THE RELATIONSHIP BETWEEN PROPRIOCEPTION AND RESPIRATION DURING EATING IN YOUNG ADULTS

by

TANI DOHERTY

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Student: Tani Doherty

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This thesis has been accepted and approved in partial fulfillment of the requirements for the Master of Science degree in the Department of Special Education and Clinical Sciences by:

Samantha Shune	Chairperson
McKay Sohlberg	Member

and

Sara D. Hodges	Interim Vice Provost and Dean of the Graduate School

Original approval signatures are on file with the University of Oregon Graduate School.

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THESIS ABSTRACT

Tani Doherty

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Swallowing is a neurologically centrally driven event; however, a variety of sensory factors (e.g., bolus volume) have been shown to influence swallow-related events (e.g., swallow apnea duration). External factors (e.g., proprioception) have been previously shown to influence preparatory swallow movements (e.g., mouth opening). Yet, it is not known whether these external factors may influence the more automatic components of swallowing. This study was designed to determine whether proprioception influences the onset of swallow apnea.

Participants (N = 14, M_{age} = 25.71 years) were presented with bites/sips of applesauce and water during self and assisted feeding conditions. Results indicated that proprioception had no impact on the timing of swallow apnea onset, supporting that swallow apnea is a centrally driven event. By gaining a better understanding of the physiological impact assisted feeding has on individuals, we can best serve individuals who rely on feeding assistance and optimize swallow safety across all populations.

CURRICULUM VITAE

NAME OF AUTHOR: Tani Doherty

GRADUATE AND UNDERGRADUATE SCHOOLS ATTENDED:

University of Oregon, Eugene
University of Arizona, Tucson

DEGREES AWARDED:

Master of Science, Communication Disorders and Sciences, 2018, University of Oregon
Bachelor of Science, Speech, Language and Hearing Sciences, 2016, University of Arizona

AREAS OF SPECIAL INTEREST:

Dysphagia

Feeding Disorders

Augmentative or Alternative Communication

Cognitive-Communication

GRANTS, AWARDS, AND HONORS:

College of Education Alumni Scholarship, University of Oregon, 2017-2018

Sertoma Communication Disorders Scholarship, Sertoma, 2017-2018

Zimmerman Scholarship Fund, University of Oregon, 2017-2018

Magna Cum Laude, University of Arizona, 2016

Regents High Honors Endorsement Award, Arizona Board of Regents, 2012-2016

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CHAPTER I

INTRODUCTION

Definition of Clinical Problem

Eating is a basic human necessity and is an integral part of everyday life. However, when the ability to swallow is compromised it can become a potentially deadly medical condition. A recent survey estimated the annual prevalence of swallowing difficulties, or dysphagia, to be 4% among all adults in the United States (Bhattacharyya, 2014). Dysphagia can directly lead to numerous negative health outcomes including dehydration, malnutrition, pneumonia, and the long-term necessity for enteral feedings (Ames et al., 2011; Karvonen-Gutierrez et al., 2008; Mick, Vokes, Weichselbaum, & Panje, 1991). Further, as mealtimes are considered a social event, dysphagia can result in decreased participation, isolation and depression. Lastly, dysphagia has been indicated to play a role in bounce-backs, or re-hospitalizations, due to its frequent complications of aspiration and pneumonia (Ney, Weiss, Kind, & Robbins, 2009).

Dysphagia can result from impairments in any of the four traditional phases of the swallow: oral preparatory, oral transport, pharyngeal, and esophageal phases. Briefly, oral preparatory involves the manipulation and formation of a cohesive bolus, which is then propelled into the pharynx during the oral transit stage (Sapienza & Ruddy, 2013). During the pharyngeal phase, the larynx is closed off to protect the airway (i.e., prevent aspiration) and the pharyngeal constrictor muscles move the bolus through the pharynx to the esophagus. The bolus then moves through the upper esophageal sphincter during the esophageal phase until it reaches the stomach. The oral preparatory and oral transit stages are considered to be under more voluntary control, while the pharyngeal and esophageal stages are under more involuntary control.

Swallowing is a highly complex sensorimotor behavior that requires coordinated activity between the respiratory, laryngeal, and masticatory systems across these four phases (McFarland & Tremblay, 2006). Swallowing requires multiple levels of nervous system function and requires sensory feedback to facilitate safe swallows. Of high importance, precise respiratory and swallowing coordination is critical to preventing aspiration during swallowing (Martin-Harris, 2005). This precise coordination supports the presence of a central pattern generator to automatically/non-volitionally control the precise timing of the movement of these systems (Hiss, Strauss, Treole, Stuart, & Boutilier, 2003).

While much of the swallowing “program” is centrally driven neurologically, a variety of sensory factors, both within the oropharyngeal cavities and external to the swallowing process, can influence the timing and onset of numerous events throughout the phases of swallowing. These events include swallow apnea duration, salivation, anticipatory mouth opening, and swallow-related muscle activation (Cattaneo et al., 2007; Hiss, Treole, & Stuart, 2001; Shune, Moon, & Goodman, 2016). Foremost, oral sensation has been found to influence the timing of swallow related events, such as swallow apnea duration. Factors of oral sensation include characteristics such as bolus taste, temperature, and consistency (Hiss et al., 2001; Steele & Miller, 2010).

While research has supported the influence of oral sensation on swallow function, little is understood regarding more external sensory cues that occur during the pre-oral phase of the swallow which may impact the initiation of the oral stages of the swallow

(Leopold & Kagel, 1997; Shune et al., 2016). The pre-oral phase that occurs prior to food/drink entering the oral cavity involves individual and environmental factors related to eating such as cognition, proprioception, and other sensory input (e.g., vision, audition). For example, the swallowing process requires behavioral and cognitive abilities to both recognize and transfer food to the mouth (Leopold & Kagel, 1997; Siebens et al., 1986). Further, actions such as seeing, smelling, or thinking about a desired food arguably greatly impact swallowing-related activities, such as salivation. Recent research has suggested the importance of these pre-oral sensorimotor cues (i.e., proprioception, vision) for timing the onset and magnitude of mouth opening during eating (Shune et al., 2016; Shune & Moon, 2016). This may be particularly relevant for older adults who may begin mouth opening movements earlier given the presence of pre-oral cues in order to maintain swallowing safety despite age-related changes across the swallowing system ("compensatory advantage"; Shune et al., 2016).

These more external sensory cues that are typically available during the eating process, such as proprioception from the arm and visual awareness of food, may be absent under certain conditions. In presence of cognitive or physical deficits, it is common that many individuals require acute or long term feeding assistance (Shune et al., 2016). However, when individuals are fed, it may alter typical swallow patterns by removing these pre-oral sensorimotor cues such as proprioception. Therefore, as a result of feeding assistance, these individuals may experience dysphagia or dysphagia-like symptoms. In other words, despite the intended benefits of feeding assistance, the removal of typical eating-related pre-oral sensorimotor cues may lead to further impairments in swallowing function. Such impairments could be extremely detrimental if they impacted swallowing efficiency (such as preparatory mouth movements) and/or swallowing safety (such as swallow/respiratory coordination).

However, the presence of this relationship remains underexplored. Previous research has documented a relationship between mouth opening and the presence/absence of pre-oral sensorimotor cues (Shune et al., 2016). Yet, the potential relationship between these cues and the more automatic components of the swallowing process (e.g., pharyngeal stage including respiratory/swallow coordination) is not known. Of importance, the relationship between respiratory timing and pre-oral sensorimotor actions is currently unclear. Respiration is typically viewed as a hardwired and centrally driven event; however, several researchers have suggested that there is variability in these patterns. Research has suggested that respiration surrounding the swallow can be impacted by sensory stimuli including bolus consistency and visual input (Klahn & Perlman, 1999; Preiksaitis & Mills, 1996; Shune et al., 2016). However, it has not been systematically investigated how swallowing-respiratory coordination can be impacted by different bolus presentations (i.e., spoon, straw) or proprioception. Given the importance of precise respiratory coordination for airway protection during swallowing, better understanding the peripheral factors that may influence respiratory coordination can improve swallow safety and decrease aspiration and penetration before, during, or after swallowing. These topics will be expanded on in the literature review below.

Review of Literature

Swallow-respiratory coordination. Swallow apnea is a brief period in which breathing ceases during the pharyngeal phase of swallowing to protect the airway. Swallow apnea is elicited before and during the pharyngeal stage of the swallow (Costa

& Lemme, 2010). Its overall duration ranges from 0.50 to 10.02 seconds with the median being 1.0 seconds for healthy adults (Costa & Lemme, 2010; Martin-Harris 2005).

In addition to the swallow apnea, there are respiratory phase patterns that serve as a further protective mechanism. Numerous researchers have explored this topic (Brodsky et al., 2010; Hiss et al., 2001; Klahn & Perlman, 1999; Martin-Harris et al., 2005) finding that an exhale-swallow-exhale pattern in which the swallow apnea period occurs during the expiratory phase of the breathing cycle may be the "best" and most prominent pattern. This pattern is thought to be ideal in terms of safety because exhaling prior to and after the swallow allows the system to move potential infiltrates away from the airway. Further, it has been suggested that this respiratory pattern results in the lungs being at optimal volume and the larynx in an ideal position for swallowing. In other words, between middle and low expiratory lung volumes with laryngeal elevation create a mechanical advantage for swallowing. Multiple studies have reported that over 93% of typical swallows are preceded by an exhalation (Martin-Harris et. al., 2005; Klahn & Perlman, 1999). However, other research has suggested that only 75% of typical swallows are preceded by exhalation (Hiss et al., 2001; Preiksaitis et. al., 1996). These differences may be attributable to study design. Those findings reporting lower percentages of the exhale-swallow-exhale pattern simulated a more natural eating environment by allowing participants to self-administer and drink from their cup, whereas the other studies directly administered the bolus to the participants mouth via syringe. Thus, while the exhale-swallow-exhale pattern appears to be the predominant pattern, it is clear that variability in these typical patterns exist, suggesting that these patterns may be influenced by external factors.

