THE EFFECT OF SWALLOWING TASK AND VISUAL FEEDBACK ON SUBMENTAL MUSCLE ACTIVITY DURING SWALLOWING

A thesis submitted in partial fulfilment of the requirements for the Degree of Master of Science in Speech and Language Sciences at the University of Canterbury

Rebecca Streith

I.D. 75815321

Department of Communication Disorders, University of Canterbury

The Rose Centre for Stroke Recovery and Research at St. George's Medical Centre

Christchurch, New Zealand

2019

Abstract

Background: One approach to swallowing rehabilitation is skill rather than strength training. This study sought to improve the calibration process used in a skill training protocol (BiSSkiT) for swallowing rehabilitation. Calibrating an achievable target range is important to ensure that the task is achievable and promotes skill rather than strength training.

Methods: This methodological study used a two-factor repeated measures design. Healthy participants completed normal and effortful swallows under two conditions: with and without visual feedback. The maximum amplitude as measured by sEMG was recorded for each swallow.

Results: Data from 35 participants was analysed. A significance difference was found between swallowing tasks but not feedback conditions. Effortful swallowing resulted in higher amplitude than normal swallowing. Effortful swallowing also had a higher variability (mean SD=17.47) than normal swallowing (mean SD=9.69).

Conclusion: The aim of this study was to determine the most consistent approach to calibrating a target range during skill training for swallowing rehabilitation. The presence or absence of visual feedback did not impact on sEMG measurements. The greater variability during effortful swallows suggests that normal swallowing should be used to calibrate a target range.

Acknowledgments

First and foremost, I would like to express my sincere gratitude to my supervisor Professor Maggie-Lee Huckabee who supported and guided me through this journey. Thank you for always challenging me to think critically.

I would also like to acknowledge Esther Guiu Hernandez for her help with statistics and her daily hugs, and the team at the Rose Centre for their warm support. I would also like to thank the participants who volunteered to take part in this study.

I will be forever grateful for the unwavering support I received from my partner Will to keep going and stay motivated. Thank you also to Jenny, Phoebe, Michelle, and Tegan for your support and supplies of chocolate.

TABLE OF CONTENTS

Chapter 1 - Literature Review

Swallowing serves two main functions that are essential to survival: nutritional intake and protection of the airway (Humbert & Joel, 2012); Jean (2001). It is an incredibly complex and rapid action – the total swallowing duration for liquids is approximately 1.0-1.5 seconds (Daniels, Schroeder, DeGeorge, Corey, & Rosenbek, 2007; Dodds, Stewart, & Logemann, 1990) depending on volume (Molfenter & Steele, 2012). The swallowing process can be interrupted by structural or neurological changes, resulting in swallowing difficulties or dysphagia (S. M. Shaw & Martino, 2013).

1.1 Anatomy and physiology of swallowing

The swallowing process has been described in three main phases: oral, pharyngeal, and oesophageal (Dodds et al., 1990; Ertekin & Aydogdu, 2003), but visual and olfactory stimuli during the pre-oral phase play an important role in readying the swallowing system (Leopold & Kagel, 1997; Maeda et al., 2004).

1.1.1 Pre-oral stage. Visual and olfactory stimuli during the pre-oral stage play an important role in increasing salivation which is imperative for mastication and bolus transfer (Leopold & Kagel, 1997; Pedersen, Sørensen, Proctor, Carpenter, & Ekström, 2018). These stimuli also activate the cortical swallowing network readying it for the oral phase of swallowing (Leopold & Kagel, 1997). Factors such as cognition, attention, hunger, and motor skills also play an important role during the pre-oral phase (Leopold & Kagel, 1997; Shune, Moon, & Goodman, 2016).

1.1.2 Oral stage. During the oral stage for solids, the tongue transports the bolus and places it between the molar surfaces for mastication. The bolus is masticated and mixed with saliva until it has reached the appropriate consistency for swallowing (K. Matsuo & Palmer, 2008; Pedersen et al., 2018). The soft palate does not continuously contact the base of tongue to create a palatoglossal seal for solid bolus textures (K. Matsuo, Hiiemae, & Palmer, 2005). However, during the oral stage for liquids, the bolus is prevented from prematurely spilling into the pharynx by the glossopalatal seal. The tongue tip then propels the bolus posteriorly while the soft palate moves up and the base of tongue moves anteriorly and inferiorly to facilitate bolus flow.

1.1.3 Pharyngeal stage. Sensory perception through mechano- and chemoreceptors plays an important role in triggering the pharyngeal swallowing response (Alvarez-Berdugo et al., 2016). Sensory information is transmitted from the receptors lining the oropharyngeal mucosa via the trigeminal, facial, glossopharyngeal and vagus nerve to the sensory cortex and the brainstem (Alvarez-Berdugo et al., 2016). The beginning of the pharyngeal stage is typically determined by the initiation of hyoid movement (Gassert & Pearson, 2016; Nam, Oh, & Han, 2015).

Overall, the pharyngeal stage consists of the following major physiological events: velopharyngeal closure, laryngeal vestibule closure, tongue base retraction, hyolaryngeal elevation, pharyngeal shortening and upper oesophageal sphincter opening

As the base of tongue drops, the soft palate moves up and seals against the posterior pharyngeal wall while the pharyngeal constrictor muscles tense to seal against the lateral aspects of the soft palate. Velopharyngeal closure seals off the nasopharynx to create the increased pressure that is required for bolus propulsion through the pharynx (Dodds et al., 1990; K. Matsuo et al., 2005; Koichiro Matsuo & Palmer, 2009; Perlman, Schultz, &

VanDaele, 1993). Elevation of the soft palate is achieved by contraction of the levator veli palatini and tensor veli palatini muscles which are innervated by the vagus and trigeminal nerve respectively (Belafsky & Lintzenich, 2013).

The hyoid bone and the larynx are pulled anteriorly and superiorly while the base of tongue pushes the bolus down and the posterior pharyngeal wall comes forward (Miller, 2008). The geniohyoid and anterior belly of the digastric elevate and pull the hyoid forward (Inokuchi et al., 2014) with the anterior belly of the digastric likely generating most of the force and the geniohyoid being responsible for the excursion (S. M. Shaw et al., 2017).

Laryngeal vestibule closure protects the airway and is achieved by adduction of the vocal folds, adduction of the aryepiglottic folds and epiglottic deflection (Vose & Humbert, 2018). The arytenoid cartilages move to adduct the vocal folds and the aryoepiglottic folds to protect the airway and decrease the size of the laryngeal inlet (Miller, 2008; Vose & Humbert, 2018). Laryngeal elevation, tongue base retraction, and pharyngeal constriction all facilitate epiglottic deflection which further protects the airway (Vose & Humbert, 2018). The epiglottis is a flexible thin cartilage that sits in between the base of tongue and the laryngeal vestibule. Inferiorly, the epiglottis attaches to the hyoid bone, the thyroid and the quadrangular membrane; during hyolaryngeal excursion the epiglottis moves from vertical to a horizontal position covering the laryngeal vestibule (Hennessy & Goldenberg, 2016). While epiglottic deflection is correlated with hyoid movement it is not necessarily dependent on it; a recent study investigating impaired epiglottic deflection found that the long pharyngeal muscles, styloglossus and hyoglossus likely play a more important role in epiglottic deflection than the submental muscles (W. G. Pearson, Jr., Taylor, Blair, & Martin-Harris, 2016). However, the study did not include the contribution of the pharyngeal constrictor muscles and did not control for underlying aetiology of dysphagia.

Pharyngeal contraction serves two main purposes; it constricts the pharynx thereby increasing the pressure on the bolus facilitating its transfer through the pharynx and it shortens the pharynx thereby elevating the upper oesophageal sphincter towards the bolus (Hosseini, Tadavarthi, Bonnie, & Pearson, 2019; Leonard, Kendall, & McKenzie, 2004). Pharyngeal constriction is the result of tongue base retraction and activation of the superior and middle pharyngeal constrictor muscles (Schwertner, Garand, & Pearson, 2016) while pharyngeal shortening is achieved by the long pharyngeal muscles (stylopharyngeus, palatopharyngeus, and salpingopharyngeus) (W. G. Pearson, Hindson, Langmore, & Zumwalt, 2013).

The upper esophageal sphincter consists of the inferior pharyngeal constrictor muscles, the cricopharyngeous muscle, and the superior portion of the esophagus (K. Matsuo & Palmer, 2008). The upper esophageal sphincter opens by first relaxing and is then pulled open by hyolaryngeal excursion (K. Matsuo & Palmer, 2008; Miller, 2008) allowing the bolus to transit through. The force of the bolus also plays an important role in opening the upper esophageal sphincter (D. Shaw et al., 1995).

1.2 Dysphagia

As described above, swallowing is a complex process requiring the timely coordination of a multitude of movements of muscles, bones, and cartilages. Difficulties with swallowing, or dysphagia, can result from any type of structural or neural damage that interferes with these movements (S. M. Shaw & Martino, 2013). Dysphagia can have significant impact on health outcomes, quality of life, and place additional financial burden on the healthcare system (Arnold et al., 2016; Attrill, White, Murray, Hammond, & Doeltgen, 2018; Eslick & Talley, 200; Patel et al., 2018).

1.2.1 Management of dysphagia. Management of dysphagia depends on the underlying cause but can be divided into two main categories: compensation and rehabilitation (Gonzalez-Fernandez, Ottenstein, Atanelov, & Christian, 2013). Historically, the focus of dysphagia management has been on the use of compensatory strategies during swallowing (Burkhead, Sapienza, & Rosenbek, 2007).

1.2.1.1 Compensatory strategies. Compensatory strategies to manage dysphagia include postural changes during swallowing such as chin tuck and head turn, sensory enhancement such as carbonating fluids or changing temperature and flavour, manipulating viscosity and volume, breath-holding, and increasing volitional control by introducing a three second preparation stage before swallowing (Johnson, Herring, & Daniels, 2014). However, compensatory strategies do not have lasting effects; patients need to remember to employ the strategy every time they swallow (which can be especially challenging for patients with cognitive impairments), and the research base for these strategies is sparse (Huckabee & Hughes, 2013; Johnson et al., 2014).

