induction of plasticity within the same circuitry. For a more comprehensive description of these principles, the reader is directed to the seminal paper by Kleim and Jones [23••]. The involvement of the cortex in swallowing is evident, and thus, the relevance of these principles in swallowing rehabilitation is clear. A subsequent manuscript by Robbins et al. [24••] translated the key principles of neuroplasticity to swallowing and provided a comprehensive discussion of key considerations and strategies to support integration of these principles into practice.

The recognition of significant cortical modulation of swallowing and potential for neural plasticity opens new avenues for swallowing rehabilitation. Development of strategies that directly target swallowing skill through principles of neural plasticity may more efficiently maximise swallowing recovery in those where dysphagia is not due to muscle weakness.

Non-invasive Brain Stimulation (NIBS)

The concept that repeated execution of a motor behaviour can lead to neuroplastic changes in the sensorimotor networks involved in the execution of that motor behaviour has led to new options for rehabilitation. The potential role of inducing such neuroplastic changes in swallowing with non-invasive brain stimulation (NIBS) provided a first entry into focused manipulation of cortical inputs to drive swallowing recovery.

In the context of swallowing rehabilitation, NIBS is a form of neuromodulatory intervention that aims to improve swallowing motor function via extrinsically induced neuroplastic changes in swallowing-related sensorimotor networks. The two most commonly researched and perhaps most refined NIBS techniques are repetitive transcranial magnetic stimulation (rTMS) [53] and transcranial direct current stimulation (tDCS) [54]. In general, NIBS techniques are applied to the cortex through the intact scalp and are thought to modulate trans-synaptic excitability and efficiency similar to long-term potentiation- and long-term depression-like mechanisms involving N-methyl-D-aspartate (NMDA) [55, 56].

Although promising, recent meta-analyses [25] and commentaries [26] highlight the variability of the treatment paradigms, as well as the heterogeneity of treatment effects. In the context of the known factors that can potentially influence extrinsically induced neuroplastic modulation (including age, genetic disposition, and recent history of synaptic activation, to name a few) [57], the role of NIBS paradigms as stand-alone swallowing rehabilitation interventions requires further investigation.

Another factor to consider in the application of NIBS approaches is the relative non-specificity of the (magnetic or electrical) stimulation of the targeted neuronal tissues. NIBS protocols are not specific to biomechanical or pathophysiological features of swallowing. It is possible that further focusing of the stimulation target, or pairing stimulation with intrinsic, behavioural activation of task-related cortical circuits through simultaneous performance of a motor task, may yield even greater, more stable benefits. Similarly, priming cortical motor networks to modulate motor cortical excitability prior to performing motor training may also further enhance rehabilitative potential [58]. Although, theoretically, this may focus the treatment towards specific behaviour, it begs critical questions: With a preponderance of muscle strengthening approaches in our dysphagia toolkit, is it logical to pair cortical stimulation with a peripheral strengthening exercise? What rehabilitation approaches do we have that recruit central neural mechanisms?

Behavioural Cortical Activation

In an attempt to increase cortical control of swallowing with greater specificity than what is afforded by brain stimulation techniques, more recent work has shifted to what might be termed behavioural swallowing skill training. In an historical reference from 1972, predating much of the research on the swallowing CPG [5–9], use of cortical input as a rehabilitation approach to drive swallowing performance was addressed by Larsen [27]. In this early manuscript, Larsen states ‘<the patient> is taught the importance of regulating his swallowing volitionally rather than on a reflex basis.

In other words, swallowing is made subject to intellectual control…. He will be taught to "think swallow" and then swallow' (p. 189–90). Much more recent research has started testing these early concepts.