A variety of factors can impact swallow apnea and phase patterns. Numerous studies have assessed the impact of gender, bolus size, taste, disease, and consistency on swallow apnea duration (Butler, Postma, & Fischer, 2004; Hiss et al., 2001; Martin-Harris, Garand, & McFarland, 2017; Preiksaitis & Mills, 1996). In general, it was found that older participants and females had longer swallow apnea durations (Hiss et al., 2001). Butler et al. (2004) assessed the impact of viscosity, taste, and volume on swallow apnea duration. They found that swallow apnea duration increased with increases in bolus volume. However, it was unaffected by changes in viscosity or taste. This was consistent with the findings from Hiss et al. (2001) as they found that swallow apnea duration increased as bolus volume did. Therefore, it appears that the duration of swallow apnea is impacted by factors such as age and bolus size.

Less studied, however, is the impact that these factors may have on swallow apnea onset. In other words, it is less clear whether these increases in duration of swallow apnea are due to an earlier onset or a later offset of swallow apnea, or both. Given what is known about the potential importance of earlier movement onset in aging to compensate for age-related changes elsewhere in the system (e.g., Shune et al., 2016), this distinction may be clinically relevant.

In addition to changes in duration, Martin-Harris et al. (2005) did find that the onset of the swallow apnea period was highly variable in a group of healthy participants and suggested that breath holding prior to swallow initiation may be a learned trait or habituated response to drinking specific to an individual. Despite the variability in onset, studies have found that swallow apnea offset is relatively stable in young adults (Martin-Harris et al., 2005). Further, Klahn and Perlman (1999) suggested that the time of onset and offset of expiration may not be as clinically important as the occurrence of expiration before, during, and after the swallow. The previous literature's focus on duration and patterns reflect (a) the proposal that swallow apnea duration can be used to determine if an individual is maintaining sufficient airway protection during swallowing and (b) the goal of swallow apnea research to establish data to compare normal and abnormal swallow physiology (Hiss et al., 2001).

Overall, in the current literature base, studies have paid more attention to swallow apnea duration with less attention being placed on swallow apnea onset. However, it is crucial to better understand swallow apnea onset and the factors that may impact it as it directly relates to *preparation* to produce optimally safe swallows. Preparatory muscle activation has been reported for a variety of motor control tasks in the limbs and linked to injury prevention and task success (Besier, Lloyd, Ackland, & Cochrane, 2001; Johansson & Westling, 1988). As research continues to focus more on motor movement onset and preparation for action, it is necessary to determine whether the respiratory and swallowing systems follows similar patterns. If so, better understanding the factors that modify apnea onset (or the preparation for swallow apnea) could lead to a clinically meaningful decrease in aspiration and penetration.

Swallow apnea does appear to be centrally driven. Neurophysiologists found evidence of specialized neural networks in the brainstem and cortex that support tight neural coupling between central control of respiration and swallowing (Martin-Harris, 2008). These findings have suggested that there are specific single neurons within these networks that demonstrate multifunctionality in the control of respiratory and swallowing behaviors (Jean, 2001). However, this neural coupling may be compromised due to age, disease, or because of the eating and swallowing task (McFarland & Tremblay, 2006). For example, neurological and head and neck cancer populations show evidence of respiratory-swallowing uncoupling, or the unlinking of the tight coordination between onset of respiratory and swallowing actions (Martin-Harris et al., 2017). Training respiratory-swallow coordination can be clinically useful for these populations (Martin-Harris et al., 2017). Martin-Harris et al. (2017) trained head and neck cancer patients to produce an optimal respiratory pattern which aimed to initiate the swallow during mid-to-low lung volumes of the expiratory phase prior to bolus intake. This study had positive outcomes resulting in fewer aspiration and penetration events in participants. Such findings support the cross-system coupling between respiration and swallowing as training respiratory patterns resulted in swallowing improvements. These findings also indicate that the relationship between respiration and swallowing is a clinically significant relationship that can be used therapeutically. This information supporting neural coupling and centrally driven commands lends to the need for more information regarding what external events surrounding eating may "uncouple" and/or interact with respiration and swallowing.

Further, it is hypothesized that airway closure occurs due to vocal fold and false vocal fold medialization. As a result, swallow apnea is thought to occur secondary to glottal closure. However, Hiss et al. (2003) suggested that swallow apnea may occur as the result of its own neural command. The researchers utilized individuals who had undergone total laryngectomies. They found that swallow apnea still occurred in these individuals despite the absence of a larynx therefore refuting the notion that swallow apnea occurs strictly as a result of glottal closure (Hiss et al., 2003). This also suggests that swallow apnea is not just a function of needing to protect the airway as in this population the trachea is surgically separated from the upper airway. Therefore, the purpose of swallow apnea may be different than previously thought.

Swallow apnea onset and timing are integral components of the pharyngeal swallow and crucial for swallow safety. Despite being centrally driven, research has demonstrated the modifiability of respiratory patterns, through both volitional (e.g., therapeutic training) and more involuntary (e.g., changes in bolus properties) means. Yet, the research has not systematically targeted onset of swallow apnea. Thus, it remains unclear what factors may ultimately dictate swallow apnea onset and whether they are modifiable.

Proprioception. Exteroception and proprioception are sensory “classes” pertinent to swallowing. Exteroception is how the brain interprets cues from the external world (i.e., vision, touch) whereas proprioceptive sensation provides awareness of ones’ body and allows the brain to interpret this interaction through external cues (Sherrington, 1906; Shune et al., 2016). These cues are crucial during mealtimes as each provide feedback during eating and drinking such as vision and proprioception.

Numerous studies have demonstrated that there is a relationship between swallow-related actions and pre-oral sensorimotor cues (including exteroceptive and proprioceptive cues). Foremost, Shune et al. (2016) found that healthy younger and older adults demonstrate anticipatory mouth movement prior to a bolus reaching their mouth. In other words, adults begin to open their mouths in anticipation of food/drink under normal circumstances. In the absence of proprioceptive cues (i.e., when the participants were being fed rather than feeding themselves), mouth opening movements were delayed.

Further, a second study by Shune and Moon (2016) looked at magnitude of mouth opening in relation to proprioceptive and exteroceptive cues. The researchers found that proprioceptive loss in combination with exteroceptive loss (i.e., removal of visual and auditory cues) during eating resulted in atypical anticipatory mouth opening magnitude and timing. Further, the effects of exteroceptive loss were observed to be greater during assisted feeding than self-feeding tasks (Shune & Moon, 2016). These findings ultimately suggest that proprioception was a key factor in mouth opening movements for eating and magnified the results of exteroceptive loss alone. Although these studies only looked at anticipatory mouth movements, it can be suggested that perhaps proprioception may be an important feedback mechanism contributing to successful eating/swallowing and linked to the onset of movement of other oral structures as well.

Other research has also supported a relationship between hand grasping during feeding and mouth movement. Numerous kinematic studies have examined reach-to-grasp movements when reaching for objects; however, there is limited research on these actions in relation to reaching and grasping items that are intended to be eaten (i.e., reach-to-bite tasks) (Quinlan & Culham, 2015). Quinlan & Culham (2015) point out that reach-to-bite tasks differ from reach-to-grasp tasks as during reach-to-grasp, participants have a clear vision of the target. In reach-to-bite, participants initially have a clear view, but lose vision of their hand as the hand continues to approach their mouth. Therefore, during reach-to-bite tasks it is hypothesized that the participants are relying on somatosensation to shape mouth size. Overall this suggests that in the absence of visual cues, individuals rely on proprioception to modify and adapt their mouth for the bolus. Castiello (1997) demonstrated this relationship by having participants feed themselves. Participants were observed to open their mouth to a size larger than the approaching bite as they moved it towards their mouth (Castiello, 1997). This was further investigated by Quinlan & Culham (2015) where participants self-fed using both a fork and their hand. The study found increased mouth opening during hand-feeding movements as opposed to forks suggesting a direct relationship between increased sensory input and mouth movement during feeding tasks.

This relationship was further illustrated in Cattaneo et al.'s (2007) study of children. The researchers assessed mylohyoid muscle activation between grasp-to-eat and grasp-to-place tasks. The mylohyoid muscle runs from the mandible to the hyoid bone and forms the floor of the oral cavity in the mouth and is important for jaw lowering during eating. It was found that during grasp-to-eat tasks, mylohyoid activation began during the reaching phase and continued throughout the rest of the action (Cattaneo et al., 2007). No mylohyoid activation was observed during the grasp-to-place tasks suggesting these results are due to the goal of the action of eating and that specific motor acts may act in a chain (Cattaneo et al., 2007). Therefore, this lends to the notion that perhaps grasp-to-eat, or self-feeding actions, are embedded in an overall eating process that may encompasses the swallowing actions, rather than all of these actions just happening in isolation. It also raises the questions of how these non-oral components of the eating process may influence, or interact with, the more centrally driven actions such as respiration and swallowing.

Interestingly, such hand-to-mouth action and connection has also been found in human infants. Butterworth and Hopkins (1988) found that during spontaneous arm movement, infants' mouths opened in anticipation of their approaching hand and they suggested that this movement does not require visual guidance. Myowa and Takeshita (2006) further assessed this in human fetuses. They observed that most arm movements resulted in contact with their face. Further, they suggested that perhaps human fetuses may perceive how to move their arms and hands to make contact with the mouth (Myowa-Yamakoshi & Takeshita, 2006). These studies demonstrate that hand-to-mouth movements may be innate and therefore are an integral, and basic, part of the eating and drinking process.