1.2.1.2 Rehabilitative strategies.

Strengthening. Traditionally, swallowing rehabilitation has largely focused on retraining muscle strength (Easterling, 2017). Overall, the evidence supporting strengthening exercises for swallowing rehabilitation is variable (Smaoui, Langridge, & Steele, 2019). Evaluation of strengthening research is confounded as research studies frequently use healthy volunteers instead of patients as participants or combine multiple exercises in one treatment protocol (Langmore & Pisegna, 2015). Considering that swallowing is a sub-maximal task (Nicosia et al., 2000), a strengthening approach might not be the most appropriate approach as prescription of strengthening exercises assumes that the underlying impairment is one of weakness.

While strength and muscle mass may increase following strength training, this does not necessarily result in a change of swallowing biomechanics or improve functional outcomes (Robbins et al., 2005; Robbins et al., 2007; Yano et al., 2019). Adherence to strength training protocols can also be poor (Wakabayashi et al., 2018).

Skill training. Skill training is an emerging approach to dysphagia rehabilitation and is based on the idea that swallowing is a complex task requiring skill rather than strength (Miles & Allen, 2015). Skill training can take many forms but typically utilises a type of biofeedback. Biofeedback involves the measurement of a physiological signal which is filtered, processed, and then converted to a visual or auditory signal (Peper, Harvey, & Takebayashi, 2009). Biofeedback aims to increase the ability to self-regulate physiological processes by developing awareness of those processes (Peper et al., 2009).

Steele et al. (2013) modified a lingual strength training protocol (Robbins et al., 2005; Robbins et al., 2007) to include a component that could be considered skill training during which patients had to achieve a randomly selected pressure target between 20%-90% of their maximum isometric pressure. Tongue pressures improved for all participants and five out of six participants no longer aspirated thin liquids post intervention. However, post-swallow residues did not improve and worsened for some of the participants. Because this study used a single-subject research design due to the small number of participants, it is difficult to generalise these findings to the general population. The combination of treatments approaches makes it difficult to evaluate the effect of each treatment component individually. Furthermore, the participants had a range of brain injuries and three participants were only six months or less post-injury and spontaneous recovery in those participants cannot be excluded.

Martin-Harris et al. (2015) trained patients with dysphagia due to head and neck cancer to improve coordination of respiration and swallowing. The training consisted of three stages: patients first learned to identify correct breathing patterns, then received visual feedback about their own breathing patterns to acquire the correct pattern, and then had to use the correct pattern without feedback. Post intervention, laryngeal closure, tongue base retraction, pharyngeal residue, and penetration/aspiration improved significantly. These findings suggest that patients can learn to modulate aspects of their swallowing when given the appropriate feedback and hierarchy of learning tasks and that this results in changes in swallowing physiology. While the treatment aim was to improve respiratory-swallowing coordination, other aspects such as tongue-base retraction also improved suggesting a generalisation effect. The study only included 30 participants, and only half of the participants were followed up after one month limiting conclusions regarding the long-term effects of treatment.

Carnaby-Mann and Crary (2008) investigated the use of transcutaneous neuromuscular electrical stimulation in conjunction with the McNeill dysphagia program using a case series design including six patients with dysphagia resulting from stroke, head and neck cancer, and traumatic brain injury. The McNeill dysphagia treatment consisted of hierarchical presentation of bolus volumes and consistencies that the patient was instructed to "swallow hard and fast with a single attempt". A successful swallowing attempt was considered when the bolus was not expectorated and no signs of aspiration were observed by the clinician (signs of aspiration for each patient had been documented during pre-treatment VFSS). While the participants received neuromuscular electrical stimulation during the treatment sessions, this can be considered a type of skill training because of the hierarchical presentation of target boluses which depended on the participant's performance. During each session, depending on the patient's performance, the treating clinician decided whether they would advance to the next level or return to the previous level specific. Four patients had clinically meaningful improved scores on a standardised clinical swallowing exam and a functional oral intake scale. Changes in hyoid and laryngeal elevation were variable across fluid consistencies and bolus volumes; only laryngeal elevation increased for 5ml nectar liquid post therapy. Gains made during treatment were maintained at 6 months post. However, the authors did not provide a detailed description of the intervention that would allow for replication. Furthermore, the combination of treatments makes it impossible to determine which treatment component caused these changes. Crary, Carnaby, Lagorio, and Carvajal (2012) then used the same McNeill treatment protocol with nine patients who had dysphagia due to head and neck cancer radiotherapy treatment, neurological condition or both. While four of the seven patients who were tube dependent had their feeding tubes removed post treatment, physiological changes were variable depending on bolus consistency. For example, hyoid and laryngeal elevation increased significantly only for thin consistencies. However, the authors also did not provide a detailed description of the treatment protocol and the small sample size limited the power of the statistical analysis.

Huckabee, Lamvik, and Jones (2014) utilised low resolution manometry to provide visual biofeedback to 16 patients that presented with dysphagia characterised by mis-sequencing of pharyngeal pressures. The patients were shown a target pattern of manometric waveforms representing a normal swallow and were then able to see the manometric waveforms of their own swallows live on a screen. They were instructed to match their pattern to the target pattern. The pressures generated during swallowing remained unchanged while the duration between pressures generated in the base of tongue region and the laryngeal adductors increased indicating improved temporal coordination between these two events. Eleven patients returned to full oral intake, out of the five that did not return to oral intake, four completed only one week of treatment.

1.2.1.3 sEMG as biofeedback in skill training. Biofeedback frequently utilises EMG (Peper et al., 2009). The EMG signal quantifies the electrical activity that is generated during muscle activation (Reaz, Hussain, & Mohd-Yasin, 2006). The motor neurons generate electrical impulses which travel along the muscle fibres causing them to contract. Because the electrical field that is generated is close to the muscle surface it can be measured, processed, and displayed as a waveform over time (Moritani, Stegeman, & Merletti, 2005; Reaz et al., 2006). The EMG signal can be measured from the skin surface or by inserting a needle into the muscle (Stepp, 2012).

Submental EMG (sEMG) has been used in several studies to either assess swallowing or to provide feedback about swallowing; it has been used either as the sole type of biofeedback or used in conjunction with other types of biofeedback. sEMG most closely represents the activity of the mylohyoid, geniohyoid, genioglossus, and anterior belly of the digastric muscles; temporally activation of these muscles precedes hyoid movement and laryngeal elevation which is one of the first biomechanical events in swallowing (Crary, Carnaby, & Groher, 2006). The sEMG signal is typically plotted as a waveform line along an x-axis representing time and along a y-axis representing amplitude of muscle activity. As muscle activity increases during swallowing, a characteristic peak is generated which provides instant visual feedback about the timing and amplitude of each swallow.

Carnaby-Mann and Crary (2010) compared eight patients who received the McNeill dysphagia treatment protocol (as described previously) with 16 patients who received traditional swallowing therapy but learned the swallowing manoeuvres with sEMG biofeedback. All participants had chronic dysphagia due to head and neck cancer or because of a neurological cause. The study found that both groups had improved functional oral scores post treatment and aspiration was eliminated in 4/6 patients receiving the McNeill dysphagia treatment and in 4/11 patients receiving traditional swallowing therapy.

Additionally, 4/6 who received the McNeill dysphagia treatment and 3/11 patients who received traditional therapy no longer required tube feeding post treatment. However, the patients who received the McNeill dysphagia treatment also received daily mandatory home therapy while this was variable and not monitored for control subjects. The type of therapy the control subjects received and which manoeuvres they learned with sEMG biofeedback was not described. The authors conclude that their findings provide evidence to support the use of the McNeill dysphagia program. However, the study lacked a clear description of the treatment and the treatment comparison protocol and only compared two very small samples of very heterogeneous participants.

Stepp, Britton, Chang, Merati, and Matsuoka (2011) developed a videogame based system that utilised sEMG to provide visual feedback about timing and amplitude of swallowing. The sEMG signal was displayed as an animal character (e.g. a fish) which moved up and down depending on muscle activation. The participants aimed to move the fish to “swallow” the targets that appeared on the screen. The targets appeared at 33%, 66%, and 100% of each participant’s maximal swallowing amplitude, making this both a skill and strength training task. The maximum amplitude was taken from saliva swallows at the beginning of the session; however, the authors did not specify what kind of instructions were given or how many swallows each participant completed. They trialled this system with an 18year old patient who was six years post brainstem stroke and six healthy volunteers. However, neither the patient nor the healthy volunteers were required to swallow to hit the target – they could control muscle activation any way they chose and the electrodes measuring sEMG were placed on the anterior neck region to measure activation of the thyrohyoid, sternohyoid, and omohyoid muscles. The healthy volunteers participated in only one session, while the patient did three sessions in week 1 and another three sessions in week 3. Each session consisted of 10 trials that were 2 minutes long with breaks in between. Both the patient and the healthy volunteers were able to learn to play the game even though the patient presented with severe dysphagia and frequently required suctioning for secretion management. The study did not include any swallowing related outcome measures, but the patient reported better secretion management.

BiSSkIT. Biofeedback in Strength and Skill Training (BiSSkiT) is a software-assisted treatment protocol that was developed for swallowing skill training. The BiSSkiT protocol utilises sEMG as a biofeedback tool. During skill training, the patient aims to place this swallowing peak into a target square. Because the target square changes position after each trial and also changes in size, the patient is constantly challenged to adapt the timing and amplitude of the swallow peak to hit the target. Stepp et al. (2011) placed some of the targets at 100% of the patient's maximal swallowing amplitude. However, in the BiSSkiT protocol the targets are placed within a 30-70% range of the patient's maximum swallowing amplitude to ensure that the task promotes skill rather than strength.

Athukorala, Jones, Sella, and Huckabee (2014) investigated the BiSSkiT training protocol with 10 patients with Parkinson's disease. Patients completed 10 one-hour sessions over two weeks. During each session they completed 100 swallow trials. Temporal aspects of swallowing as measured by sEMG and the timed water swallow and quality of life as measured by the SWAL-QOL questionnaire improved significantly and these improvements were maintained at two weeks post intervention. No significant changes were observed on the time that patients required to chew and swallow solids as measured by the Test of Mastication and Swallowing Solids. However, the study did not include an instrumental outcome measure such as videofluroscopy to detect changes in the swallowing biomechanics and pathophysiology and/or changes in aspiration.