Research by Jing et al. [28] has found that specific neural networks can be intrinsically stimulated through engagement of perceptual and cognitive schemes of swallowing. This task-based functional magnetic resonance imaging (fMRI) study compared brain activity of healthy participants ($n = 29$) during swallowing and while watching someone swallow. Across both conditions, the supplementary motor area (SMA) and left middle temporal gyrus were activated. Hence the authors suggest that contemplating swallowing activates similar neural pathways as executed swallowing, thus suggesting potential for cortical re-organisation. A similar study evaluated not only cortical representation of imagined swallowing, but also the ability to purposely manipulate identified regions of cortical activation. Kober and colleagues [29] utilised fMRI to evaluate if imagined swallowing produced comparable activation to executed swallowing. Similar to Jing et al. [28], these two tasks produced comparable brain activation, but this study also identified activation of the bilateral cerebellum, basal ganglia and insula. In an extension of the Kober et al. study [29], participants received neurofeedback, an online representation of brain activation in regions of interest identified in the first study. The authors report that the use of feedback increased activation not only of targeted regions, but with extension to other cortical regions involved in swallowing.

But would this mental recruitment of swallowing networks carry over to functional outcomes? Szynkiewicz et al. [30] investigated outcomes of a 6-week mental practice regime. Typically ageing participants imagined completing a lingual strengthening exercise programme—they did not actually perform the lingual movements. By week 6, all participants had significantly improved objective measures in lingual strength, compared to baseline. These three studies represent a growing body of emerging research that support the engagement of cortical control of swallowing and enhancement of cortical activation with feedback.

Motor Learning and Biofeedback

The processes of motor learning and relearning are dependent on neuroplasticity, inasmuch as they result in the formation and pruning of neural pathways [59]. Motor learning and relearning describe the ability to acquire/reacquire permanent movement of coordinated, skilled actions in response to practice and experience [60]. By definition, this underlines the fundamental goal of swallowing rehabilitation. Zimmerman et al. [59] provide an excellent review and framework of motor learning theories applied to dysphagia management. This paper highlights three key factors that underpin successful motor relearning, including (i) specificity of practice, (ii) task challenge, and (iii) feedback. Swallowing skill training is an approach that incorporates vital theories of experience-dependent plasticity into dysphagia rehabilitation. This method centres around gaining volitional control of timing, force, and/or coordination of the muscles or processes involved in swallowing through functional practice. The use of biofeedback modalities is often used to facilitate learning [47].

Feedback can be generally defined as intrinsic or extrinsic [61, 62]. Intrinsic feedback is the sensory-perceptual information felt when performing a task [63]. In the case of patients with neurological impairment, intrinsic feedback systems may be impacted by sensory loss. Extrinsic feedback, commonly referred to as biofeedback, is delivered through an external source, via either visual, auditory, or haptic methods [61]. Importantly, extrinsic feedback augments intrinsic feedback by providing information to supplement sensory loss and establish new sensory engrams [62, 64]. This point is critical in dysphagia management since many conditions impact the sensory system [65, 66], which is essential across all phases of deglutition to produce accurate swallowing motor output [64–67]. Essentially, biofeedback converts concealed movement into user-friendly output so that swallowing can be more easily adapted to the desired performance [62]. This process of error-based learning [68] encourages active patient involvement to improve task accuracy and is also believed to promote motivation and treatment adherence [62, 69].

A recent systematic review and meta-analysis examined the effects of biofeedback as an adjunct to swallowing therapy for adults with dysphagia [70]. In total, 23 studies ($n = 448$ participants) conducted between the years 1976 and 2016 were included in the analysis [70]. Across all studies, the most common instrumentation included sEMG, accelerometry, and lingual manometry. All but one of the studies incorporated swallowing as a therapy exercise during intervention, reflecting the principle of task specificity. The study meta-analysis included only five controlled studies (stroke $n = 95$; head and neck cancer $n = 33$; mixed aetiology $n = 10$) focusing on execution of primarily strengthening exercise and found that biofeedback treatment enhanced hyoid displacement compared to control treatment. However, what is unclear from the studies included in this review is whether treatment outcomes were influenced by the use of biofeedback or the use of strengthening exercise. The studies did not compare treatment outcomes with biofeedback to outcomes without biofeedback; thus, the *active* treatment cannot be elucidated. Consequently, this report did not really address the effects of biofeedback, rather the combined effects of biofeedback with strengthening. Importantly, the authors suggested that additional work is required to indicate whether biofeedback is more effective when used in skill training paradigms than with strength training for dysphagia management.