Summary. We currently know that mouth opening for eating is linked to and impacted by proprioception and that mouth opening is delayed when this cue is removed. Furthermore, we know that the pharyngeal and esophageal phases of the swallow are centrally driven. Literature suggests that swallow apnea may be as well. It is known that volitionally manipulating respiratory phase patterns can increase swallow safety. Yet, it is less explored what factors modify respiratory patterns and swallow apnea onset. It is possible that proprioception, as it is known to impact other, more volitional aspects of the eating process, is one such factor.

Purpose of Current Study

Currently, the potential relationship between proprioception and the onset of the swallow apneic period is not defined. Proprioception has an impact on pre-oral mouth movements during eating, but these mouth movements occur during the more volitional stages of eating. Additionally, while much attention has been placed on factors impacting respiratory phase patterns and swallow apnea duration, little is known regarding what factors may impact the onset of the swallow apneic period. Unfortunately, assisted feeding, one common therapeutic technique to address eating and feeding difficulties, generally reduces the availability of pre-oral cues such as proprioception. Thus, beyond the theoretical implications, by gaining a better understanding of what factors impact respiratory-swallowing coordination, this can allow us to use this information to increase safety during mealtimes for a variety of clinical populations.

The purpose of this study was to investigate the relationship between upper limb movement and swallow apnea onset during eating in healthy young adults. Given the paucity of information regarding this topic, it is important to first explore this potential relationship in healthy individuals. Further, younger adults make up a growing population of individuals with dysphagia. Of adults in the general population with dysphagia, nearly 16% are under the age of 30 (Bhattacharyya, 2014). Dysphagia in younger adults can be caused by numerous etiologies. Traumatic brain injury (TBI) is the most common cause of dysphagia in this age demographic. Falls and motor vehicle accidents are the two leading causes of TBI (Centers for Disease Control and Prevention, 2015). Roughly 17% of overall adult TBI patients experience dysphagia as a result of their injury (Safaz, Alaca, Yasar, Tok, & Yilmaz, 2008). Dysphagia in younger adults can also commonly occur as a result of persistent gastroesophageal reflux (Bhattacharyya, 2014). Further, the average age of certain diseases that are commonly associated with dysphagia (e.g., stroke, spinal cord injury) continues to decrease (Chen, He, & DeVivo, 2016; Kissela et al., 2012; Mozaffarian et al., 2016) creating an additional subset of younger adults with dysphagia. While many studies have incorporated younger adults for normative swallowing data, less is known regarding the factors impacting and interacting with swallow function in the younger adult population.

Specifically, the goal of this study was to better understand what impact proprioception has on the onset of the swallow apneic period. We hypothesized that younger adults would exhibit a later onset of the swallow apnea period during assisted feeding trials than during self-fed trials. Such a result would suggest that proprioception is one important sensorimotor cue in timing swallow apnea onset, supporting a link between the peripheral and central components of eating and swallowing. The results can allow us to better understand what physiological impact it has on young adults to consider for individuals who rely on feeding assistance to optimize swallow safety.

CHAPTER II

METHODS AND PROCEDURES

Participants

Participants included 14 healthy younger adults ranging in age from 18-30 years old. Inclusion criteria included normal or corrected hearing and vision, vestibular function, and upper extremity range of motion. Qualifications also included a negative history of confounding medical, neurological, or musculoskeletal disease as well as medication usage that could affect neurologic or motor function. Participants were administered the Mini-Mental State Exam (MMSE; score $\geq$ 26) and screenings for oral motor, balance, and extremity function and oral and extremity sensation to ensure that all were within functional limits. Participants were recruited through online advertisements in Eugene, Oregon. The final sample of participants ranged in age from 20 to 30 years old (*M* = 25.71, *SD* = 2.78) and included 7 females and 7 males (See Table 1).

Table 1
Participant characteristics

Participant ID	Age	Sex	Handedness	MMSE Score	Education Level
1	24	F	R	30	Bachelor’s degree
2	23	F	R	30	Bachelor’s degree
3	26	M	R	30	Bachelor’s degree
4	27	F	R	30	Bachelor’s degree
5	30	F	R	30	Bachelor’s degree
6	30	M	L	30	Bachelor’s degree
7	25	F	R	30	Bachelor’s degree
8	26	M	R	29	Bachelor’s degree
9	26	M	R	30	Bachelor’s degree
10	26	F	R	30	Bachelor’s degree
11	23	F	R	30	Bachelor’s degree
12	29	M	R	29	GED
13	25	M	R	29	Bachelor’s degree
14	20	M	R	30	High school

Note: F = female; GED = general education development; L = left; M = male; MMSE = Mini-mental state exam score; R = right.

Procedures and Analysis

Task procedures. The study took place in a laboratory located inside the basement of the Clinical Services Building at the University of Oregon. All task procedures were approved by the Institutional Review Board. Testing took place over a one-day visit, typically lasting one hour. Two members of the research team carried out all study related tasks for the day of testing, one assumed the role of the "examiner" and the other of the "feeder". Prior to beginning the study, the examiner described the study details to the participant. The participant then signed the written informed consent form for the study (see Appendix) prior to participation. Participants then completed all screening tasks (i.e., informal and formal screens of cognition, balance, and oral motor and upper extremity function and sensation). Upon the completion of the study, participants received a $10 gift card as compensation.

The protocol was divided into three task conditions: "typical self-feeding", "typical assisted feeding", and "blindfolded assisted feeding;" further details of each condition are provided below. The protocol was modified from previous investigations on the influence of pre-oral sensory cues on swallowing (Shune & Moon, 2016; Shune et al., 2016). The order of condition presentation was randomly assigned for each participant prior to the study. Prior to each individual condition, participants were read a description of what to expect, were asked to refrain from bringing their head forward when eating (i.e., bring the cup/spoon to their mouth rather than their head to the cup/spoon), and were told to eat and drink as naturally as possible (see Table 2 on the following page). During all conditions, participants were presented with average-sized boluses of pureed food (applesauce) via spoon (approximately 1 teaspoon) and 20mL of thin liquid (water), measured via syringe, in a small cylinder glass with a straw. Each condition was broken into two blocks, A and B, of ten trials each (five applesauce and five water trials in each block). The order of stimulus presentations was randomly assigned within the blocks. Thus, participants consumed ten swallows of each consistency per condition, divided into two blocks of ten trials each, for a total of 20 swallows per condition. Between trials the feeder refilled the spoon and cup. Prior to each trial, the participant was asked to finish the entire sip of water and bite of puree. Additionally, between each trial, participants were instructed to leave their hand on a designated "start" pressure sensor that measured the onset and offset of each trial.

Table 2
Condition Scripts

Condition	Script
Typical self-feeding	"You will be presented with multiple sips of water and bites of applesauce. Please drink the water and eat the applesauce as naturally as possible. As best as you can, please drink the entire amount of water and eat the entire bite of applesauce in one swallow. Also, do your best to bring the food/drink to your mouth instead of your head to the spoon/cup. Before each sip/bite, place your arm in the start position here on the blue sensor. You may begin reaching for your next sip/bite when you hear me say "Go". We will do two sets of ten swallows each. Do you have any questions?"
Typical assisted-feeding	"You will be presented with multiple sips of water and bites of applesauce and XX will be feeding you. Please drink the water and eat the applesauce as naturally as possible. As best as you can, please drink the entire amount of water and eat the entire bite of applesauce in one swallow. Also, do you best to let XX bring the food/drink to your mouth instead of you bringing your head to the spoon/cup. She will begin reaching for the next sip/bite when she hears me say "Go". We will do two sets of ten swallows each. Do you have any questions?"
Blindfolded assisted-feeding	"You will be presented with multiple sips of water and bites of applesauce while wearing a blindfold. XX will be feeding you. Please drink the water and eat the applesauce as naturally as possible. As best as you can, please drink the entire amount of water and eat the entire bite of applesauce in one swallow. You will not receive any information about when she will begin the sip/bite. We will do two sets of ten swallows each. Do you have any questions?"

During the “typical self-feeding” condition, the participant was responsible for bringing the spoon or cup and straw to her/his own mouth (i.e., self-feeding). The participant was cued by the examiner regarding which stimulus to reach for each trial. During this condition, the participant was also asked to only use their dominant arm to reach for the spoon or cup. During both the “assisted typical feeding” and “blindfolded assisted feeding” conditions, the feeder presented the puree or thin liquid to the participant as dictated by the examiner (i.e., assisted feeding). During the “blindfolded assisted feeding” condition, the participant was also blindfolded and was not provided with any sensory cues as to when the food or drink would reach their mouth or what consistency it would be. Thus, across the conditions two important cues for feeding and eating were manipulated: proprioception (self-feeding vs assisted feeding) and vision (wearing vs not wearing a blindfold).

After the completion of the third condition for the participant, the examiner asked the participant follow-up questions related to the study. Questions included, “What sensory cues did you use?” and “What conditions were easiest for you and why?”.

Data collection. Data for the current study were collected as part of a larger study investigating the influence of pre-oral sensory cues on swallow function. All data collected will be described below to provide a complete picture of the experimental set-up. The signals analyzed for the current study will be clearly delineated.

Across all conditions, lip, jaw, respiration, and arm activation/movements were tracked using the BioPac MP150 system (BioPac, Goleta, CA). Briefly, muscle activation related to lip and jaw movement was measured using electromyography (EMG), respiratory movements were measured via nasal cannula and respiratory belt transducers, arm movement (elbow flexion) was measured using a goniometer, the onset of hand movement was measured via a pressure-activated switch, and the time when the spoon/straw reached the lips was measured using a moisture-activated switch. The data from all of these channels (EMG, respiration, goniometer, switches) were recorded in real time using the AcqKnowledge 5.0 software program. A picture of the experimental set-up and equipment is included in Figure 1.