Perry, Sevitz, Curtis, Kuo, and Troche (2018) used the BiSSkiT software application skill training with a patient with multiple system atrophy who developed dysphagia characterised by delayed swallowing, aspiration, and post-swallow pharyngeal residue. The patient completed 6 x1hour sessions over 6 weeks with the BiSSKit software. He also completed home practice consisting of either swallowing "hard" or "soft" in response to prompts given via a videomodule. He reported completing about 60 swallows per week but compliance was not monitored. Accuracy as measured by hitting the target improved. The patient reported that his swallowing improved, and instrumental assessment showed that the delayed swallow and aspiration were eliminated, and post-swallow residue was reduced. The investigators concluded that the patient had learnt to reorganise their swallowing motor patterns which improved swallowing efficiency and safety.

Current BiSSkiT calibration process. Setting targets for intervention and consequently establishing treatment intensity can be difficult, (Baker, 2012) but is an important consideration when applying the principles of neuroplasticity to an intervention (Robbins et al., 2008). During the BiSSkiT training protocol, to ensure that the task is achievable and promotes skill, rather than strength, the target square is placed within a 30-70% range of the patient's maximum swallowing amplitude (i.e. the range of the y-axis). The range of the y-axis is calibrated from the mean amplitude generated during five effortful swallows prior to the training protocol. Maximum strength is measured is by asking the patient to complete five effortful swallowing manoeuvres. However, for patients with swallowing difficulties, effortful swallowing can be a challenging and not always achievable task.

The effortful swallow manoeuvre is typically used as a strengthening task to increase tongue base retraction (Pouderoux & Kahrilas, 1995) and tongue base to posterior pharyngeal wall movement (Fritz, Cerrati, & Fang, 2014; Lazarus, Logemann, Song, Rademaker, & Kahrilas, 2002). The effortful swallow alters normal swallowing parameters resulting in increased oral pressures, longer and higher hyoid excursion, longer laryngeal vestibule closure, delayed onset of pharyngeal pressures and upper esophageal sphincter relaxation, prolonged duration of pharyngeal pressures and upper esophageal sphincter relaxation (Hind, Nicosia, Roecker, Carnes, & Robbins, 2001; Hiss & Huckabee, 2005).

Currently patients receive visual feedback during the calibration phase. External cues can influence the swallowing process; for example, (Daniels et al., 2007) found that verbal cues to swallow a bolus decrease the total swallow duration in healthy individuals. Studies examining cortical control of swallowing have found that visual feedback results in different cortical activation patterns and greater functional connectivity between brain regions involved in swallowing (Humbert & Joel, 2012; Humbert & McLaren, 2014; Kawai et al., 2009). However, the effect of visual feedback during the calibration process on swallowing amplitude has not been investigated.

1.3 Conclusion and aim of research

In summary, while swallowing rehabilitation is beginning to shift from strength to skill training and utilising sEMG as a biofeedback tool, there are inherent challenges in setting the target range so that the task promotes skill rather than strength. Currently, effortful swallows are used to calculate a maximum swallowing amplitude and the target range is set in relation to this maximum amplitude in the BiSSkiT protocol. However, performing this manoeuvre has to be learned and patients with dysphagia may have difficulty performing this manoeuvre correctly and consistently. The current study sought to determine whether normal or effortful swallowing resulted in less variability in healthy individuals and therefore could be used as a calibration task. The current study also examined the effect of visual feedback, i.e. seeing the sEMG signal, on variability and amplitude of swallowing to determine whether visual feedback should be given during the calibration process.

1.3.1 Research Questions. The current study sought to answer the following research questions:

1. Does the swallowing task (normal versus effortful swallowing) affect swallowing amplitude?
2. Does visual feedback (seeing the sEMG signal during swallowing versus not seeing it) during calibration affect swallowing amplitude?
3. Which swallowing task and feedback condition results in the least amount of variability?

Chapter 2 – Method

2.1 Ethics

Ethics consent was granted by the University of Canterbury Human Ethics Committee (HEC 2019/15/LR-PS).

2.2 Design

This methodological study used a two-factor repeated measures design. All participants completed two different swallowing tasks: normal swallowing and effortful swallowing. Each task was performed under two conditions: with and without visual feedback. The order of the conditions was the same for all participants (no visual feedback followed by visual feedback) but the order of the tasks was counterbalanced across participants within each condition. This means that participant 1 started with the normal swallowing task, participant 2 started with the effortful swallowing task and so forth. All participants started with no visual feedback to ensure that their performance during the no visual feedback condition was not influenced by previous exposure to visual feedback.

2.3 Participants

A required sample size of 36 participants based on a small effect size of 0.2 and a power of 0.8 was calculated a-priori using G*Power, a statistical analysis software program (Faul, Erdfelder, Buchner, & Lang, 2009; Faul, Erdfelder, Lang, & Buchner, 2007). Participants had to be aged 18 years or older and able to give informed consent to participate in the study. Participants with self-reported dysphagia or with a neurological condition or injury that could affect their swallowing were excluded (see Appendix 1 and Appendix 2).

2.4 Procedures

All participants provided informed consent prior to participating in the study. Participants attended one session which lasted approximately 20-30 minutes. Participants were seated comfortably in a chair. Before attaching sEMG electrodes, the submental skin was cleansed with an alcohol wipe to optimise skin-electrode impedance and reduce noise in the EMG signal (Clancy, Morin, & Merletti, 2002). Male participants were asked to be clean-shaven to be able to participate in the study. A self-adhesive triode electrode patch was placed under the chin so that the two recording electrodes were aligned with the midline of the submental muscles. The ground electrode was placed laterally (either right or left) to the midline.

All participants completed two tasks (five normal and five effortful swallows) under two conditions (without and with visual feedback). All participants completed 20 swallows in total, with approximately 30 seconds between swallows. Participants were offered breaks and sips of water as required.

2.4.1 Swallowing tasks. For the normal swallowing tasks, participants were instructed to ‘swallow when you are ready’. For the effortful swallowing task, participants were instructed to ‘swallow with as much effort as you can when you are ready’.

2.4.2 Feedback conditions. Each participant first completed a set of effortful and normal swallows without visual feedback. This was achieved by facing the computer monitor displaying the sEMG signal away from the participant so that it was only visible to the experimenter. Each participant completed the remaining two sets with visual feedback; the monitor was turned so that the participant could see the sEMG signal displayed.

2.4.3 sEMG signal processing. The raw sEMG signal was automatically processed by the BiSSkiT software. Artefact in the signal was removed by using the ‘remove DC offset’ function in the software.

2.4.4 Identification of swallowing peak. The researcher conducting the experiment observed the participant swallowing and manually marked the waveform peak that corresponded to each swallow. The swallowing amplitude for each swallow as marked by the researcher was recorded and saved at the end of each session.

Chapter 3 – Results

In total, 36 participants were recruited for the study. One participant was excluded from the data analysis due to a measurement error which could have been due to incomplete contact between the skin and the electrode. Of the 35 participants' whose data were included in the analysis, 27 were female and 8 were male. The mean age was 26.17 years (range=18-44years).

3.1 Task conditions: Amplitude and variability

The individual data measurements for all participants for each swallowing task and feedback conditions are included in Appendix 3. The descriptive data across all participants

Table 1

Amplitude Measurements for All Participants by Feedback Condition and Swallowing Task

Task	Mean	sd	median	max	min
Condition 1 (No visual feedback)					
Effortful	68.59	38.07	63.65	197.83	7.29
Normal	31.17	23.78	24.16	168.71	5.20
Condition 2 (Visual feedback)					
Effortful	81.82	51.14	69.01	281.83	10.29
Normal	31.77	23.82	25.20	185.84	5.41

are summarised in Table 1. Overall, effortful swallowing resulted in a higher amplitude during both feedback conditions.

Figure 1 shows the outliers for each participant per swallowing task and feedback condition. All but one participant had outliers for at least one swallowing task. The difference between mean and median sEMG amplitude suggested that the data was not normally distributed. The asymmetric and varying heights of the lower and upper quartiles also indicate that the data did not follow a normal distribution. Modelling using maximum likelihood estimation showed that homoskedasticity was not met and consequently non-parametric testing was used to investigate interaction between task and feedback condition. A non-parametric Friedman rank sum test of difference among repeated measures was

Table 2

Standard Deviation for the Amplitude across all Participants for Each Condition and Each Swallowing Task.

Task	mean	max	median	min
Condition 1 (No visual feedback)				
Effortful	15.23	59.98	11.55	2.35
Normal	9.58	59.29	6.22	1.84
Condition 2 (Visual feedback)				
Effortful	19.70	53.71	17.08	3.24
Normal	9.80	68.58	5.41	0.89

completed and rendered a Chi-square value of 71.853 which was significant ($p<0.05$) between swallowing tasks but not between feedback conditions.

To explore the variability in task performance Table 2 specifically displays the mean and the range for the standard deviation. Overall, effortful swallowing resulted in a larger standard deviation than normal swallowing, but the coefficient of variation was smaller for the effortful swallowing condition (Table 3).

Table 3

Coefficient of Variation for the Amplitude across all Participants for Each Condition and Each Swallowing Task.

Task	mean	max	median	min
Condition 1 (No visual feedback)				
Effortful	0.23	0.74	0.22	0.05
Normal	0.29	0.64	0.26	0.14
Condition 2 (Visual feedback)				
Effortful	0.24	0.59	0.19	0.07
Normal	0.29	0.94	0.25	0.08

3.2 Feedback conditions: Amplitude and variability

As reported above, the Friedman rank sum test showed no significance difference in amplitude between feedback conditions. The standard deviation for effortful swallowing with visual feedback was slightly larger than for effortful swallowing without visual feedback

(Table 2) but there was no difference in the coefficient of variation between conditions (Table 3).