Swallowing Skill Training with Biofeedback

Arguably, the distinction between swallowing skill training and strength training protocols with biofeedback is non-explicit and likely represents more of a continuum than categorization. Execution of an effortful swallow, for example, does not require complex skill; thus, biofeedback can be considered adjunctive. However, the Mendelsohn manoeuvre [71] demonstrates components of skill-based training by requiring patients to volitionally modulate timing aspects of swallowing. This task is challenging to perform even for healthy controls without some type of visualisation. Recent research has documented little change in UES function after a treatment protocol of Mendelsohn manoeuvres with sEMG biofeedback to monitor floor of mouth muscle activation [72, 73]. One might argue that this is not surprising as it employed monitoring and sustained contraction of floor of mouth muscles when it was unclear if the primary abnormality was weakness of those muscles. This rehabilitation approach may be misdirected if non-compliance of the UES were inhibiting opening.

In an attempt to separate strength from skill components in rehabilitation, Athukorala et al. [31] applied sEMG biofeedback to a specific skill-based training approach. The purpose of this approach was to improve *precision* in the timing and magnitude of submental muscle contraction with biofeedback to upregulate conscious control. Ten patients with Parkinson's disease (PD) completed 10 h of skill training spread across a 2-week treatment period. During sessions, participants were instructed to swallow such that the peak of the sEMG waveform hit a target that moved randomly about the screen. Effortful type swallowing was prevented by calibrating targets between 20 and 80% of the individual's maximum submental muscle strength. Following three consecutive 'hits', the target reduced in size by 10%, adhering to the construct of task challenge. Alternatively, the size of the target automatically increased by 10% with three repeated 'misses'. Sessions comprised 100 dry/saliva swallows across 5 blocks of 20 swallowing trials, providing high intensity and high repetitions. Significant improvements were documented in all measures of functional swallowing using the timed water swallowing test [74] (volume per swallow, time per swallow, volume over time) as well as all measures of sEMG activity (premotor time [reaction time], pre-swallow time [anticipatory movement], and total duration of swallowing). Swallowing-related quality of life was also improved as measured with the SWAL-QOL [75]. All treatment gains were maintained at the 2-week follow-up. This sustained change in behaviour may indicate improved neural connectivity as a function of skill-based treatment [76]. Furthermore, training was completed using saliva swallowing only; transference of improvement to swallowing liquid bolus indicates that the protocol promoted skill-acquisition of functional swallowing behaviour. This ability to adapt and modify tasks based on changing conditions likely provides long-term benefits for improved swallowing [77].

Further exploratory research applied the same protocol [31] to a case study involving a 44-year-old male with multiple system atrophy (MSA) cerebellar disorder [32]. The patient completed 1-h weekly treatment sessions and daily home practice for a 6-week period. Home-based treatment required the patient to practice variable swallowing trials, facilitated through a smartphone video module. Post-treatment instrumental evaluation found reduced post-swallow residue and elimination of premature spillage and aspiration. Patient-subjective report included decreased coughing and choking episodes and improved quality of life. The authors conclude that the biofeedback treatment improved the timing and control of the patient's swallowing, which translated into quality-of-life outcomes.

Of perhaps greater interest is if we can produce change in isolated components of the pharyngeal motor plan outside of muscle strengthening. In this context, the use of biofeedback may be considered an integral component of skill training, rather than an adjunct to task execution. Recent research has investigated the capacity of patient-driven high-resolution manometry (HRM) biofeedback to modify resting pressure of the UES in isolation. Nativ-Zeltzer and colleagues [33] recruited ten patients undergoing HRM for assessment of dysphagia, globus, chronic cough, and gastroesophageal reflux. In a single session, patients were able to increase the average resting and maximum UES pressure, using the HRM colour plots as biofeedback. While some participants were able to decrease basal UES tone, no statistically significant effect was seen for this condition. Winiker et al. [34] used similar methods to evaluate the capacity for healthy adults to adapt UES tone across a 2-week (10 h) training protocol. Similar to Nativ-Zeltzer et al. [33], participants could increase UES pressure following 1 week of practice; however, there was no evidence for purposeful pressure decrease.