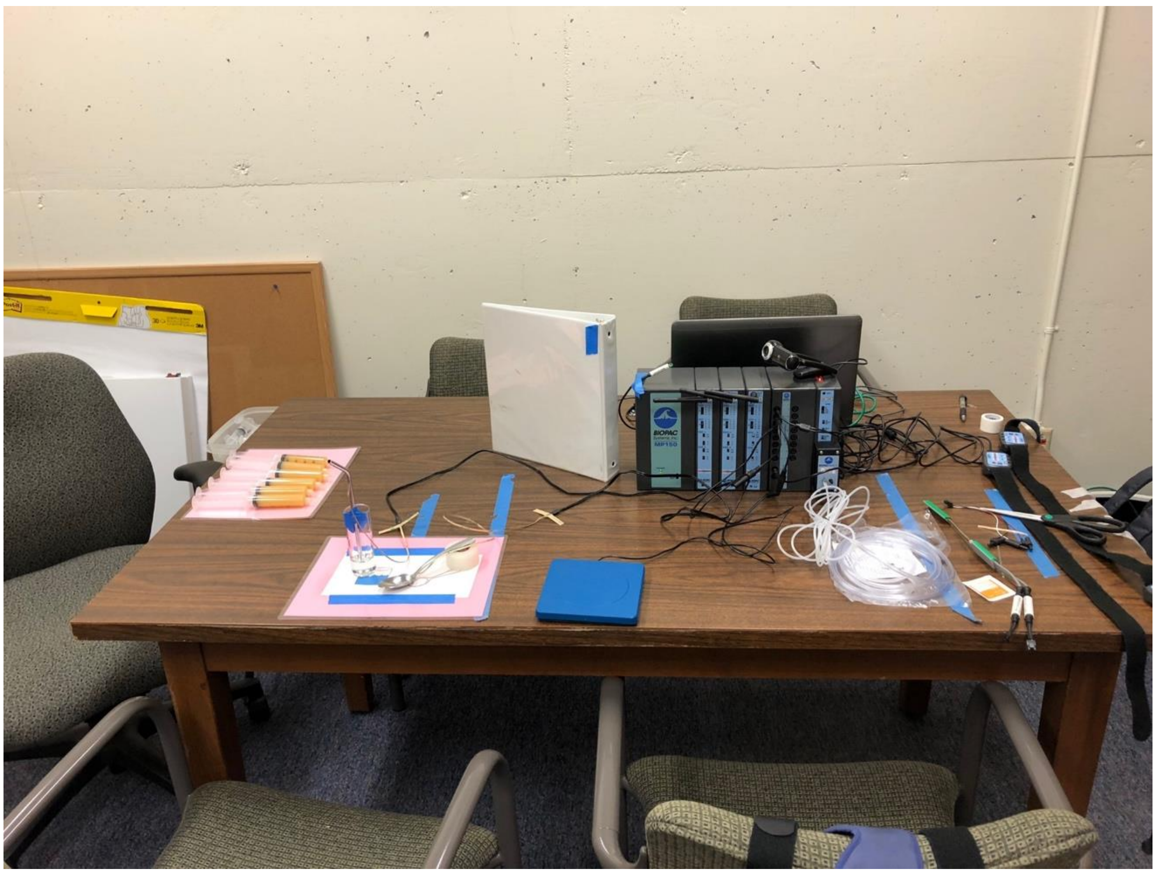

Figure 1. Experimental set-up.

The onset of each trial, defined as the onset of hand movement to reach for the stimulus to be consumed, was collected through the usage of a pressure-activated switch (blue switch pad in Figure 1). Between trials, participants (self-feeding condition) or the feeder (assisted feeding conditions) were instructed to rest their hand on the blue switch pad, activating the switch. The switch was de-activated when the participants/feeder lifted their hand to reach for the specified stimulus. Moisture-activated switches (Taction Pads, Adaptivation Inc., Sioux Falls, SD) were adhered to the straw and spoon that were used for stimulus presentation to provide temporal information related to when the straw or spoon first touched the participant's mouth.

Arm movement, measured via the angle of the elbow, was tracked through the usage of the BioPac Twin-axis 110mm Goniometer. The goniometer was attached to the participant's or feeder's dominant arm with cloth based tape, with the first transducer below the elbow and the second above it when the arm was in a straight position. The transmitter was attached to the participant's shoulder with Velcro (see Figure 2 below).

Figure 2. Goniometer arm attachment.

Respiratory measures were assessed using respiration belt transducers which were placed during maximum exhalation around the abdomen and chest. Respiratory flow was also tracked via nasal cannula (see Figure 3 below).

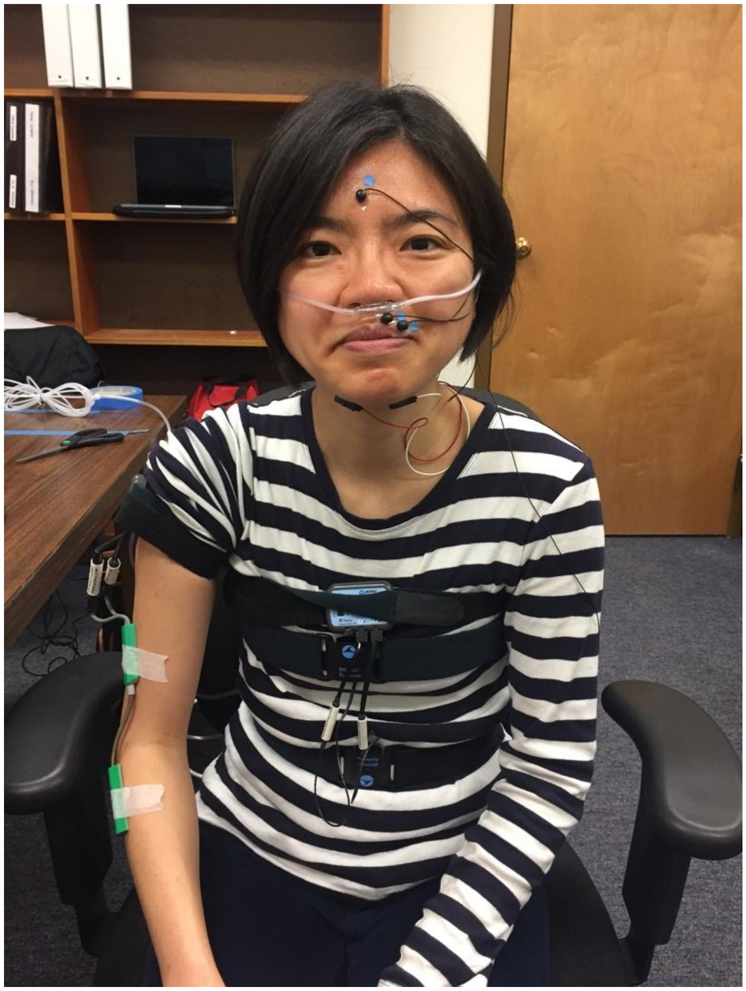

Figure 3. Respiratory belt transducer and nasal cannula arrangement.

Electromyography (EMG) electrodes were placed on the skin over two general muscle groups to measure onset of lip puckering (orbicularis oris) and jaw lowering (submental muscles) and to approximate hyolaryngeal movement during the swallow (submental muscles). Prior to sensor placement, the participants skin was cleansed with an alcohol preparation pad to ensure a strong seal, and an adhesive washer was placed around the electrode to adhere it to the skin. Two small electrodes were placed on the superior orbicularis oris in relation to participant handedness (i.e., right-handed participants had sensors placed on the left side to avoid interference during self-feeding), and two electrodes were placed on the submental muscles (mylohyoid, geniohyoid, and the anterior belly of the digastric below the chin and next to the midline). A third EMG electrode was placed on the forehead to ground the electrodes (see Figure 4 below).

Figure 4. EMG electrode placement.

Analysis. The data signals were analyzed using the AckKnowledge 5.0 software system. From each of the collected signals, multiple onset times were derived via manual analysis (see description below). Time of onset for each variable was recorded into an Excel spreadsheet.

The onset of each trial was recorded through the use of the pressure-activated blue switch, which was used as the “start position” for the hand. The onset of the trial, or the time point when the participant/feeder took their hand off the sensor, was recorded as the “reach to grasp” variable as it marked the onset of arm movement toward grasping the spoon/cup (see Figure 5 on the following page).

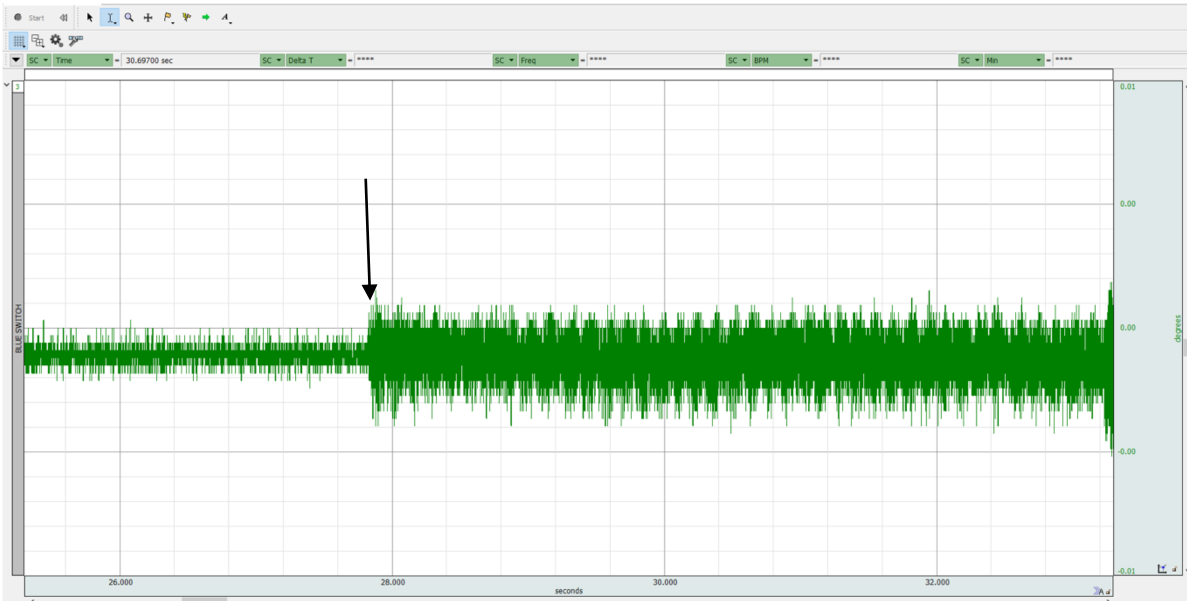

Figure 5. A sample waveform for the pressure-activated switch. The arrow indicates the onset of the reach to grasp movement.

