Dysphagia Management & Rehabilitation:
Applying Principles of Motor Performance & Learning

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ABSTRACT

The presentation will challenge clinicians to critically appraise approaches of dysphagia management and rehabilitation using principles of motor learning and exercise science. We will review foundational principles of these disciplines and discuss their clinical implications for maximizing neuroplasticity, muscular adaptation, and overall recovery of swallowing function. These principles will be applied to dysphagia evaluation and the swallowing rehabilitation literature. Case studies will give participants opportunities to apply newly acquired knowledge within the session.

LEARNING OBJECTIVES

After participating in this seminar, learners will be able to:

- Summarize basic knowledge of strength training and motor learning
- Apply evidence-based principles of exercise science and motor learning in designing/implementing swallowing exercises
- Distinguish differences between skill-based and strength-based tasks and their application for treatment options of dysphagia
- Identify assessment methods to classify deficits/impairments in sensory-based, motor-based, and sensorimotor-based dysphagia
- Recommend appropriate assessment/treatment strategies for persons with dysphagia integrating principles of exercise science and motor performance and learning

INTRODUCTION

- Evidence-based dysphagia management
    - Strive to balance *scientific evidence* (quantitative research studies), *clinical experience* (professional consensus statements, practice groups, evidence-based continuing education) and *patient circumstances* (QoL, treatment burden, satisfaction surveys)
    - We are not limited to the evidence in SLP journals!
- Compensatory vs. rehabilitation strategies
    - **Compensatory**: *Immediate* effects regarding bolus flow and/or airway protection when a bolus is present (confirmed via testing), some consideration of how strategies fit functional impairments but not necessarily physiological deficits
    - **Rehabilitative**: *Sustained* effects on swallowing physiology even when technique not being used, often performed when bolus is not present, reflects peripheral and/or central nervous plasticity
        - Many review articles have emphasized incorporating principles of motor learning, neuroplasticity and/or exercise science to guide swallowing rehabilitation for better patient outcomes (Burkhead, Sapienza, & Rosenbek, 2007; Easterling, 2017; Huckabee & Lamvik-Godzdzikowska, 2018; Humbert & German, 2013; Langmore & Pisegna 2015; Logemann, 2005; McKenna et al., 2017; Robbins et al., 2008; Rogus-Pulia & Connor, 2016; Stathopoulos & Duhan, 2006; Waito et al., 2017).

- Rehabilitation utilizes our nervous system's ability to *adapt* contingent upon the *quality and quantity of practice and experience* it undergoes
  - **Peripheral (Neuromuscular) Adaptation**
    - Physiological changes: muscle fiber shifts and hypertrophy, increased recruitment of motor units (Deschenes & Kraemer, 2002; Moritani, 1993; Powers & Howley, 2001)
    - Functional changes: increased force and accuracy of movements
    - Primary training methods: Resistance Training
  - **Central (Neuroplasticity) Adaptation:** morphological and functional neural changes
    - Physiological changes: synaptogenesis, glial cell proliferation in areas of task behavior, increased dendritic density, long-term potentiation and suppression of neural networks (Draganski & May, 2008)
    - Functional changes: Sustained and improved neural function involved in trained task with associated improvements in behavior
    - Primary training methods: Motor Learning, Skill Training

FOUNDATIONAL CONCEPTS OF EXERCISE SCIENCE AND MOTOR LEARNING

- **Resistance training**
  - Structured such that the *load* (amount of resistance or work involved) and the *volume* (frequency of visits, number of repetitions) challenges or *overloads* the system
    - Overload is NECESSARY for functional gains and needs to *progress* accordingly as the performer's strength/ability increases (Bird, Tarpenning, & Marino, 2005)
    - Biomedical equipment that provide quantitative measures of strength in the oropharyngeal musculature may be costly but significantly assists with designing individualized and effective exercise programs
  - Improved performance/strength tied with *specificity* of the exercise (Bird et al., 2005), which may or may not carry over to other tasks
    - E.g., increasing tongue-to-palate pressures can also increase pharyngeal pressures (Huckabee & Steele, 2006; Steele & Huckabee, 2007) whereas oral muscle strengthening would not be expected to generalize to improvements in articulatory precision (Lof, 2018)
  - Initial *short-term* boost in task performance generally due to *peripheral neural adaptation* in muscle activation and *muscle fiber changes* to become more fatigue-resistant (Deschenes & Kraemer, 2002; Moritani, 1993)
    - These improvements typically plateau quickly
  - *Long-term* and more sustainable adaptation in the neuromuscular system is *muscle fiber hypertrophy* which increases muscles' force-generating capacity (Powers & Howley, 2001)
    - Requires *weeks* of effective resistance training (Deschenes & Kraemer, 2002; Moritani & deVries, 1979)
  - *Maintenance exercises* should be considered in strengthening regimens to avoid detraining effects