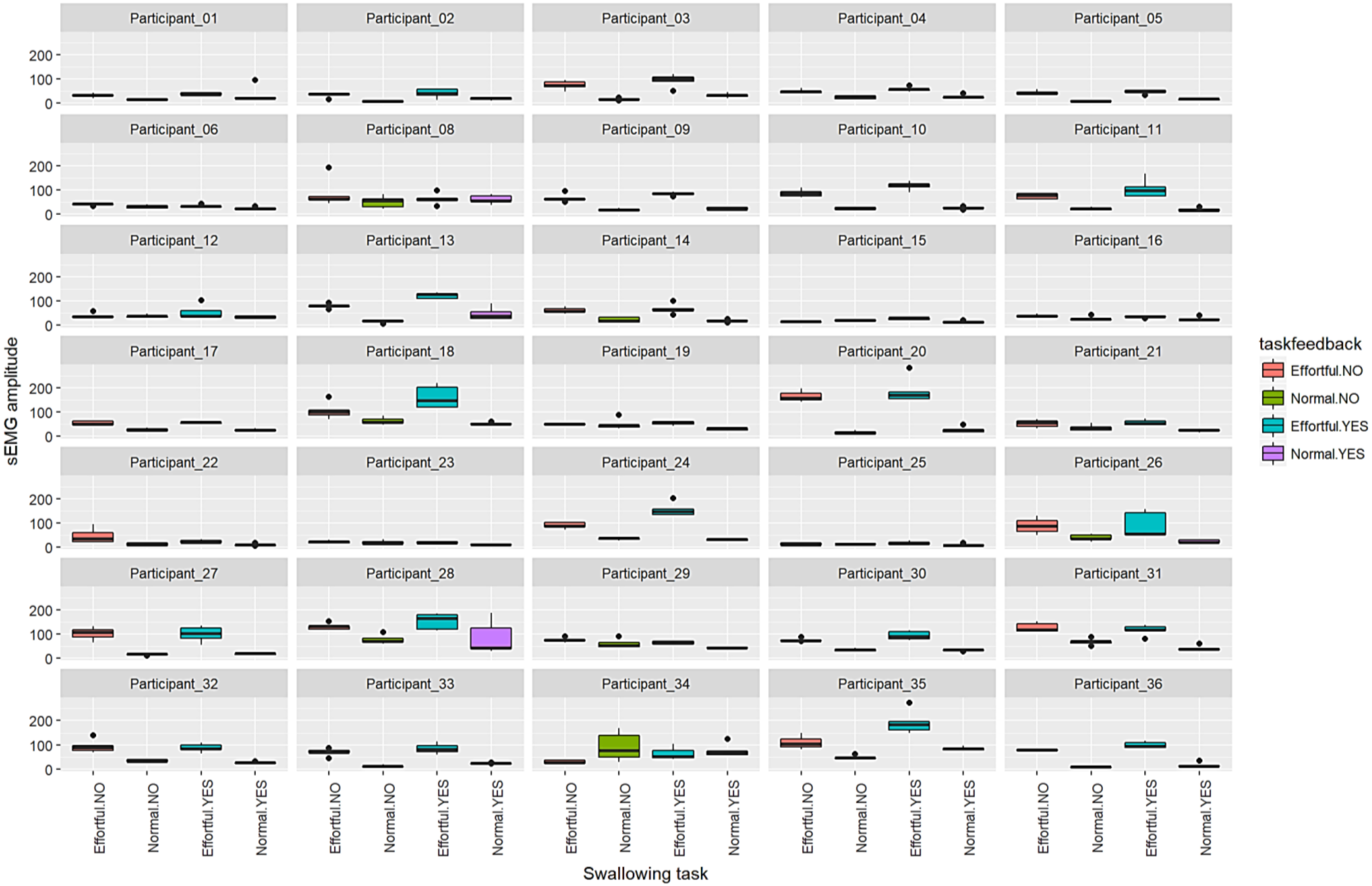

Figure 1. Boxplots of sEMG amplitude per task and feedback condition for each participant.

Chapter 4 – Discussion

Establishing the appropriate target for intervention is often difficult as intensity, frequency, length of intervention and the type of intervention all need to be considered (Baker, 2012). This study sought to improve the calibration process used in the BiSSkiT protocol as patients with dysphagia often have great difficulty completing an effortful swallow. Calibrating an achievable target range is important to ensure that the task promotes skill rather than strength training.

4.1 Effect of feedback condition and swallowing task

This study examined the effect of visual feedback and swallowing task on sEMG amplitude. There was only a difference between swallowing tasks but not feedback conditions. Normal swallowing occurred at approximately 41% of effortful swallowing which is consistent with other findings (Ng, 2018). However, Ng (2018) normalised sEMG readings while the current study used raw sEMG readings, making it difficult to compare findings across studies. Using raw sEMG signals also severely limited the ability to compare measurements across participants in the current study (Halaki & Ginn, 2012). A recent study examined the effect of increasing the load on the submental muscles by using kinesiology taping to restrict movement of the hyolaryngeal complex (Park, Jung, Kim, & Lee, 2020). The authors hypothesized that restricting hyolaryngeal movement would increase the resistance the submental muscles have to overcome during swallowing. The study used sEMG to measure activation of the submental muscles during swallowing. The results suggest that submental muscle activation was significantly higher during the tape condition compared to the no-tape condition. Furthermore, muscle activation increased again significantly when a higher resistance tape was used. Mean sEMG during normal swallowing (µV32.15) was very similar to the current findings (µV31.77). However, even with the higher resistance tape, mean sEMG was lower than during the effortful swallowing condition in the current study.

The presence or absence of visual feedback during the task did not impact on sEMG readings. Maeda et al. (2004) found that drink-related visual stimuli resulted in faster initiation of voluntary swallowing than unrelated visual stimuli but the type of visual stimulus did not impact on swallowing amplitude as measured by sEMG. However, their comparison did not include a swallowing condition without a visual stimulus. The current findings suggest that the presence or absence of visual feedback does not impact on muscle activation as measured by sEMG. This consistent with findings from a recent study examining the effect of visual feedback on muscle activation during an elbow flexion task (Gentil et al., 2017). However, another study found that visual feedback did not impact on EMG amplitude variability during a finger pinching task it did so on during a jaw clenching task (Iida et al., 2013). A possible explanation for this discrepancy is that these studies examined different tasks that require different muscles and specific patterns of muscle activation and are influenced in different ways by visual stimuli.

4.2 Variability within swallowing tasks

The current study sought to identify the swallowing task that would be the most consistent and therefore the most appropriate to use during the calibration process. The coefficient of variation represents the standard deviation in relation to the mean; a greater coefficient of variation suggest greater variability of measurements (Norman & Streiner, 2014). The task with the smallest mean coefficient of variation and median coefficient of variation was the effortful swallowing task. However, the mean and median for effortful swallowing was also more than double the mean and median of normal swallowing. Therefore, the coefficient of variation for effortful swallowing is likely smaller because the measurements are higher. Analysis of the boxplots of individual participants' data showed that normal swallowing had fewer outliers and lower IQRs suggesting that the normal swallowing task had less variability than the effortful swallowing task.

The number of outliers shows the great variability in both normal and effortful swallowing. For example, one participant's (participant 18) minimum amplitude during effortful swallowing was 70.40μV while the maximum was 161.41μV (more than double the minimum). Ding, Logemann, Larson, and Rademaker (2003) also found large variability of sEMG swallowing amplitudes within healthy individuals even when controlling for bolus size and restricting head movements during swallowing.

Many of the participants required sips of water during the tasks suggesting that perhaps they did not have sufficient saliva to initiate a swallow. Lack of saliva and a dry mouth may have impacted on the effort required to initiate both a normal and an effortful swallow. Healthy individuals complete a spontaneous saliva swallow approximately once per minute (Crary, Sura, & Carnaby, 2013; Pehlivan et al., 1996). To ensure that the normal swallowing task was as natural as possible, the interval between swallows should have been a minimum of 60 seconds instead of 30 seconds. The amount of saliva swallowed could not be measured or influenced and as bolus size impacts muscle activation the differing amounts of saliva may have also contributed to the variability within tasks.

The variability during effortful swallows could also be due to inconsistent performance of the manoeuvre by the participants. The participants were not given training in performing an effortful swallow but just instructed to "swallow hard". However, effortful swallows can be executed in different ways. Huckabee and Steele (2006) found that when healthy individuals were instructed to focus on tongue to palate contact during effortful swallowing this resulted in a higher sEMG amplitude measurement than a focus on no tongue to palate contact. The impact of intrinsic lingual muscle activity on measurements was not controlled for in the current study and could have influenced measurements as participants may have even been exploring and trying to ‘learn’ this new movement i.e. using tongue to palate contact inconsistently.

4.3 Calibration process for skill training

sEMG can be a valuable tool for providing biofeedback in skill training for swallowing rehabilitation. Currently, the BiSSkiT training protocol utilizes sEMG to challenge the patient to control both the amplitude and timing of swallowing.

The effortful swallow task resulted in larger variability in swallowing amplitudes compared to the normal swallowing task. This finding suggests that normal swallowing should be used for calibrating the target range for skill training. This could take the form of placing the target within the range of normal swallows or within a certain distance from the average of five normal swallows. Currently, the target is set between 30-70% of effortful swallowing. However, considering the large standard deviation and the large range for normal swallowing, it is very difficult to determine the range the target should be in. The observed variability suggests that perhaps the timing aspect during skill training is more important than the amplitude aspect.

4.4 Limitations

The size of screen was automatically adjusted depending on the highest sEMG reading. Participants who started with no visual effortful swallowing and then were given visual feedback during the next set of swallows and asked to perform normal swallows would have perhaps felt that their normal swallow appeared small compared to the screen size and then subconsciously adjusted their swallowing.

Even though the required sample size was calculated a-priori and the required number was recruited, one participant was excluded from the analysis. The sample consisted mostly of young female participants which makes it difficult to generalise findings to the overall population.

4.5 Conclusion

The presence or absence of visual feedback did not impact on sEMG measurements. However, there was great variability within participants during both normal and effortful swallowing. Considering the greater variability within effortful swallows, the challenge of executing the effortful swallowing manoeuvre correctly, and the inherent difficulties in measuring a ‘true’ effortful swallow, the target range during skill training with the BiSSkiT protocol should be calibrated based on the range of normal swallowing.

4.6 Future directions

Future research should focus on establishing a range for normal saliva swallowing so this can be utilised in the calibration process for skill training using BiSSkiT and investigate how spontaneous swallowing tasks impact amplitude as measured by sEMG. Measuring the sEMG amplitude of unconscious saliva swallows and comparing these to cued normal swallows may provide more insight into the variability of swallowing.