The moisture-activated switches adhered to the straw and spoon provided information regarding the onset of the time the straw or the spoon reached the participants' lips. Onset was determined by a distinct increase of signal thickness and was recorded as the "oral sensation" variable as it marked the onset of sensory input to the oral cavity during eating (see Figure 6 on the following page).

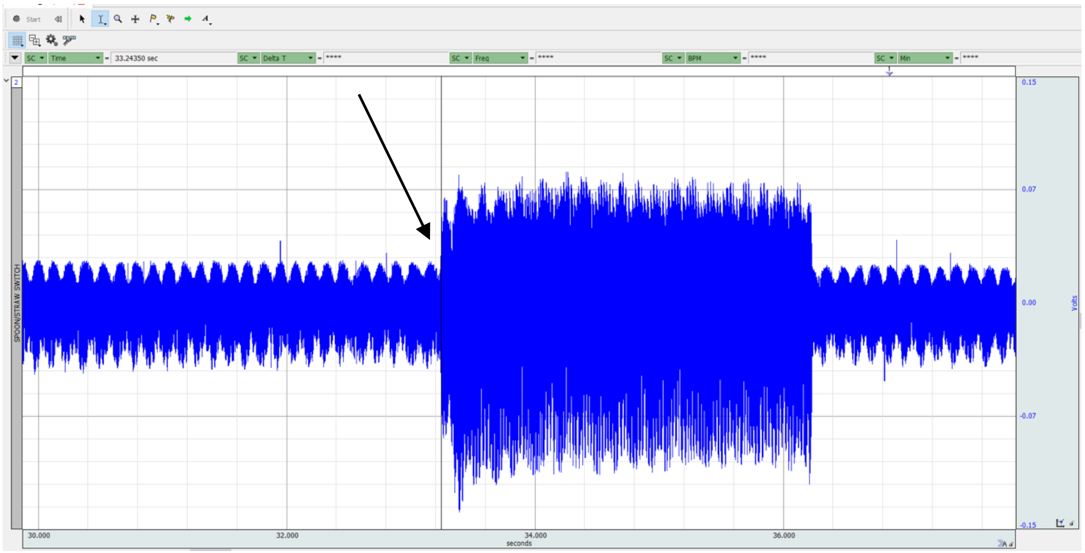

Figure 6. A sample waveform for the moisture-activated switch. The arrow indicates the onset of oral sensation.

The goniometer signals were used to determine the onset of the feeding gesture, or the “reach to feed” variable, which represented the time that the participant or the feeder grasped the cup or spoon and began moving it towards the participant’s mouth. This data point was determined by a change in direction in the goniometer signal, representing a change in elbow flexion, and is shown in Figure 7.

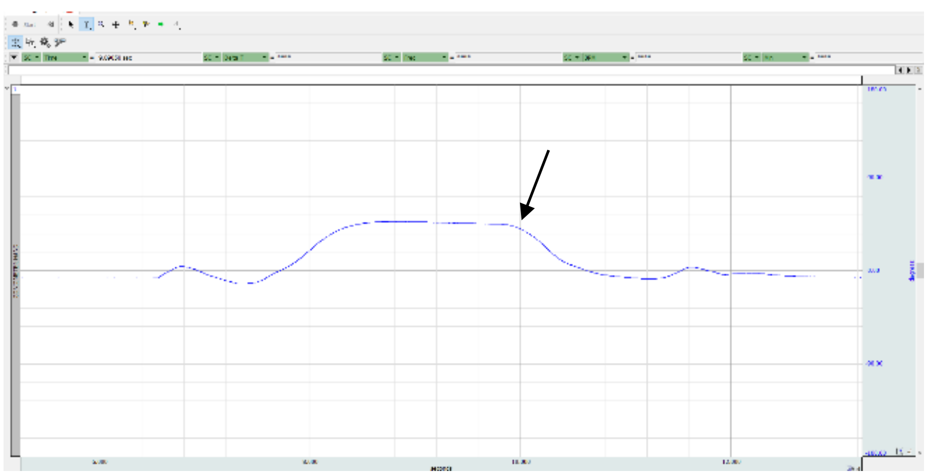
Figure 7. A sample goniometer waveform. The arrow indicates the onset of the reach to feed movement.

Respiratory patterns were assessed in three different ways. The first analysis point was obtained through the nasal cannula signal. Onset of swallow apnea was defined as when no airflow was moving in or out of the nasal cannula (signal plateau around 0 volts). Given that some individuals do not have nasal airflow at various points (i.e., talking, mouth breathing) these plateaus were limited to moments surrounding the swallow. This was recorded as the “swallow apnea” variable. Chest and belly signals (“chest apnea” and “belly apnea” variables, respectively), which were recorded through the usage of the respiratory belt transducers, were also analyzed by hand. The pause in breathing preceding the swallow was determined by a plateau in the signals and confirmed against the period of “swallow apnea” indicated by the nasal cannula signal. These respiratory signals are represented in Figure 8 below. The signal from the nasal cannula is the top line, the chest signal is the line in the middle, and the belly signal is the bottom line.

Figure 8. Sample respiratory waveforms for the nasal cannula (top line), chest (middle), and belly (bottom) signals. The arrows indicate the approximate onset of apnea.

EMG signals were also recorded. Prior to analysis, orbicularis oris and submental muscle signals were transformed. First, a bandpass signal was applied to both signals. For each signal, a low frequency cutoff was fixed at 250Hz and a high frequency cutoff at 500Hz. Afterwards, the signals were integrated with an average over samples using root mean square. After this, the signal was transformed utilizing the AcKnowledge 5.0 electromyography function to locate muscle activation at a fixed rate, and was set to discard transitions shorter than 0.1 seconds. The onset for lip activation (“pucker” variable) was defined by a distinct change in the transformed orbicularis oris muscle activation signal as compared to baseline (i.e., when the muscle activation waveform turned “on” see Figure 9).

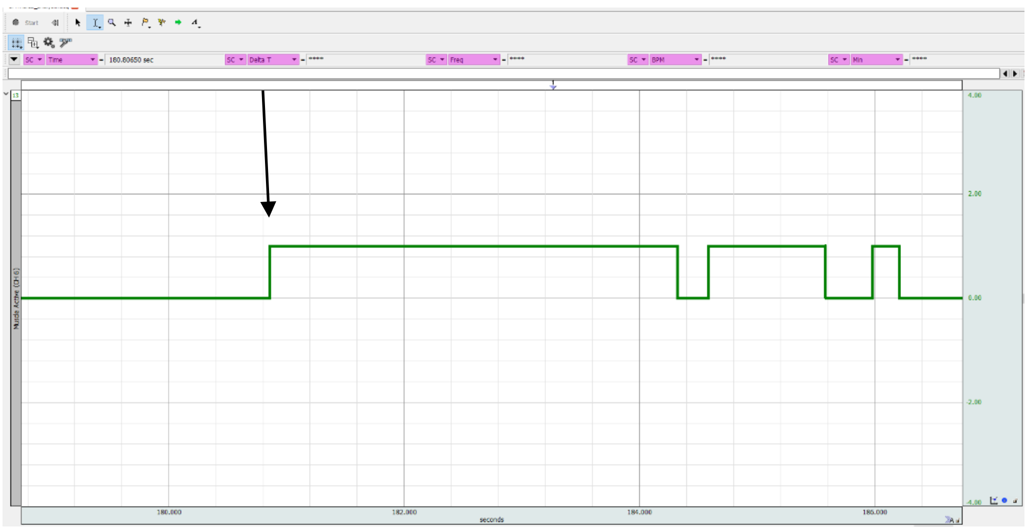

Figure 9. Sample transformed muscle activation waveform for the orbicularis oris. The arrow indicates the onset of lip pucker.

Two periods of submental muscle activation served as points for analysis. First, jaw lowering onset was analyzed using the transformed submental muscle activation signal and was defined by a distinct change in the signal compared to baseline ("mouth opening" variable; see Figure 10).

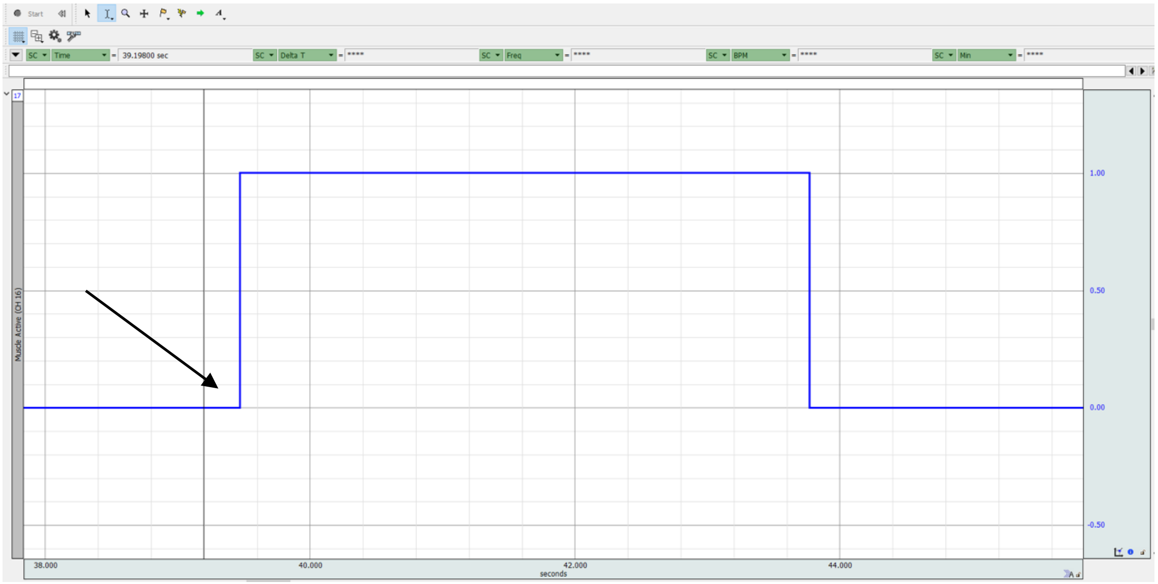

Figure 10. Sample transformed muscle activation waveform for the submental muscles. The arrow indicates the onset of mouth opening/jaw lowering.