- **Motor Learning**
  - Motor learning principles aim to provide *practice and feedback conditions* that enhance sensorimotor skill learning
    - "Learning" reflects *permanent changes* in the nervous system and can lead to task automaticity with increased speed and accuracy, efficiency in setting temporal and amplitude motor parameters, and developing better feedback systems (Schmidt & Wrisberg, 2008)
  - Swallowing is mediated by a *central pattern generator* (CPG; dedicated circuit to generate specific movement sequences modulated by sensory input) (Barlow & Estep, 2006)
    - CPGs similar to how *motor programs* work in managing *degrees of freedom* (independent aspects of motor control and action) and setting system *parameters* (movement time, amplitude/force of movement) (Schmidt & Wrisberg, 2008)
  - Principles of motor learning (PML) facilitate *skilled movements* rather than strength/force ability
    - Swallowing is a *sensorimotor skill* and has motor learning capacity (Humbert et al., 2013)
    - Although swallowing requires some level of oropharyngeal strength, it is a submaximal task (Nicosia et al., 2000) and dysphagia can often manifest in ways other than weakness
  - *Motor skill training* can induce both grey- and white-matter neural changes with associated improvement in task-at-hand (Draganski et al., 2004; Scholz, Klein, Beherns, & Johansen-Berg, 2009)
    - PML applied to motor skill training enhances neuroplasticity and behavioral outcomes (Mawase, Uehara, Bastian, & Celnik, 2017)
  - The role of *sensation* is significant in motor learning, as resultant motor performance is modulated/contingent upon the *input* it receives
    - Swallowing behaviors can be modified by sensory properties of the bolus (Lazarus, 2017) making it a potential avenue in motor learning; however, sensory manipulation has historically been considered as a "compensatory" strategy and only recently has been explored as a dysphagia rehabilitation strategy (Dietsch et al., 2019)
  - The *practice conditions* and the type/frequency of *feedback* shape the flexibility of the motor plan and program to make it more robust
    - Practice conditions include a high *intensity* (quality and quantity of deliberate practice) and *specificity* (training to match similar experiences of intended behavior)
    - Practice should be *variable*, *random*, and *complex* when possible to challenge the system. These conditions also require ready modification to one's motor program, making motor programming and accurate parameter setting experiences more robust (Maas et al., 2008; Schmidt & Wrisberg, 2008)
    - Feedback is critical in developing awareness in accuracy of movement.
      1. *Biofeedback* in swallowing components can enhance one's ability to modify, monitor, and challenge the swallowing system (Albuquerque, Pernambuco, da Silva, Chateaubriand, & da Silva, 2019)
      2. *Intermittent and delayed feedback* challenges performers and engages sensorimotor feedback systems (Maas et al., 2008; Schmidt & Wrisberg, 2008)

DEFICIT-DRIVEN DYSPHAGIA ASSESSMENT

- Symptoms vs signs vs impairments vs deficits; different but related to each other in somewhat predictable ways
- A range of assessment tools to address these different levels
  - *Symptom*: client-reported limitation
    - Eating Assessment Tool (EAT-10), M.D. Anderson Dysphagia Inventory (MDADI), SWAL-QOL and SWAL-CARE, Dysphagia Handicap Index (DHI)
  - *Sign*: clinician-observed limitation
    - Massey Bedside Swallow Screen, Mann Assessment of Swallowing Ability (MASA)
  - *Impairment*: functional effect
    - Penetration-Aspiration Scale (PAS), Functional Oral Intake Scale (FOIS), ASHA National Outcome Measurement System (NOMS), Dysphagia Outcome Severity Scale (DOSS)
  - *Deficit*: anatomical/physiological abnormality
    - Modified Barium Swallow Impairment Profile (MBSImP™), Test of Mastication and Swallowing Solids (TOMASS), Computational Analysis of Swallowing Mechanics (CASM)
- Indications of sensory, motor, and sensorimotor deficits
  - *Sensory*: somewhat stimulus-specific; over-responsivity, under-responsivity, stimulus-seeking
  - *Motor*: fairly consistent across circumstances; weakness, abnormal tone
  - *Sensorimotor*: breakdown in sensory processing/integration and/or formulating appropriate motor response to stimulus; incoordination re: timing and amplitude of movements
- The nature of the deficit determines the management approach
  - Need to consider additional factors such as developmental vs. acquired, acute vs. chronic, single-incident vs. degenerative, sensory vs. motor vs. sensorimotor vs. other
  - Accurate identification of impairments and deficits is critical for treatment selection and success