References

Alvarez-Berdugo, D., Rofes, L., Casamitjana, J. F., Padrón, A., Quer, M., & Clavé, P. (2016). Oropharyngeal and laryngeal sensory innervation in the pathophysiology of swallowing disorders and sensory stimulation treatments. *Annals of the New York Academy of Sciences, 1380,* 104-120. doi:10.1111/nyas.13150

Arnold, M., Liesirova, K., Broeg-Morvay, A., Meisterernst, J., Schlager, M., Mono, M. L., . . . Sarikaya, H. (2016). Dysphagia in acute stroke: Incidence, burden and impact on clinical outcome. *PLoS ONE, 11*(2). doi:10.1371/journal.pone.0148424

Athukorala, R. P., Jones, R. D., Sella, O., & Huckabee, M. L. (2014). Skill training for swallowing rehabilitation in patients with Parkinson's disease. *Archives of Physical Medicine and Rehabilitation, 95*(7), 1374-1382. doi:10.1016/j.apmr.2014.03.001

Attrill, S., White, S., Murray, J., Hammond, S., & Doeltgen, S. (2018). Impact of oropharyngeal dysphagia on healthcare cost and length of stay in hospital: A systematic review. *BMC Health Services Research, 18*(1). doi:10.1186/s12913-018-3376-3

Baker, E. (2012). Optimal intervention intensity. *International Journal of Speech-Language Pathology, 14*(5), 401-409. doi:10.3109/17549507.2012.700323

Belafsky, P. C., & Lintzenich, C. R. (2013). Development, anatomy, and physiology of the pharynx. In R. Shaker (Ed.), *Principles of deglutition: A multidisciplinary text for swallowing and its disorders* (pp. 165-173): Springer New York.

Burkhead, L. M., Sapienza, C. M., & Rosenbek, J. C. (2007). Strength-training exercise in dysphagia rehabilitation: Principles, procedures, and directions for future research. *Dysphagia, 22*(3), 251-265. doi:10.1007/s00455-006-9074-z

Carnaby-Mann, G. D., & Crary, M. A. (2008). Adjunctive neuromuscular electrical stimulation for treatment-refractory dysphagia. *Annals of Otology, Rhinology & Laryngology, 117*(4), 279-287. doi:10.1177/000348940811700407

Carnaby-Mann, G. D., & Crary, M. A. (2010). McNeill dysphagia therapy program: A case-control study. *Archives of Physical Medicine and Rehabilitation, 91*(5), 743-749. doi:https://doi.org/10.1016/j.apmr.2010.01.013

Clancy, E. A., Morin, E. L., & Merletti, R. (2002). Sampling, noise-reduction and amplitude estimation issues in surface electromyography. *Journal of Electromyography and Kinesiology, 12*(1), 1-16. doi:https://doi.org/10.1016/S1050-6411(01)00033-5

Crary, M. A., Carnaby, G. D., & Groher, M. E. (2006). Biomechanical correlates of surface electromyography signals obtained during swallowing by healthy adults. *Journal of Speech, Language, and Hearing Research, 49*(1), 186-193. doi:10.1044/1092-4388(2006/015)

Crary, M. A., Carnaby, G. D., Lagorio, L. A., & Carvajal, P. J. (2012). Functional and physiological outcomes from an exercise-based dysphagia therapy: A pilot investigation of the mcneill dysphagia therapy program. *Archives of Physical Medicine and Rehabilitation, 93*(7), 1173-1178. doi:10.1016/j.apmr.2011.11.008

Crary, M. A., Sura, L., & Carnaby, G. (2013). Validation and demonstration of an isolated acoustic recording technique to estimate spontaneous swallow frequency. *Dysphagia, 2*(1), 86-94.

Daniels, S. K., Schroeder, M. F., DeGeorge, P. C., Corey, D. M., & Rosenbek, J. C. (2007). Effects of verbal cue on bolus flow during swallowing. *American Journal of Speech-Language Pathology, 16*(2), 140-147. doi:doi:10.1044/1058-0360(2007/018)

Ding, R., Logemann, J. A., Larson, C. R., & Rademaker, A. W. (2003). The effects of taste and consistency on swallow physiology in younger and older healthy individuals: A surface electromyographic study. *Journal of Speech, Language, and Hearing Research, 46*(4), 977-989. doi:10.1044/1092-4388(2003/076)

Dodds, W. J., Stewart, E. T., & Logemann, J. A. (1990). Physiology and radiology of the normal oral and pharyngeal phases of swallowing. *American Journal of Roentgenology, 154*(5), 953-963. doi:10.2214/ajr.154.5.2108569

Easterling, C. (2017). 25 Years of dysphagia rehabilitation: What have we done, what are we doing, and where are we going? *Dysphagia, 32*(1), 50-54. doi:10.1007/s00455-016-9769-8

Ertekin, C., & Aydogdu, I. (2003). Neurophysiology of swallowing. *Clinical Neurophysiology, 114*(12), 2226-2244. doi:10.1016/S1388-2457(03)00237-2

Eslick, G. D., & Talley, N. J. (200). Dysphagia: Epidemiology, risk factors and impact on quality of life - a population based study. *Alimentary Pharmaclogy & Therapeutics, 27*, 971-979.

Faul, F., Erdfelder, E., Buchner, A., & Lang, A.-G. (2009). Statistical power analyses using G*Power 3.1: Tests for correlation and regression analyses. *Behavior Research Methods, 41*, 1149-1160.

Faul, F., Erdfelder, E., Lang, A.-G., & Buchner, A. (2007). G*Power 3: A flexible statistical power analysis program for the social, behavioral, and biomedical sciences. *Behavior Research Methods, 39*, 175-191.

Fritz, M., Cerrati, E., & Fang, Y. (2014). Magnetic resonance imaging of the effortful swallow. *Annals of Otology, Rhinology & Laryngology, 123*(11), 786-790.

Gassert, R. B., & Pearson, W. G., Jr. (2016). Evaluating muscles underlying tongue base retraction in deglutition using muscular functional magnetic resonance imaging (mfMRI). *Magnetic Resonance Imaging, 34*(2), 204-208. doi:10.1016/j.mri.2015.10.029

Gentil, P., Bottaro, M., Noll, M., Werner, S., Vasconcelos, J. C., Seffrin, A., & Campos, M. H. (2017). Muscle activation during resistance training with no external load - effects of training status, movement velocity, dominance, and visual feedback. *Physiology & Behavior, 179*, 148-152. doi:https://doi.org/10.1016/j.physbeh.2017.06.004

Gonzalez-Fernandez, M., Ottenstein, L., Atanelov, L., & Christian, A. B. (2013). Dysphagia after stroke: An overview. *Current Physical Medicine and Rehabilitation Reports, 1*(3), 187-196. doi:10.1007/s40141-013-0017-y

Halaki, M., & Ginn, K. (2012). Normalization of EMG signals: To normalize or not to nrmalize and what to normalize to? In G. R. Naik (Ed.), *Computational Intelligence in Electromyography Analysis - A Perspective on Current Applications and Future Challenges* (pp. 175-194): IntechOpen.

Hennessy, M., & Goldenberg, D. (2016). Surgical anatomy and physiology of swallowing. *Operative Techniques in Otolaryngology, 27*, 60-66.

Hind, J. A., Nicosia, M. A., Roecker, E. B., Carnes, M. L., & Robbins, J. (2001). Comparison of effortful and noneffortful swallows in healthy middle-aged and older adults. *Archives of Physical Medicine and Rehabilitation, 82*(12), 1661-1665. doi:10.1053/apmr.2001.28006

Hiss, S. G., & Huckabee, M. L. (2005). Timing of pharyngeal and upper esophageal sphincter pressures as a function of normal and effortful swallowing in young healthy adults. *Dysphagia, 20*(2), 149-156. doi:10.1007/s00455-005-0008-y

Hosseini, P., Tadavarthi, Y., Bonnie, M. H., & Pearson, W. G., Jr. (2019). Functional Modules of Pharyngeal Swallowing Mechanics. *Laryngoscope Investigative Otolaryngology, 4*(3), 341-346. doi:http://dx.doi.org/10.1002/lio2.273

Huckabee, M. L., & Hughes, L. (2013). Compensatory management and treatment in dysphagia. In R. Shaker, P. C. Belafsky, G. N. Postma, & C. Easterling (Eds.), *Principles of deglutition: A multidisciplinary text for swallowing and its disorders* (pp. 785-797). New York, NY: Springer.

Huckabee, M. L., Lamvik, K., & Jones, R. (2014). Pharyngeal mis-sequencing in dysphagia: Characteristics, rehabilitative response, and etiological speculation. *Journal of the Neurological Sciences*, *343*(1-2), 153-158. doi:10.1016/j.jns.2014.05.064

Huckabee, M. L., & Steele, C. M. (2006). An analysis of lingual contribution to submental surface electromyographic measures and pharyngeal pressure during effortful swallow. *Archives of Physical Medicine and Rehabilitation*, *7*, 1067-1072.

Humbert, I. A., & Joel, S. (2012). Tactile, gustatory, and visual biofeedback stimuli modulate neural substrates of deglutition. *NeuroImage*, *59*, 1485-1490.

Humbert, I. A., & McLaren, D. G. (2014). Differential psychophysiological interactions of insular subdivisions during varied oropharyngeal swallowing tasks. *Physiological Reports*, *2*(3). doi:10.1002/phy2.239

Iida, T., Komiyama, O., Obara, R., Baad-Hansen, L., Kawara, M., & Svensson, P. (2013). Influence of visual feedback on force: EMG curves from spinally innervated versus trigeminally innervated muscles. *Archives of Oral Biology*, *58*(3), 331-339. doi:https://doi.org/10.1016/j.archoralbio.2012.12.005

Inokuchi, H., González-Fernández, M., Matsuo, K., Brodsky, M. B., Yoda, M., Taniguchi, H., . . . Palmer, J. B. (2014). Electromyography of swallowing with fine wire intramuscular electrodes in healthy human: Activation sequence of selected hyoid muscles. *Dysphagia*, *29*(6), 713-721. doi:10.1007/s00455-014-9566-1

Jean, A. (2001). Brain stem control of swallowing: Neuronal network and cellular mechanisms. *Physiological Reviews*, *81*(2), 929-969. doi:10.1152/physrev.2001.81.2.929

Johnson, D. N., Herring, H. J., & Daniels, S. K. (2014). Dysphagia management in stroke rehabilitation. *Current Physical Medicine and Rehabilitation Reports, 2*(4), 207-218. doi:10.1007/s40141-014-0059-9

Kawai, T., Watanabe, Y., Tonogi, M., Yamane, G., Abe, S., Yamada, Y., & Callan, A. (2009). Visual and auditory stimuli associated with swallowing: An fMRI study. *The Bulletin of Tokyo Dental College, 50*(4), 169-181.