Second, an approximation of the onset of hyolaryngeal movement during the pharyngeal swallow response was analyzed using the submental activation signal ("pharyngeal swallow" variable). This was marked as a second period of increased muscle activation as compared to baseline. As surface EMG may pick up additional muscle activation signals, we also utilized visual means (i.e., video recordings and time point markings made during the study by the examiner) to visually approximate when the pharyngeal swallow occurred. These visual signals in conjunction with the submental EMG provided a clearer picture regarding the approximate onset of the pharyngeal swallow response (see Figure 11 on the following page).

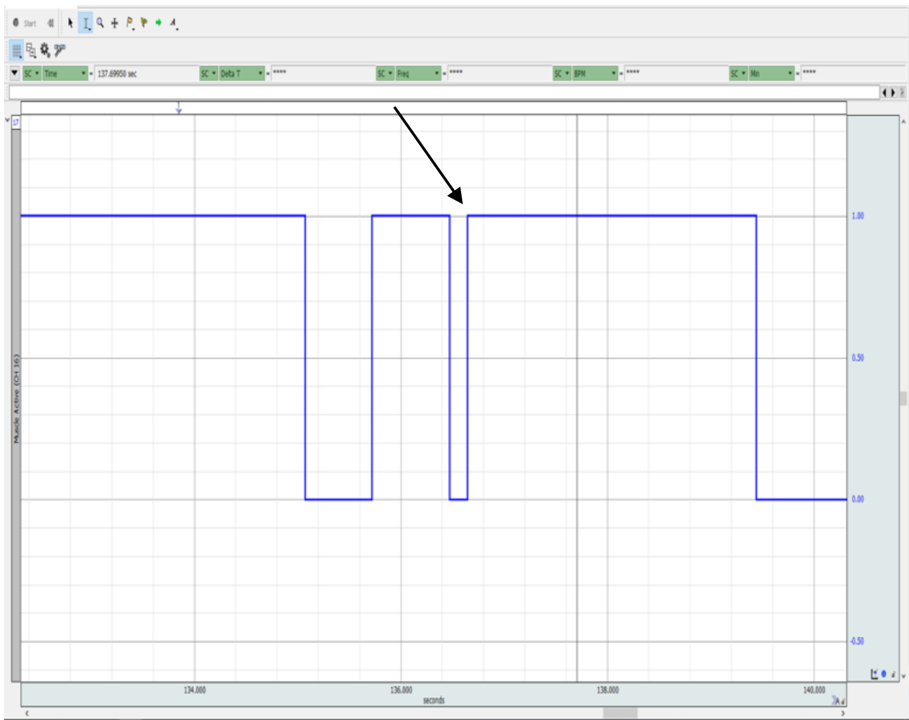

Figure 11. Sample transformed muscle activation waveform for the submental muscles. The arrow indicates the onset of pharyngeal swallow.

While all the signals were analyzed and variables derived across all conditions, the goal of the current study was to specifically explore the impact of proprioception on respiratory patterns (namely swallow apnea) during eating. Swallow apnea was considered relative to three important time points: onset of initial reaching movement (an event more peripheral to the swallow, but the marker of onset of the eating sequence), onset of feeding (another more peripheral event, but the marker of the onset of feeding action) and onset of pharyngeal swallow (a central event in the swallow sequence that is tightly linked to respiration).Thus, the final analysis set for the current study only included the data from following variables: reach to grasp, reach to feed, oral sensation, swallow apnea, chest apnea, and pharyngeal swallow from the “typical self-feeding” and “assisted typical feeding” conditions. A description of each of these variable is summarized in Table 3. Individual trials were excluded from the analysis if the participant laughed or talked during the trial. Statistical analyses of the relative onset measures using paired t-tests was conducted.

Variable	Description
Reach to grasp	The onset of the trial or the time point when the participant/feeder took their hand off the sensor and moved their arm toward grasping the cup/spoon
Reach to feed	The onset when the participant or the feeder began moving the cup or spoon towards the participant’s mouth (after the cup/spoon had been grasped)
Oral sensation	The onset of the straw or spoon touching the participant’s lips
Swallow apnea	The onset of no airflow was moving in or out of the nasal cannula (limited to the moments surrounding the swallow)
Chest apnea	The onset of the pause in chest breathing preceding the swallow represented by a plateau in the signal and confirmed against the period of “swallow apnea” indicated by the nasal cannula signal
Pharyngeal swallow	An approximation of the onset of hyolaryngeal movement during the pharyngeal swallow response using the submental activation signal and video recordings

Table 3. Study variables and descriptions.

Inra-rater and inter-rater reliability measures were completed on approximately 20% of the data (i.e., 8 trials per participant). Intra-rater and inter-rater reliability were 83.0% and 78.7%, respectively. Regarding inter-rater reliability, when there was a large discrepancy between the first and second coders, the coding definitions were reviewed together and the signals were re-measured.

CHAPTER III

RESULTS

The purpose of this study was to investigate the relationship between upper limb movement and swallow apnea onset. Specifically, we sought to explore whether proprioception influences the onset of the swallow apneic period in younger adults. We hypothesized that younger adults would exhibit a later onset of the swallow apnea period during assisted feeding trials than during self-fed trials. The following section is divided into three segments: "Respiration relative to grasp and feeding movements," "Respiration relative to pharyngeal swallow movements" and an overall summary of the results. For variable names and definitions please refer to Table 3 in "Methods and Procedures".

Respiration Relative to Grasp and Feeding Movements

To examine the impact of proprioception on swallow apnea, onset time for the apnea measures were first calculated relative to the more peripheral eating events (reach to grasp and reach to feed; see Table 4). For pureed consistencies, the onset of "swallow apnea" relative to "reach to grasp" was earlier when the participants fed themselves (M = 5.202, SD = 9.48) as compared to when they were fed by the feeder (M = 6.083, SD = 1.150; $t(13) = 2.22$, $p = 0.044$). The same result was observed during water trials; "swallow apnea" onset was earlier when the participants fed themselves (M = 5.105, SD=1.434) as compared to when they were fed by the feeder (M = 6.223, SD = 1.513; $t(13) = 2.912$, $p = 0.012$). A similar pattern was observed with the "chest apnea" variable in relation to "reach to grasp" (see Table 4 below). These results indicate that the onset of swallowing-related apnea relative to the onset of motor movement for eating (i.e., reaching to grasp) occurs later when being fed.

Table 4
Respiration relative to reach grasp and feeding movements

		Mean (seconds)		**Standard Deviation**		***t*-test**		***p*-value**	
Variables		Puree	Water	Puree	Water	Puree	Water	Puree	Water
Swallow apnea/grasp	SF	5.202	5.105	9.48	1.434	2.22	2.912	0.044*	0.012*
	AF	6.083	6.223	1.150	1.513				
Swallow apnea/feed	SF	3.628	3.897	0.703	1.159	0.316	0.151	0.757	0.881
	AF	3.536	3.848	1.243	1.370				
Chest apnea/grasp	SF	5.197	4.855	1.241	1.796	2.281	3.098	0.040*	0.008*
	AF	6.32	6.276	1.327	1.250				
Chest apnea/feed	SF	3.365	3.536	0.871	0.969	0.911	0.814	0.378	0.429
	AF	3.788	3.900	1.771	1.00				

Note: AF = assisted feeding condition; feed = "reach to feed;" grasp = "reach to grasp;" SF = self-feeding condition. Variables are presented A/B where the values are onset time (seconds) of variable A relative to variable B. An asterisk (*) indicates a statistically significant difference ($p < .05$).

A similar pattern was not observed when examining the onset of "swallow apnea" relative to the "reach to feed" movement. No significant differences were observed when participants were feeding themselves (puree: $M = 3.628$, $SD = 0.703$; water: $M = 3.897$, $SD = 1.159$) as compared to when they were fed by the feeder (puree: $M = 3.536$, $SD = 1.243$; $t(13) = .316$, $p = 0.881$) (water: $M = 3.848$, $SD = 1.370$; $t(13) = 0.151$, p = 0.881). Similarly, no differences were observed for "chest apnea" for both pureed and water trials (see Table 4). Taken together with the previous findings, this suggests that the feeder and participant brought the cup/spoon to their mouth at the same rate once it was grasped.