MOTOR LEARNING IN EVIDENCE-BASED DYSPHAGIA REHABILITATION

- When critically appraising swallowing treatment options, ask if the approach/technique is working on *STRENGTH* or *SKILL*?
  - For strength-related exercises, what *loads* and *volumes* are implemented? Can we effectively *overload* the system? Can we *progressively* increase difficulty/resistance? What part of swallowing is this strength task *specific* to? (And remember, just because exercise is targeting muscles involved in swallowing, there may be little evidence for transference effects that improve swallowing physiology).
  - For skill-related exercises, what practice conditions are involved and at what levels (e.g., *specificity*, *intensity*, *variability*, *complexity*)? Is this *challenging/modulating parameters* (force/speed of swallowing movement)? What *feedback* is being provided?

Expiratory muscle strength training (EMST)

- Description: Performers forcefully exhale in a spring-loaded valve via a pressure threshold device at certain durations and repetitions at a resistance typically based on their expiratory maximum capacity.
- Evidence: Improved buccinator strength documented in one RCT (Park JS et al., 2016). Strong evidence of improved hyoid displacement and/or improved respiratory support/coordination; results maintained in multiple patient populations; appropriate level of resistance is key (Byeon, 2016a; Hegland et al., 2016; JS Park JS et al., 2017; JS Park et al., 2016; Plowman et al., 2016; Reyes et al., 2015; Troche et al., 2010; Troche et al., 2014).
- Incorporated principles? STRENGTH-based. Can incorporate overload and progression principles with most devices of EMST. Mainly specific to muscles involved in hyolaryngeal excursion in swallowing. Volume and load vary across patient populations.

Respiratory-swallow training

- Description: Performers participate in a systematic, educational- and behavioral-based treatment of executing accurate respiratory phases in swallowing using visual biofeedback.
- Evidence: Improved tongue base retraction and laryngeal vestibular closure sustained 1 month after treatment (Martin-Harris et al., 2015).
- Incorporated principles? SKILL-based. The systematic training program is intense and specific to safe respiratory coordination in swallowing.

Tongue-to-palate strength training

- Description: Participants engage in lingual presses in anterior and/or posterior regions of the tongue against varying resistance.
- Evidence: Most studies use one of two commercial systems to measure/train pressures, mixed results at best re: functional bolus control effects despite consistent evidence of increased tongue-to-palate pressures (Lazarus et al., 2014; Namasivayam-MacDonald et al., 2017; Oh, 2015; Park JS et al., 2015; Robbins et al., 2005; Rogus-Pulia et al., 2016; Yeates et al., 2008).
- Incorporated principles? STRENGTH-based. If using device (e.g., IOPI), then have chance to incorporate principles of overload and progression. Devices also have potential for biofeedback. Specific to strengthening muscles involved in lingual-palatal pressure generation for bolus propulsion and clearance. Regimens of load and volume vary, yet work is being done to understand optimal loads for lingual strength gains (Van den Steen et al., 2019).

Tactile-thermal stimulation (TTS)

- Description: Performers receive combined tactile and thermal stimulation to the anterior faucial pillars.
- Evidence: Increased neural activation in swallows with vs. without TTS (Teismann et al., 2009).
- Incorporated principles? Does not theoretically include strength or skill-based principles; could "prime" system for swallowing by stimulating sensory tracts of glossopharyngeal nerve but is not specific to normal feeding/swallowing behaviors.

Skill Training Treatments: 1) Tongue Pressures Strength and Accuracy Training (TPSAT), 2) Biofeedback in Swallowing Skill Training (BiSSkiT)

- Description: 1) Participants perform in exercises that include maximum isometric lingual presses and presses of a certain percentage of their max in the anterior and posterior portions of the tongue. 2) Performers work on swallowing within a certain temporal and force-related target using a sEMG biofeedback.
- Evidence: Solid RCT evidence supports reduced vallecular residue in post stroke population (Steele et al., 2016) but not BI (Steele et al., 2013). In small cohort of persons with PD, temporal aspects of the swallow were improved immediately after treatment but had mixed results in maintainance measures after 2 weeks (Athukorala, Jones, Sella & Huckabee, 2015).
- Incoporated principles? 1) STRENGTH- and SKILL-based. Incorporates intense practice, overload, progression, and uses principles of random practice to train lingual force parameters. Specific to strengthening muscles involved in lingual-palatal pressure generation for bolus propulsion and clearance. 2) SKILL-based. Intense swallowing skill approach that uses specificity and principles of random, variable, and complex practice to challenge accurate swallowing parameters. Incorporates biofeedback to enhance precision of swallowing movements.