Langmore, S. E., & Pisegna, J. M. (2015). Efficacy of exercises to rehabilitate dysphagia: A critique of the literature. *International Journal of Speech-Language Pathology, 17*(3), 222-229. doi:10.3109/17549507.2015.1024171

Lazarus, C. L., Logemann, J. A., Song, C. W., Rademaker, A. W., & Kahrilas, P. J. (2002). Effects of voluntary maneuvers on tongue base function for swallowing. *Folia Phoniatrica et Logopaedica, 54*(4), 171-176.

Leonard, R., Kendall, K. A., & McKenzie, S. (2004). Structural displacements affecting pharyngeal constriction in nondysphagic elderly and nonelderly adults. *Dysphagia, 19*(2), 133-141. doi:10.1007/s00455-003-0508-6

Leopold, N. A., & Kagel, M. C. (1997). Dysphagia-ingestion or deglutition?: A proposed paradigm. *Dysphagia, 12*(4), 202-206. doi:10.1007/pl00009537

Maeda, K., Ono, T., Otsuka, R., Ishiwata, Y., Kuroda, T., & Ohyama, K. (2004). Modulation of voluntary swallowing by visual inputs in humans. *Dysphagia, 19*(1), 1-6. doi:10.1007/s00455-003-0023-9

Martin-Harris, B., McFarland, D., Hill, E. G., Strange, C. B., Focht, K. L., Wan, Z., . . . McGrattan, K. (2015). Respiratory-swallow training in patients with head and neck cancer. *Archives of Physical Medicine and Rehabilitation, 96*(5), 885-893. doi:10.1016/j.apmr.2014.11.022

Matsuo, K., Hiiemae, K. M., & Palmer, J. B. (2005). Cyclic motion of the soft palate in feeding. *Journal of Dental Research, 84*(1), 39.

Matsuo, K., & Palmer, J. B. (2008). Anatomy and physiology of feeding and swallowing: Normal and abnormal. *Phys Med Rehabil Clin N Am, 19*(4), 691-707.

Matsuo, K., & Palmer, J. B. (2009). Coordination of mastication, swallowing and breathing. *Japanese Dental Science Review, 45*(1), 31-40. doi:https://doi.org/10.1016/j.jdsr.2009.03.004

Miles, A., & Allen, J. E. (2015). Management of oropharyngeal neurogenic dysphagia in adults. *Current Opinion in Otolaryngology and Head and Neck Surgery, 23*(6), 433-439. doi:10.1097/MOO.0000000000000206

Miller, A. J. (2008). The neurobiology of swallowing and dysphagia. *Developmental Disabilities Research Reviews, 14*(2), 77-86. doi:10.1002/ddrr.12

Molfenter, S. M., & Steele, C. M. (2012). Temporal variability in the deglutition literature. *Dysphagia, 27*(2), 162-177. doi:10.1007/s00455-012-9397-x

Moritani, T., Stegeman, D., & Merletti, R. (2005). Basic physiology and biophysics of EMG signal generation. In R. Merletti & P. Parker (Eds.), *Electromyography: Physiology, Engineering, and Noninvasive Applications* (Vol. 11, pp. 1-25). Hoboken, NJ, USA: John Wiley & Sons.

Nam, H. S., Oh, B.-M., & Han, T. R. (2015). Temporal characteristics of hyolaryngeal structural movements in normal swallowing. *The Laryngoscope, 125*(9), 2129-2133. doi:10.1002/lary.25229

Ng, K. (2018). *Clinical classification of strength and skill impairments in neurogenic dysphagia.* (Doctoral Thesis). University of Canterbury, Christchurch, New Zealand. Retrieved from http://hdl.handle.net/10092/16404

Nicosia, M. A., Hind, J. A., Roecker, E. B., Carnes, M., Doyle, J., Dengel, G. A., & Robbins, J. (2000). Age effects on the temporal evolution of isometric and swallowing pressure. *Journals of Gerontology, 55*(11), M634-M640. doi:10.1093/gerona/55.11.M634

Norman, G. R., & Streiner, D. L. (2014). *Biostatistics: The bare essentials*(4 ed.).

Park, J.-S., Jung, Y.-J., Kim, H.-H., & Lee, G. (2020). A novel method using kinesiology taping for the activation of suprahyoid muscles in healthy adults: A preliminary research. *Dysphagia, 35*(4), 636-642. doi:10.1007/s00455-019-10071-4

Patel, D. A., Krishnaswami, S., Steger, E., Conover, E., Vaezi, M. F., Ciucci, M. R., & Francis, D. O. (2018). Economic and survival burden of dysphagia among inpatients in the United States. *Diseases of the Esophagus, 31*(1). doi:10.1093/dote/dox131

Pearson, W. G., Hindson, D. F., Langmore, S. E., & Zumwalt, A. C. (2013). Evaluating swallowing muscles essential for hyolaryngeal elevation by using muscle functional magnetic resonance imaging. *International Journal of Radiation Oncology, Biology, Physics, 85*(3), 735-740. doi:https://doi.org/10.1016/j.ijrobp.2012.07.2370

Pearson, W. G., Jr., Taylor, B. K., Blair, J., & Martin-Harris, B. (2016). Computational analysis of swallowing mechanics underlying impaired epiglottic inversion. *Laryngoscope, 126*(8), 1854-1858. doi:10.1002/lary.25788

Pedersen, A. M. L., Sørensen, C. E., Proctor, G. B., Carpenter, G. H., & Ekström, J. (2018). Salivary secretion in health and disease. *Journal of Oral Rehabilitation, 45*(9), 730-746. doi:10.1111/joor.12664

Pehlivan, M., Yuceyar, N., Ertekin, C., Celebi, G., Ertas, M., Kalayci, T., & Aydogdu, I. (1996). An electronic device measuring the frequency of spontaneous swallowing: Digital phagometer. *Dysphagia, 11*(4), 259-264.

Peper, E., Harvey, R., & Takebayashi, N. (2009). Biofeedback an evidence based approach in clinical practice. *Japanese Journal of Biofeedback Research, 36*(1), 3-10.

Perlman, A. L., Schultz, J. G., & VanDaele, D. J. (1993). Effects of age, gender, bolus volume, and bolus viscosity on oropharyngeal pressure during swallowing. *Journal of Applied Physiology, 75*(1), 33.

Perry, S. E., Sevitz, J. S., Curtis, J. A., Kuo, S.-H., & Troche, M. S. (2018). Skill training resulted in improved swallowing in a person with multiple system atrophy: An endoscopy study. *Movement Disorders Clinical Practice, 5*(4), 451-452. doi:10.1002/mdc3.12628

Pouderoux, P., & Kahrilas, P. J. (1995). Deglutitive tongue force modulation by volition, volume, and viscosity in humans. *Gastroenterology, 108*(5), 1418-1426.

Reaz, M. B. I., Hussain, M. S., & Mohd-Yasin, F. (2006). Techniques of EMG signal analysis: Detection, processing, classification and applications. *Biological Procedures Online, 8*(1), 11-35. doi:10.1251/bpo115

Robbins, J., Butler, S. G., Daniels, S. K., Gross, R. D., Langmore, S., Lazarus, C. L., . . . Rosenbek, J. C. (2008). Swallowing and dysphagia rehabilitation: Translating principles of neural plasticity into clinically oriented evidence. *Journal of Speech, Language, and Hearing Research, 51*(1), S276-S300. doi:10.1044/1092-4388(2008/021)

Robbins, J., Gangnon, R. E., Theis, S. M., Kays, S. A., Hewitt, A. L., & Hind, J. A. (2005). The effects of lingual exercise on swallowing in older adults. *Journal of the American Geriatrics Society, 53*(9), 1483-1489. doi:10.1111/j.1532-5415.2005.53467.x

Robbins, J., Kays, S. A., Gangnon, R. E., Hind, J. A., Hewitt, A. L., Gentry, L. R., & Taylor, A. J. (2007). The effects of lingual exercise in stroke patients with dysphagia.

Archives of Physical Medicine and Rehabilitation, 88(2), 150-158. doi:10.1016/j.apmr.2006.11.002

Schwertner, R. W., Garand, K. L., & Pearson, J. W. G. (2016). A novel imaging analysis method for capturing pharyngeal constriction during swallowing. *Journal of Imaging Science, 1*(1).

Shaw, D., Cook, I. J., Gabb, M., Holloway, R. H., Simula, M. E., Panagopoulos, V., & Dent, J. (1995). Influence of normal aging on oral-pharyngeal and upper esophageal sphincter function during swallowing. *American Journal of Physiology - Gastrointestinal and Liver Physiology, 268*(3), 389-396. doi:10.1152/ajpgi.1995.268.3.G389

Shaw, S. M., & Martino, R. (2013). The normal swallow: Muscular and neurophysiological control. *Otolaryngologic Clinics of North America, 46*(6), 937-956. doi:10.1016/j.otc.2013.09.006

Shaw, S. M., Martino, R., Mahdi, A., Sawyer, F. K., Mathur, S., Hope, A., & Agur, A. M. (2017). Architecture of the suprahyoid muscles: A volumetric musculoaponeurotic analysis. *Journal of Speech, Language, and Hearing Research, 60*(10), 2808-2818. doi:10.1044/2017_JSLHR-S-16-0277

Shune, S. E., Moon, J. B., & Goodman, S. S. (2016). The Effects of Age and Preoral Sensorimotor Cues on Anticipatory Mouth Movement During Swallowing. *Journal of Speech, Language and Hearing Research (Online), 59*(2), 1-11. doi:http://dx.doi.org/10.1044/2015_JSLHR-S-15-0138

Smaoui, S., Langridge, A., & Steele, C. M. (2019). The effect of lingual resistance training interventions on adult swallow function: A systematic review. *Dysphagia*. doi:10.1007/s00455-019-10066-1

Steele, C. M., Bailey, G. L., Polacco, R. E. C., Hori, S. F., Molfenter, S. M., Oshalla, M., & Yeates, E. M. (2013). Outcomes of tongue-pressure strength and accuracy training for dysphagia following acquired brain injury. *International Journal of Speech-Language Pathology, 15*(5), 492-502. doi:10.3109/17549507.2012.752864

Stepp, C. E. (2012). Surface electromyography for speech and swallowing systems: Measurement, analysis, and interpretation. *Journal of Speech, Language, and Hearing Research, 55*, 1232-1246. doi:10.1044/1092-4388(2011/11-0214)

Stepp, C. E., Britton, D., Chang, C., Merati, A. L., & Matsuoka, Y. (2011). *Feasibility of game-based electromyographic biofeedback for dysphagia rehabilitation.* Paper presented at the 5th International IEEE/EMBS Conference on Neural Engineering.