Given the presence of a significant difference in "swallow apnea" onset relative to "reach to grasp" between self-feeding and assisted feeding, but the lack of such a difference when examining "swallow apnea" relative to "reach to feed," further analyses were completed. Specifically, post-hoc it was hypothesized that the apparent "delay" in onset of the apneic period during assisted feeding as compared to self-feeding was due to a longer reach to grasp gesture rather than an actual difference in swallow apnea onset timing. To explore this hypothesis, we separated out the relevant components of the pre-oral, oral, and pharyngeal stages of the swallow from the full "reach to grasp" to "swallow apnea" sequence. In other words, we explored differences in the timing of the full pre-oral gesture ("reach to grasp" relative to "oral sensation"), the feeding gesture ("reach to feed" relative to "oral sensation"), and the oropharyngeal stage ("oral sensation" relative to "swallow apnea"). A significant difference was observed in "reach to grasp" relative to "oral sensation" when comparing self and assisted feeding. Relative to "reach to grasp", the onset of "oral sensation" was approximately 1 second earlier when participants fed themselves puree/water than when they were fed by the feeder (see Table 5 below). However, no difference was observed when comparing only the feeding movement relative to the onset of "oral sensation" during the self-fed and assisted feeding conditions for any stimulus. Additionally, no difference was observed between the onset of "oral sensation" and "swallow apnea" between the two conditions. This suggests that the difference in time for the hand to reach the mouth is due to "reach to grasp" rather than the "reach to feed". This also suggests that the "reach to grasp" movement is driving the differences between the self-feeding and assisted feeding conditions. These conclusions can be applied to the finding that the onset of the swallow apnea period occurred earlier when participants fed themselves as compared to when they were being fed. Together, this suggests that the timing difference between self- and assisted feeding for the onset of the swallow apnea period relative to onset of moving the hand for feeding may be attributed to the increased time it takes for the feeder to reach for the food item as compared to when the participants reached him/herself.

Table 5
Oral sensation relative to grasp/feed and swallow apnea

		Mean		**Standard Deviation**		***t*-test**		***p*-value**	
Variables		Puree	Water	Puree	Water	Puree	Water	Puree	Water
Grasp/oral sensation	SF	3.00	2.742	0.803	0.978	3.461	3.991	0.004*	0.001*
	AF	3.97	3.863	0.866	0.987				
Feed/oral sensation	SF	1.432	1.434	0.443	0.545	0.206	0.482	0.839	0.638
	AF	1.469	1.504	0.856	0.162				
Oral sensation/ swallow apnea	SF	2.277	2.223	0.860	0.945	0.943	1.286	0.364	0.222
	AF	2.468	2.746	1.086	1.029				

Note: AF = assisted feeding condition; feed = “reach to feed;” grasp = “reach to grasp;” SF = self-feeding condition. Variables are presented A/B where the values are onset time (seconds) of variable A relative to variable B. An asterisk (*) indicates a statistically significant difference ($p < .05$).

Respiration Relative to Pharyngeal Swallow Movements

To examine the impact of proprioception on swallow apnea, onset time for the apnea measures were also calculated relative to pharyngeal swallow movements, an event in the swallow sequence thought to be centrally coordinated with respiratory timing (see Table 6 below). No significant differences were observed in “swallow apnea” relative to “pharyngeal swallow” between when participants fed themselves (puree: *M* = -0.792, *SD* = 1.285; water: *M* = -0.183, *SD* = 1.246) as compared to when they were fed by the feeder (puree: *M* = -0.457, *SD* = 1.027; *t*(13) = .867, *p* = 0.401) (water: *M* = -0.429, *SD* = 0.953; *t*(13) = 0.726, *p* = 0.480). Similar findings were observed when using the “chest apnea” relative to “pharyngeal swallow” variable (see Table 6). Therefore, this relationship does not appear to be influenced by proprioception. This provides a stronger argument for a more centrally driven pattern of respiratory-swallow coordination and that perhaps respiratory timing is invariant to proprioceptive cueing.

Table 6
Respiration and pharyngeal swallow movements

		Mean		**Standard Deviation**		***t*-test**		***p*-value**	
Variables		Puree	Water	Puree	Water	Puree	Water	Puree	Water
Swallow apnea/ pharyngeal swallow	SF	-0.792	-0.183	1.285	1.246	0.867	0.726	0.401	0.480
	AF	-0.457	-0.429	1.027	0.953				
Chest apnea/ pharyngeal swallow	SF	-0.162	-0.578	0.681	0.126	0.002	1.183	0.998	0.258
	AF	-0.163	-0.376	1.751	0.749				
Grasp/ pharyngeal swallow	SF	5.692	5.704	0.856	1.427	2.321	2.601	0.037*	0.022*
	AF	6.505	6.654	0.731	1.155				
Feed/ pharyngeal swallow	SF	4.116	4.116	0.567	0.567	0.654	0.563	0.524	0.258
	AF	3.964	4.279	0.654	0.995				

Note: AF = assisted feeding condition; feed = “reach to feed;” grasp = “reach to grasp;” SF = self-feeding condition. Variables are presented A/B where the values are onset time (seconds) of variable A relative to variable B. An asterisk (*) indicates a statistically significant difference (*p* < .05).

Additional post hoc analyses were done to explore the entire eating sequence from reaching onset through pharyngeal swallow, similar to the analyses of reaching onset to apnea onset. Of interest, significant differences were observed between the self-feeding and assisted feeding conditions for the onset of the “pharyngeal swallow” relative to “reach to grasp” for both puree and water trials (see Table 6). This represents the amount of time between when the participant or feeder first started to reach and when the participant swallowed. This value encompasses the entire pre-oral, oral preparatory, and transit stages and was longer when someone was being fed versus when feeding themselves. It is likely that this difference again reflects the increased duration of the “reach to grasp” gesture for the feeder as compared to the participant as described previously. Notably, no difference was found between the two conditions for “pharyngeal swallow” relative to “reach to feed” (see Table 6), similar to what was observed previously.

Summary

Several timing differences regarding the more peripheral (e.g., reach to grasp) components of eating relative to respiration and the pharyngeal swallow were found to be significant. Foremost, swallow apnea relative to the onset of the reach to grasp gesture was later when being fed as compared to when self-feeding. Similar findings were observed when examining the pharyngeal swallow relative to the onset of the reach to grasp gesture. However, these appeared to be due to a longer reach to grasp gesture. In other words, the feeder took longer to reach for the cup/spoon as compared to the participant. However, once the cup/spoon started moving towards the mouth (reach to feed), and through the swallow apnea and pharyngeal swallow, the timing differences between the two conditions stayed relatively constant (see Figure 12). Together, this suggests that proprioception may not influence the onset of the more centrally driven components of swallowing, namely respiration and the pharyngeal swallow.

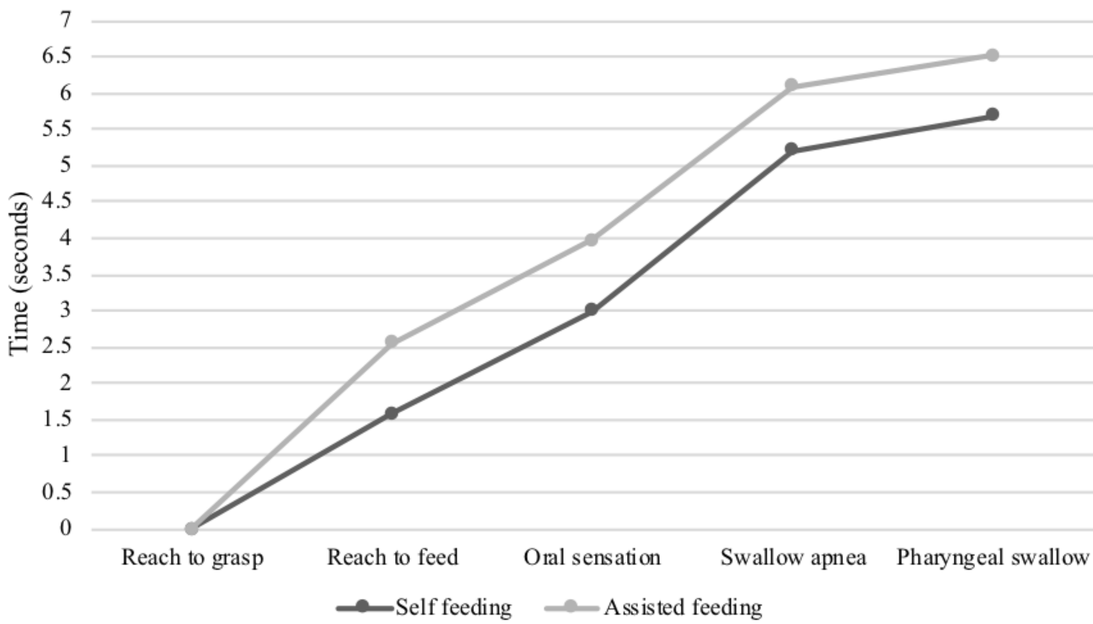

Figure 12. Onset times of eating-related events relative to reach to grasp for self- and assisted feeding conditions.

CHAPTER IV

DISCUSSION

The purpose of this study was to investigate the relationship between upper limb movement and swallow apnea onset during eating in healthy young adults. Specifically, this study aimed to determine if proprioception has an impact on the onset of the swallow apneic period. We hypothesized that younger adults would exhibit a later onset of the swallow apnea period during assisted feeding trials than during self-fed trials.

The findings of this study indicated that swallow apnea relative to the onset of "reach to grasp" was later when being fed as compared to when self-feeding. However, this appeared to be due to a longer reach to grasp gesture. In other words, the feeder took longer to reach for the cup/spoon as compared to the participant. However, once the spoon/cup started moving toward the mouth (reach to feed gesture) through the swallow apnea and pharyngeal swallow, the temporal difference between the two conditions stayed relatively constant (Figure 12). There was also no significant difference between self- and assisted feeding for the onset of swallow apnea relative to the pharyngeal swallow. This suggests that proprioception may not influence the onset of the more centrally driven components of swallowing, including the timing of swallow apnea onset.