Effortful swallow

- Description: Performers are instructed to swallow at an increased effort-level, the language used in instructions matter and could change swallow performance (Huckabee & Steele, 2006; Steele & Huckabee, 2007).
- Evidence: moderate evidence of long-term benefits to tongue strength and oral manipulation in patient groups after 4-6 weeks of exercise (Clark & Shelton, 2014; Kraaijenga et al., 2017). Others noted higher tongue-to-palate pressures in healthy persons after several weeks of training (Oh, 2015; Park T & Kim, 2016). Mixed evidence for increased pharyngeal pressures, pharyngeal constriction ratios (summarized in Langmore & Pisegna, 2015); improved PCR shown when combined with NMES but no control condition (Kim et al., 2017). Positive evidence of long-term benefit in some studies but differences in dosing and exercise regime confound interpretation of studies (Ashford et al., 2009; Kraaijenga et al., 2015; Langmore & Pisegna, 2015; JW Park et al, 2012); one study of patients with head/neck CA found no significant changes in HLE (Kraaijenga et al., 2017).
- Incorporated principles? STRENGTH- and SKILL-based. Limitations with load resistance and progression. Volume and intensity varies in literature. Principle of specificity highly utilized in both strength and skill components. Trains performers to challenge amplitude parameters of swallowing.

McNeill Dysphagia Therapy Program (MDTP)

- Description: Performers participate in a systematic PO trial regimen implementing a “swallow fast and strong” technique.
- Evidence: improved functional outcomes reported in limited trials but several issues with controls and outcome measures (Carnaby-Mann & Crary, 2010; Crary, Carnaby, LaGorio, & Carvajal, 2012; Lan et al., 2012). Improvements reported in one uncontrolled study (Sia et al, 2015); no other published reports
- Incorporated principles? SKILL-based. Highly specific to eating/drinking swallowing behaviors, does implement speed and force modulation of swallowing parameters.

Neuromuscular electrical stimulation (NMES)

- Description: Performers receive electrical stimulation typically over the submental muscles, usually implemented as an adjunctive therapy paired with an exercise.
- Evidence: Several commercial systems; most studies found little benefit in comparison to "traditional therapy" in a range of patient groups; sensory level of stimulation generally more favorable than contraction-eliciting level (Baijens et al., 2008; Byeon & Koh, 2016; Christiaanse et al., 2011; Gallas et al., 2010; Heijnen et al., 2012; Lim et al., 2009; Xia et al., 2011; Zhang et al., 2016). Some poorly controlled studies show limited benefit in comparison to or in combination with "traditional therapy" (Beom et al., 2015; Tang et al., 2017); others found no benefit in well-controlled studies (Christiaanse et al., 2011; Heijnen et al., 2012; Langmore et al., 2016; Ryu et al., 2009; Zhang et al., 2016) and even reductions in HLE and swallowing safety depending on electrode placements (Humbert et al., 2006).
- Incorporated principles? Does not theoretically include strength or skill-based principles since it's typically an adjunct to other therapy options. May influence submental muscle activity, but variation in recommended intensity and duration of electrical stimulation with possibility of worsening function.

Masako (tongue-hold) exercise

- Description: Performers initiate a dry swallow while holding the tongue in an anterior position by gently using their front teeth.
- Evidence: Limited evidence of long-term benefit (Langmore & Pisena, 2015); one study compared Masako to NMES after stroke and found equal benefit after 5/wk x 4wks (Byeon, 2016b).
- Incorporated principles? STRENGTH-based. Limitations with load resistance and progression. Variability in volume of exercise. Mainly specific to muscles involved in tongue base retraction and pharyngeal constriction in swallowing. Indirectly challenges amplitude of swallowing parameters.

Shaker/Chin tuck against resistance (CTAR)

- Description: Using gravity in a supine position or object to provide resistance that's placed under the chin, performers participate in isometric and/or isokinetic contractions of lifting head/tucking chin.
- Evidence: Early Shaker literature strongly supports improvements maintained over time; more recent papers focus on CTAR vs Shaker with generally comparable results for the two exercises (Easterling et al., 2005; Gao & Zhang, 2016; Logemann et al., 2009; Mishra et al., 2015; Sze et al., 2016; Yoon et al., 2014).
- Incorporated principles? STRENGTH-based. Can incorporate overload principle, specific to muscles in hyolaryngeal excursion. For Shaker, general protocol for volume/intensity (3x30s isometric head lifts with 60s rest in between reps and 30 continuous isokinetic head lifts performed 3x/day for 6wks).