Vose, A., & Humbert, I. A. (2018). "Hidden in plain sight": A descriptive review of laryngeal vestibule closure. *Dysphagia*. doi:10.1007/s00455-018-9928-1

Wakabayashi, H., Matsushima, M., Momosaki, R., Yoshida, S., Mutai, R., Yodoshi, T., . . . Ichikawa, H. (2018). The effects of resistance training of swallowing muscles on dysphagia in older people: A cluster, randomized, controlled trial. *Nutrition, 48*, 111-116. doi:https://doi.org/10.1016/j.nut.2017.11.009

Yano, J., Yamamoto-Shimizu, S., Yokoyama, T., Kumakura, I., Hanayama, K., & Tsubahara, A. (2019). Effects of tongue-strengthening exercise on the geniohyoid muscle in young healthy adults. *Dysphagia*. doi:10.1007/s00455-019-10011-2

Appendix 1

Department: Department of Communication Disorders/ Rose Centre for Stroke Recovery and Research
Telephone: +64 3 369 2385
Email: Rebecca.streith@pg.canterbury.ac.nz
15.04.2019
HEC Ref: HEC 2019/15/LR-PS

BiSSkiT Calibration Study
Information Sheet for Participants

My name is Rebecca Streith and I'm a PhD candidate at the Rose Centre for Stroke Recovery and Research at the University of Canterbury under the supervision of Professor Maggie-Lee Huckabee.

My PhD research focuses on swallowing rehabilitation for adults. Traditionally, rehabilitation for swallowing has involved strength training. An emerging approach to swallowing rehabilitation is skill training which focuses on increasing the timing, precision, and coordination of the muscles involved in swallowing. Because swallowing is difficult to visualise, the Rose Centre has developed an application called BiSSkiT which utilises surface electromyography to provide visual feedback about swallowing to patients. Surface electromyography is a non-invasive procedure that measures the electric activity of muscles at rest and during movement. Because the muscles under the chin play an important role in swallowing, BiSSkiT measures their activity and displays this activity as a line on a screen. The line moves up or down as muscle activity increases or decreases and forms a characteristic peak during swallowing. During skill training, patients aim to hit a moving target with this peak. This research study will examine how the screen range is best calibrated before training because the range of the screen plays an important role in making the training tasks achievable for patients.

If you choose to take part in this study, your involvement in this project will require that you attend one session which will last approximately 20-30 minutes. You will be seated comfortably in a chair and a sticky patch with electrodes will be attached to the skin area under your chin. If you have a beard you will be asked to shave the area under your chin before participating in the study. Before attaching the sticky patch the skin area under your chin will also be wiped with an alcohol wipe. You will then be asked to do five swallows (approximately one every 30 seconds) under four different conditions. This means you will be asked to do a total of 20 swallows. You will be offered breaks and sips of water in-between the four conditions.

There are no known risks associated with the performance of the tasks and application of the procedures.

Participation is voluntary and you have the right to withdraw at any stage without penalty. You may ask for your raw data to be returned to you or destroyed at any point. If you withdraw, I will remove information relating to you. However, once analysis of raw data starts, it will become increasingly difficult to remove the influence of your data on the results.

The results of the project may be published, but you may be assured of the complete confidentiality of data gathered in this investigation: your identity will not be made public without your prior consent. To ensure anonymity and confidentiality, your data will be de-identified and stored securely in password protected electronic form at the Rose Centre for Stroke Recovery and Research at the University of Canterbury. It will be kept for ten years and then destroyed. It is likely that the data collected will be published as part of a thesis. A thesis is a public document and will be available through the UC Library.

If you would like to receive a copy of the summary of results of the project, please indicate this to the researcher on the consent form and provide your email address.

The project is being carried out as part of a PhD research project by Rebecca Streith under the supervision of Professor Maggie-Lee Huckabee, who can be contacted by emailing maggie-lee.huckabee@canterbury.ac.nz. She will be pleased to discuss any concerns you may have about participation in the project.

This project has been reviewed and approved by the University of Canterbury Human Ethics Committee, and participants should address any complaints to The Chair, Human Ethics Committee, University of Canterbury, Private Bag 4800, Christchurch (human-ethics@canterbury.ac.nz).

If you agree to participate in the study, you are asked to complete the consent form and return it to the researcher in person before participating in the study.

Appendix 2

Department: Department of Communication Disorders/ Rose Centre for Stroke Recovery and Research
Telephone: +64 3 369 2385
Email: rebecca.streith@pg.canterbury.ac.nz

BiSSkiT Calibration Study
Consent Form for Participants

- ☐ I have been given a full explanation of this project and have had the opportunity to ask questions.
- ☐ I understand what is required of me if I agree to take part in the research.
- ☐ I understand that participation is voluntary and I may withdraw at any time without penalty. Withdrawal of participation will also include the withdrawal of any information I have provided should this remain practically achievable.
- ☐ I understand that any information or opinions I provide will be kept confidential to the researcher and their supervisor and that any published or reported results will not identify the participants. I understand that a thesis is a public document and will be available through the UC Library.
- ☐ I understand that all data collected for the study will be kept in locked and secure facilities and/or in password protected electronic form and will be destroyed after ten years.
- ☐ I understand the risks associated with taking part and how they will be managed.
- ☐ I understand that I can contact the researcher Rebecca Streith or supervisor Professor Maggie-Lee Huckabee for further information. If I have any complaints, I can contact the Chair of the University of Canterbury Human Ethics Committee, Private Bag 4800, Christchurch (human-ethics@canterbury.ac.nz)
- ☐ I would like a summary of the results of the project.
- ☐ By signing below, I agree to participate in this research project.

Name:__________________________Signed:____________________________Date:___________

☐ I would like a summary of results when prepared. Please email to:

Email address *(for report of findings, if applicable)*:

____

Please return this form in person to the researcher Rebecca Streith before participating in the study.

Appendix 3

Table 1

Descriptive statistics for each participant across feedback condition and swallowing task.

Feedback	Task	Participant	mean	SD	median	max	min	CV	IQR
NO	Effortful	01	32.87	7.75	33.87	42.87	21.87	0.24	6.00
NO	Effortful	02	34.92	11.28	38.32	43.32	15.32	0.32	5.00
NO	Effortful	03	74.49	19.01	73.29	95.29	47.29	0.26	22.00
NO	Effortful	04	49.37	8.09	47.37	62.37	42.37	0.16	8.00
NO	Effortful	05	43.08	9.48	41.68	57.68	32.68	0.22	8.00
NO	Effortful	06	41.11	4.18	42.11	45.11	34.11	0.10	2.00
NO	Effortful	08	86.98	59.98	62.78	192.78	45.78	0.69	14.00
NO	Effortful	09	67.56	17.26	62.56	96.56	50.56	0.26	5.00
NO	Effortful	10	87.22	15.39	85.82	109.82	71.82	0.18	19.00
NO	Effortful	11	74.97	12.36	77.57	87.57	61.57	0.16	23.00
NO	Effortful	12	38.15	10.83	34.75	56.75	29.75	0.28	6.00
NO	Effortful	13	79.20	9.92	79.20	93.20	65.20	0.13	2.00
NO	Effortful	14	61.41	11.55	58.01	77.01	48.01	0.19	14.00

Table 1

Descriptive statistics for each participant across feedback condition and swallowing task.

Feedback	Task	Participant	mean	SD	median	max	min	CV	IQR
NO	Effortful	15	14.58	2.35	15.58	16.58	11.58	0.16	4.00
NO	Effortful	16	39.01	5.17	38.21	47.21	34.21	0.13	5.00
NO	Effortful	17	52.86	9.24	50.46	63.46	42.46	0.17	15.00
NO	Effortful	18	105.00	34.50	99.40	161.40	70.40	0.33	21.00
NO	Effortful	19	49.33	4.06	49.33	53.33	44.33	0.08	7.00
NO	Effortful	20	165.03	22.40	157.83	197.83	141.83	0.14	26.00
NO	Effortful	21	51.90	14.83	54.90	68.90	32.90	0.29	21.00
NO	Effortful	22	46.56	34.67	35.31	95.31	20.31	0.74	36.75
NO	Effortful	23	21.96	5.67	22.16	30.16	16.16	0.26	7.00
NO	Effortful	24	89.22	12.52	86.02	102.02	72.02	0.14	16.00
NO	Effortful	25	12.29	4.30	10.29	17.29	7.29	0.35	6.00
NO	Effortful	26	87.95	32.06	86.75	128.75	50.75	0.36	46.00
NO	Effortful	27	100.95	26.03	107.55	130.55	63.55	0.26	28.00
NO	Effortful	28	130.04	13.65	131.84	150.84	115.84	0.10	12.00
NO	Effortful	29	75.20	9.63	73.80	89.80	63.80	0.13	7.00

Table 1

Descriptive statistics for each participant across feedback condition and swallowing task.

Feedback	Task	Participant	mean	SD	median	max	min	CV	IQR
NO	Effortful	30	74.73	6.47	72.13	86.13	70.13	0.09	1.00
NO	Effortful	31	126.35	17.98	116.55	150.55	111.55	0.14	28.00
NO	Effortful	32	94.01	27.56	89.41	139.41	69.41	0.29	21.00
NO	Effortful	33	69.24	15.69	69.44	87.44	44.44	0.23	6.00
NO	Effortful	34	30.31	6.80	26.71	37.71	24.71	0.22	13.00
NO	Effortful	35	109.70	26.66	103.50	148.50	82.50	0.24	33.00
NO	Effortful	36	78.86	3.85	79.26	84.26	74.26	0.05	4.00
NO	Normal	01	16.07	3.35	15.87	19.87	11.87	0.21	5.00
NO	Normal	02	8.78	2.61	8.32	12.32	5.62	0.30	3.00
NO	Normal	03	17.29	4.64	17.29	23.29	10.29	0.27	1.00
NO	Normal	04	23.57	6.69	22.37	30.37	15.37	0.28	11.00
NO	Normal	05	10.68	2.55	9.68	14.68	8.68	0.24	3.00
NO	Normal	06	31.51	7.06	30.11	41.11	24.11	0.22	10.00
NO	Normal	08	51.18	24.71	54.78	83.78	23.78	0.48	34.00
NO	Normal	09	19.56	3.94	17.56	25.56	16.56	0.20	5.00

Table 1

Descriptive statistics for each participant across feedback condition and swallowing task.