Low-resolution (3 channel) pharyngeal manometry has been applied to dysphagia intervention to facilitate patient control and coordination of pressure patterns for swallowing. Huckabee et al. [52] identified a cohort of patients presenting with dysfunctional timing of pressure initiation at the proximal and distal pharynx, leading to nasal redirection, aspiration, and pharyngeal residue. Sixteen patients underwent twice daily, 1-h sessions for a minimum of 1 week. Using the pressure waveforms associated with proximal and distal pharyngeal pressure as visual biofeedback, participants were coached to volitionally increase the temporal separation of the two peaks that represented maximum pressure between the upper and lower pharynx while swallowing. Eleven of 16 patients returned to pressure patterns approximating those of healthy controls, resulting in resolution of nasal redirection, aspiration, and pharyngeal residual, as well as return to a normal diet. Biofeedback is considered to be most beneficial when providing information about a function not directly observable, allowing a participant to see what they cannot easily see or feel. In this regard, pharyngeal manometry, although somewhat uncomfortable, may provide a valuable avenue for feedback of specific features of the pharyngeal response.

A different approach to visual biofeedback was used by Martin-Harris and colleagues [35] to improve swallowing-respiratory patterns. Thirty patients with head and neck cancer underwent a hierarchical training approach that consisted of three modules: (i) *identification* of respiratory-swallowing patterns, trained via visual diagrams on the KayPENTAX Digital Swallowing Workstation; (ii) *performance acquisition* of optimal swallowing-respiratory patterns with liquid boluses and visual biofeedback; and, finally, (iii) *mastery* to achieve the correct expiratory-swallow-expiratory pattern, without visual feedback, to 80% accuracy. With twice-weekly, 1-h training sessions, all participants were able to achieve mastery within 4 weeks, which was accompanied by significant improvements in laryngeal vestibule closure and penetration aspiration scale scores. Additionally, significant improvements were seen in tongue-base retraction and pharyngeal residual, which may suggest a type of task transference associated with skill-based training. Also consistent with a skill-based, cortically driven change, all participants who attended the 1-month follow-up demonstrated maintenance of treatment effects.

Conclusion

Our expanding understanding of cortical contribution to swallowing motor control has informed the development and iterative refinement of increasingly specific rehabilitation approaches. As supported by this narrative review, the emerging emphasis on motor control, rather than muscle strength, implicates a critical role for the use of biofeedback modalities to allow conscious insights into specific aspects of the generally obscure swallowing process. Collectively, the body of research referred to in this review is a call to arms for researchers to continue to refine rehabilitation approaches that address specific characteristics of underlying swallowing impairment. Additionally, the hope is that clinicians will intentionally transcend a focus on compensatory dysphagia management and embrace the potential of neuroplastic changes for improved cortical control of swallowing. Perhaps a future review will comment on today's era as a transitionary period between our current understanding of cortical swallowing networks and future interventions that selectively target neural networks responsible for distinct aspects of swallowing motor control.

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Declarations

Conflict of Interest Maggie-Lee Huckabee reports author royalties from Plural Publishing (paid to her). Their research centre (Rose Centre for Stroke Recovery and Research) invoices hosts for honorarium which consequently supports further research or supports post graduate students. They have a patent pending for Biofeedback in Strength and Skill Application. They also have an unpaid board membership for Swallowing Technologies Ltd. Sebastian Doeltgen reports payment or honoraria from Speech Pathology Australia. The other authors declare that they have no conflict of interest.

Human and Animal Rights and Informed Consent This article does not contain any studies with human or animal subjects performed by any of the authors.

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•• Of major importance

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