Mendelsohn maneuver

- Description: Performers volitionally hold the highest peak of hyolaryngeal excursion during repetitions of a dry swallow.
- Evidence: Strong evidence of extended benefit in multiple well-controlled studies including multiple populations and outcome measures (Ding et al., 2002; Hoffman et al., 2012; Langmore & Pisegna, 2015; McCullough & Kim, 2013).
- Incorporated principles? STRENGTH- and SKILL-based. Limitations with load resistance and progression; however, prolongs duration of submental contraction in hyolaryngeal excursion (which exercise is

specific in targeting). Challenges swallowing parameters by training autonomous control in movement aspects of the swallow.

Prophylaxis in head-neck cancer

- Description: Performers participate in a combination of swallowing-related exercises to prevent and/or improve dysphagia before/during/after chemoradiotherapy.
- Evidence: Several programs of exercise being evaluated (Cnossen et al., 2017; Govender et al., 2017; Kraaijenga et al., 2015; Mortensen et al., 2015; Ohba et al., 2016; Wall al., 2016); key is compliance, recent systematic review summarizes results of several key studies (Govender et al., 2017).
- Incorporated principles? STRENGTH-based; however, the main purpose of these regimens is to preserve function by keeping muscles activated and preventing tissue fibrosis. A heavy dose of exercises engaging many muscles involved in swallowing has been successful in preserving function. In the scenario of dysphagia manifesting during or after chemoradiotherapy, then selecting treatment regimens utilizing motor learning and resistance training principles that address their deficits would be appropriate.

Transcranial magnetic stimulation (TMS)

- Description: A copper wire coil is placed over the cortex of the participant, which produces a magnetic field and can impact neural function in areas it is pulsating over.
- Evidence: Better recovery compared to sham maintained 3 months post-treatment, stimulate unaffected hemisphere, settings matter (Du et al., 2016; Kumar et al., 2011; Pisegna et al., 2016; Yang et al., 2015).
- Incorporated principles? Does not theoretically include strength or skill-based principles; however, can have inhibitory and/or excitatory effects over cortices relevant in swallowing which then has potential to impact swallowing skills. Wide variation in recommended intensity, duration, and location of TMS.

Sensory Stimulation

- Description: Performers receive sensory stimulation (e.g., somatosensory, olfactory, taste, chemesthetic, etc.) to internal/external orofacial and oropharyngeal areas.
- Evidence: Punctate saltatory facial stimulation (Rosner & Barlow 2016) led to long-term changes in oromotor neural cortex; vibration over the larynx (Mulheren & Ludlow, 2017) increased bloodflow to swallowing-relevant regions. Several labs have shown (1) immediate advantageous changes to swallowing mechanics by manipulating bolus parameters of taste, temperature, volume, etc. (Cola et al., 2010; Dietsch et al., 2019; Michou et al., 2012) and (2) increased cortical bloodflow to relevant regions with taste stimuli (Babaei et al., 2010; Humbert & Joel, 2012; Mulheren & Ludlow, 2017; Wahab et al., 2010). Ongoing work in Dietsch lab is exploring the longer-term neuroplastic changes and recovery of swallowing motor patterns associated with specific taste stimuli.
- Incorporated principles? SKILL-based. Sensory stimulation has burgeoning literature in neural activation and impact on motor function. Specific or combinations of sensory stimulation can modulate swallowing temporal and amplitude parameters.

SUMMARY

- Within swallowing rehabilitation, we can work on facilitation of peripheral and/or central adaptation to the swallowing system

- Implementing evidence-based principles of motor learning and exercise science to dysphagia treatment may lead to more effective services and patient outcomes
- Deficit-driven assessment helps guide treatment selection and planning
- Quantity and quality of rehabilitation evidence ranges widely, especially those incorporating principles of motor learning and exercise science
- Building a better foundation of evidence and improving patient outcomes require collaboration between clinicians and researchers to be relevant and reliable

REFERENCES AND RESOURCES- this is not a comprehensive list of all resources on these topics, just those that were included in the presentation. ** designates review or meta-analyses papers

Motor Learning and Exercise Science in Swallowing Rehab Resources

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Worksheet for Small-Group Application Activity
Case Studies in Dysphagia Assessment and Management

Patient-reported symptoms: ____

Clinician-observed signs: ____

Functional impairments: ____

Physiological Deficit	Sensory, Motor, Both, Other	Resistance, Skill, Both, Other	Possible Rehab Strategy	Evidence Base for Deficit-Strategy Match?	Motor Learning Principles to Incorporate