Feedback	Task	Participant	mean	SD	median	max	min	CV	IQR
NO	Normal	10	24.62	4.44	22.82	29.82	19.82	0.18	7.00
NO	Normal	11	22.72	5.85	22.52	31.52	16.52	0.26	6.00
NO	Normal	12	37.75	6.63	38.75	47.75	30.75	0.18	6.00
NO	Normal	13	15.40	6.22	17.20	20.20	5.20	0.40	6.00
NO	Normal	14	22.01	11.14	17.01	35.01	12.01	0.51	20.00
NO	Normal	15	19.58	4.24	19.58	23.58	13.58	0.22	6.00
NO	Normal	16	27.41	8.96	24.21	43.21	21.21	0.33	2.00
NO	Normal	17	26.46	5.79	24.46	34.46	21.46	0.22	9.00
NO	Normal	18	62.66	14.52	56.26	84.26	48.26	0.23	16.00
NO	Normal	19	49.33	21.85	44.33	87.33	33.33	0.44	9.00
NO	Normal	20	15.23	6.02	13.83	24.83	9.83	0.40	6.00
NO	Normal	21	34.30	12.46	31.90	53.90	22.90	0.36	13.00
NO	Normal	22	12.11	4.38	10.31	17.31	8.31	0.36	8.00
NO	Normal	23	19.16	7.58	15.16	31.16	13.16	0.40	8.00
NO	Normal	24	34.22	4.66	37.02	38.02	27.02	0.14	5.00

Table 1

Descriptive statistics for each participant across feedback condition and swallowing task.

Feedback	Task	Participant	mean	SD	median	max	min	CV	IQR
NO	Normal	25	12.09	1.92	12.29	14.29	9.29	0.16	2.00
NO	Normal	26	38.75	12.47	34.75	53.75	22.75	0.32	15.00
NO	Normal	27	15.55	2.92	16.55	17.55	10.55	0.19	2.00
NO	Normal	28	76.59	20.22	70.34	105.84	59.84	0.26	15.25
NO	Normal	29	59.80	18.17	51.80	89.80	45.80	0.30	16.00
NO	Normal	30	34.33	5.50	35.13	42.13	28.13	0.16	6.00
NO	Normal	31	67.15	14.15	68.55	87.55	48.55	0.21	8.00
NO	Normal	32	33.61	6.38	32.41	41.41	25.41	0.19	8.00
NO	Normal	33	11.04	4.88	10.44	18.44	5.44	0.44	4.00
NO	Normal	34	92.71	59.29	77.71	168.71	28.71	0.64	89.00
NO	Normal	35	48.10	7.16	45.50	60.50	42.50	0.15	3.00
NO	Normal	36	8.74	1.84	9.26	11.26	6.56	0.21	1.90
YES	Effortful	01	38.27	6.07	36.87	45.87	30.87	0.16	8.00
YES	Effortful	02	41.72	18.88	41.32	59.32	14.32	0.45	25.00
YES	Effortful	03	94.09	26.26	101.29	120.29	51.29	0.28	17.00

Table 1

Descriptive statistics for each participant across feedback condition and swallowing task.

Feedback	Task	Participant	mean	SD	median	max	min	CV	IQR
YES	Effortful	04	57.97	9.76	58.37	73.37	47.37	0.17	6.00
YES	Effortful	05	47.48	8.41	48.68	54.68	33.68	0.18	7.00
YES	Effortful	06	33.31	5.93	34.11	42.11	26.11	0.18	4.00
YES	Effortful	08	63.58	23.25	60.78	98.78	33.78	0.37	7.00
YES	Effortful	09	84.56	7.11	84.56	92.56	73.56	0.08	5.00
YES	Effortful	10	116.62	17.20	117.82	136.82	90.82	0.15	14.00
YES	Effortful	11	105.97	38.60	97.57	168.57	73.57	0.36	37.00
YES	Effortful	12	54.35	29.72	37.75	103.75	32.75	0.55	24.00
YES	Effortful	13	122.40	11.90	127.20	134.20	108.20	0.10	20.00
YES	Effortful	14	68.21	20.66	64.01	101.01	44.01	0.30	6.00
YES	Effortful	15	28.18	5.03	29.58	34.58	22.58	0.18	7.00
YES	Effortful	16	35.21	4.74	36.21	39.21	27.21	0.13	3.00
YES	Effortful	17	55.26	3.63	56.46	58.46	50.46	0.07	6.00
YES	Effortful	18	161.66	46.31	148.26	219.26	119.26	0.29	81.00
YES	Effortful	19	53.53	8.07	57.33	60.33	41.33	0.15	10.00

Table 1

Descriptive statistics for each participant across feedback condition and swallowing task.

Feedback	Task	Participant	mean	SD	median	max	min	CV	IQR
YES	Effortful	20	188.43	53.55	168.83	281.83	152.83	0.28	27.00
YES	Effortful	21	56.70	10.94	51.90	72.90	47.90	0.19	15.00
YES	Effortful	22	23.31	7.31	20.31	33.31	15.31	0.31	9.00
YES	Effortful	23	19.16	3.24	17.16	23.16	16.16	0.17	5.00
YES	Effortful	24	154.62	27.78	146.02	201.02	134.02	0.18	24.00
YES	Effortful	25	16.49	6.42	14.29	26.29	10.29	0.39	7.00
YES	Effortful	26	90.35	53.71	55.75	156.75	46.75	0.59	89.00
YES	Effortful	27	99.55	31.90	102.55	134.55	55.55	0.32	42.00
YES	Effortful	28	152.24	32.75	163.84	183.84	114.84	0.22	59.00
YES	Effortful	29	63.60	6.76	60.80	71.80	56.80	0.11	11.00
YES	Effortful	30	93.53	17.08	90.13	114.13	75.13	0.18	28.00
YES	Effortful	31	115.15	21.62	117.55	135.55	79.55	0.19	14.00
YES	Effortful	32	87.41	16.82	83.41	108.41	64.41	0.19	16.00
YES	Effortful	33	84.04	21.78	80.44	113.44	58.44	0.26	27.00
YES	Effortful	34	64.31	24.91	52.71	102.71	42.71	0.39	28.00

Table 1

Descriptive statistics for each participant across feedback condition and swallowing task.

Feedback	Task	Participant	mean	SD	median	max	min	CV	IQR
YES	Effortful	35	193.10	48.60	184.50	273.50	149.50	0.25	35.00
YES	Effortful	36	99.26	12.81	94.26	116.26	88.26	0.13	21.00
YES	Normal	01	35.47	33.25	20.87	94.87	17.87	0.94	2.00
YES	Normal	02	18.92	4.98	20.32	24.32	12.32	0.26	7.00
YES	Normal	03	33.09	9.52	33.29	46.29	20.29	0.29	7.00
YES	Normal	04	28.17	6.94	26.37	40.37	23.37	0.25	2.00
YES	Normal	05	16.88	3.11	17.68	20.68	13.68	0.18	5.00
YES	Normal	06	24.11	5.57	23.11	33.11	19.11	0.23	5.00
YES	Normal	08	61.78	17.61	56.78	82.78	38.78	0.28	21.00
YES	Normal	09	22.76	5.02	21.56	27.56	15.56	0.22	6.00
YES	Normal	10	26.22	5.41	26.82	32.82	17.82	0.21	2.00
YES	Normal	11	19.57	7.04	16.57	31.57	13.57	0.36	3.00
YES	Normal	12	33.15	5.46	33.75	38.75	25.75	0.16	8.00
YES	Normal	13	46.80	26.35	38.20	89.20	25.20	0.56	27.00
YES	Normal	14	18.41	5.08	19.01	25.01	11.01	0.28	3.00

Table 1

Descriptive statistics for each participant across feedback condition and swallowing task.

Feedback	**Task**	**Participant**	**mean**	**SD**	**median**	**max**	**min**	**CV**	**IQR**
YES	Normal	15	13.98	3.97	12.58	20.58	10.58	0.28	3.00
YES	Normal	16	26.21	8.43	23.21	41.21	21.21	0.32	1.00
YES	Normal	17	24.86	4.39	24.46	31.46	20.46	0.18	5.00
YES	Normal	18	52.26	4.85	50.26	60.26	48.26	0.09	4.00
YES	Normal	19	30.53	6.46	33.33	38.33	23.33	0.21	9.00
YES	Normal	20	26.43	13.13	24.83	47.83	14.83	0.50	11.00
YES	Normal	21	23.50	5.41	24.90	27.90	14.90	0.23	6.00
YES	Normal	22	9.87	4.45	9.31	17.31	5.41	0.45	1.30
YES	Normal	23	10.76	0.89	10.16	12.16	10.16	0.08	1.00
YES	Normal	24	31.42	3.29	32.02	35.02	28.02	0.10	6.00
YES	Normal	25	8.97	4.76	7.29	17.29	5.69	0.53	2.00
YES	Normal	26	23.55	7.12	18.75	32.75	17.75	0.30	11.00
YES	Normal	27	16.95	2.70	18.55	19.55	13.55	0.16	4.00
YES	Normal	28	83.84	68.58	40.84	185.84	28.84	0.82	84.00
YES	Normal	29	42.20	4.22	42.80	46.80	35.80	0.10	4.00

Table 1

Descriptive statistics for each participant across feedback condition and swallowing task.

Feedback	Task	Participant	mean	SD	median	max	min	CV	IQR
YES	Normal	30	33.13	4.06	35.13	36.13	26.13	0.12	2.00
YES	Normal	31	40.35	10.45	37.55	58.55	32.55	0.26	4.00
YES	Normal	32	26.21	3.11	25.41	31.41	23.41	0.12	2.00
YES	Normal	33	23.04	1.82	23.44	25.44	20.44	0.08	1.00
YES	Normal	34	76.71	27.50	66.71	124.71	58.71	0.36	14.00
YES	Normal	35	84.90	8.02	84.50	97.50	77.50	0.09	8.00
YES	Normal	36	17.06	10.18	12.26	35.26	12.26	0.60	1.00