Findings Relative to Previous Literature

The results of the current study support that swallow apnea onset does not appear to be impacted by proprioceptive information. These results differ from the previous literature that reported an impact of proprioception on the more volitional aspects of the eating/swallowing process (e.g., mouth opening). Shune et al. (2016) found that anticipatory mouth movements were delayed in presence of proprioceptive loss. At first glance, the findings of the current study appeared similar to the previous findings given that when using the onset of hand movement as the reference point, both studies found delayed respiratory/mouth opening onset in the assisted feeding condition. However, during the Shune et al. (2016) study, participants and feeders began with the bite/sip in their hand (i.e., at the onset of the trial, the cup/spoon was already in their hand). Therefore, the onset of hand movement in the previous study was more in line with the onset of our “reach to feed” gesture in the current study. Thus, the mouth opening delay in the original studies during assisted feeding differed from the lack of difference for onset of swallow apnea in the current study when using the reach to feed gesture.

Castiello (1997) suggested that individuals rely on somatosensation to modify and adapt their mouth for the bolus in the absence of visual cues during feeding. It is unclear if there is a parallel in this relationship in that individuals would rely on, or increase their reliance on, visual cues in the absence of somatosensation, which occurs during assisted feeding. It is important to consider that during the current study, the length of the “reach to feed” gesture remained constant between assisted and self-feeding. During assisted feeding trials, as proprioception was taken away from the participant, the participant had to rely on visual cues as much as possible as the spoon or straw approached their mouth. Given the lack of timing differences found when using the “reach to feed” gesture as a reference point in the current study, it appears as though participants were doing just that.

Previous studies have suggested that exteroceptive stimuli (i.e., vision) can influence pre-oral mouth opening timing and magnitude, particularly when proprioceptive and exteroceptive loss co-occur (Shune et al., 2016). Therefore, if the current study also analyzed the simulated visual loss in addition to proprioceptive loss condition (e.g., blindfolded assisted feeding), the results may have yielded a difference between the conditions.

The results of the current study also support that respiratory-pharyngeal swallow coordination was not impacted by proprioception. Precise respiratory and swallowing coordination is crucial for preventing aspiration during swallowing (Martin-Harris et al., 2005b). Therefore, this precise coordination supports the presence of a central pattern generator to automatically/non-volitionally control the precise timing of movement of these systems (Hiss et al., 2003). Given that it could be detrimental, and dangerous, to the system if this precise coordination were disrupted by external factors, we may expect more peripheral pieces of the swallow to not influence the timing. As swallow apnea onset was not impacted by proprioception, particularly apnea onset relative to the pharyngeal swallow, it supports that swallow apnea onset may be a centrally driven event that is also centrally linked to the swallow reflex itself.

Neurophysiologists have identified specialized neural networks in the brainstem and cortex which support a “tight” neural coupling between respiration and swallowing (Jean, 2001). Some studies have discussed that the neural link between respiration and the swallow may become “uncoupled” due to age, disease, or because of the eating and swallowing task (e.g., posture, compensatory strategy usage, bolus presentation) (Martin-Harris, 2008). However, the results of the current study support the presence of this “tight” coupling in that proprioceptive cues did not influence respiratory-swallowing coordination. Previous findings by Hiss et al. (2001) found that swallow apnea duration can be influenced by external factors such as bolus volume. However, while bolus volume provides some external information (e.g., visual cues of the size, proprioceptive cues of the weight), more centrally cues are obtained once the bolus is in the oral cavity. Thus, in the previous literature on swallow apnea duration, the system may be responding to the oropharyngeal sensory cues provided by the bolus as the size of the bolus impacts other aspects of the swallow such as muscle recruitment. In the current study, we essentially studied “all or nothing” proprioception in the presence of intact visual cues. Thus we cannot rule out the potential importance of proprioception in terms of providing information regarding how we need to swallow given varying degrees of other important sensory cues (e.g., big bite/small bite, sticky food/smooth food).

The current study sought to understand if proprioception may influence this neural coupling. The findings suggested that proprioception did not influence the onset swallow apnea. Therefore, although proprioception did not influence swallow apnea onset, it is still remains unknown if and which other factors *could* impact onset. Further, while we were particularly interested in swallow apnea onset because of its importance for swallow safety, it is possible that other aspects of the swallow apnea, such as duration, may be impacted by more peripheral input such as proprioception as previous findings have found that it can be influenced by external factors (e.g., bolus volume).

Clinical Significance

The findings of this study suggest that proprioception has little impact on swallow apnea onset. However, previous literature has pointed to the importance of proprioceptive cues on the eating process. Additionally, it is important to consider that this study was done in healthy younger individuals who have a high degree of functional reserve, so it is possible that when there is less reserve (e.g., older adults, given the presence of disease), proprioception may play a greater role in the timing of swallow-related events and therefore needs to be attended to.

As such, these results are of importance to consider for individuals who rely on assisted feeding for both short and long term periods of time. Although assisted feeding is recommended for increasing safety (e.g., decreasing risk of choking), it ultimately provides individuals with less sensory cues (i.e., proprioception, visual) that are known to be involved in and influence the eating process (Shune & Moon, 2016). Additionally, mealtime support is generally a task given to less trained staff members who may be unaware of issues such as positioning, pacing, and bolus size (Aziz & Campbell-Taylor, 1999; Chadwick, Jolliffe, & Goldbart, 2003).

Currently, there is limited to no specific research regarding assisted feeding in the young adult population and among non-institutionalized individuals. Batchelor-Murphy et al. (2017) assessed assisted feeding in nursing home residents who required mealtime assistance. Generally, direct hand feeding has been the most widely utilized method to provide feeding assistance. This study compared the efficacy of three handfeeding techniques: direct hand, over hand, under hand. During direct hand feeding, the caregiver holds the object (e.g., fork, spoon, cup) with the intent to provide food/fluids without any active involvement from the resident. During over hand feeding, the caregiver put his/her hand over the residents to support/guide them with self-feeding. During under hand, the resident holds the object (e.g., fork, spoon, cup) and the caregiver places their hand under the resident's hand. Theoretically, this allows the resident to more greatly feel as though they initiated and are in control of the movement as compared to over hand feeding.

Batchelor-Murphy et al. (2017) found that direct hand and under hand resulted in greater intake than over hand and are viable options to increase meal intake. However, they found that the under hand feeding technique also reduced negative feeding behaviors (i.e., turning head away, spitting food out, refusal to open mouth) commonly associated with direct hand feeding. Although this study specifically looked at intake rather than swallow safety, the results indicate that under hand feeding is a viable option which promotes equivalent intake to direct hand with less feeding behaviors. Of interest, negative feeding behaviors can be linked to dysphagia: as individuals with dementia lose their functional communication abilities, they may express their perceived difficulties with swallowing (e.g., pharyngeal residue, pain with swallowing) through negative behaviors. As under hand feeding provides individuals with proprioceptive cues not available during direct hand feeding, this lends further support for the role proprioception plays in influencing the feeding – and perhaps also the swallowing – process.

Notably, the current study found that the "reach to feed" gesture took the same length of time for both the feeders and the participants. This result may have been due to high level of awareness and specialized experience and coursework for providing feeding assistance that the feeders in the current study possessed. In practice, feeding assistance is often a task given to less trained staff members who do not have the time, skill, or specialized training to do the task perfectly (Aziz & Campbell-Taylor, 1999; Chadwick et al., 2003). These staff members are often engaged in multiple tasks at once and often are not focusing solely on feeding one individual. The results of the current study suggest that there is no impact on swallow apnea onset, a crucial safety mechanism in swallowing, when the length of time is consistent for bringing food to the mouth. It is unclear if a lack of impact on swallow apnea would be present given alterations in the length of the feeding gesture. If the length of the feeding gesture was found to differ between highly trained and untrained feeders, this suggests a potential benefit of more trained and dedicated feeding staff who can be highly aware of typical self-feeding patterns.

These considerations should also be taken into account during informal bedside swallowing assessments and formal swallowing assessments such as modified barium swallow and fiberoptic endoscopic evaluation of swallowing (FEES) studies. Often, clinicians administer the bites and sips of food and drink to the patients and watch them swallow to assess overall swallow safety and to make diet recommendations. When the clinician is feeding the patient, the patient is not getting typical eating-related proprioceptive cues. Thus, it is not clear whether this would result in different swallowing patterns, or study outcomes, as compared to having the patient self-feed. Additionally, as the current study only looked at healthy individuals, we do not know what patterns look like in individuals with dysphagia, suggesting a need for further research.

Further, regarding treatment, this study highlights the importance for clinicians to have a strong underlying understanding of swallow physiology and the factors, both central and peripheral, that influence the swallow. Plowman and Humbert (2018) found that among 188 practicing speech-language pathologists, there was a low level of agreement on binary ratings on swallowing events and moderate to poor levels of accuracy for identifying disordered swallowing. Beyond indicating the need for better understanding swallow physiology and the events involved, these results also suggest the importance of understanding the range of normal function. If timing of swallowing events can be impacted by factors such as bolus size, flavor, and assisted feeding, observed "delays" or differences in physiology may not always be an actual abnormality. As speech-language pathologists are the main health care provider for the evaluation and treatment of dysphagia, it is crucial for clinicians to be aware of these factors to ensure accurate assessment and that their own actions may not be impacting patient outcomes during treatment.

Further, after the current study, participants were asked follow-up questions regarding their perceptions about being fed and what cues they relied on during the different conditions. Overall, participants reported that they preferred to feed themselves versus being fed by someone else. They reported that they felt "awkward". Regarding sensory cues, participants indicated that they relied heavily on visual cues during assisted feeding and "the feeling and movement of their own arm" during self-feeding. Therefore, these responses alone support the importance of sensory input through both visual and proprioceptive means for individuals during feeding tasks. Although differences were not seen in onset of respiration, it might be that this onset is influenced by other factors (e.g., vision) or is more centrally driven while other aspects of swallowing are more modifiable peripherally. It is also possible that younger adults have a more flexible system, allowing them to modify their reliance on the cues that were available.

Based on the results of this study, proprioception, which is known to influence some aspects of the eating process (e.g., mouth opening), may influence the timing of additional peripheral swallow events (i.e., reach to grasp). Therefore, it is important to consider this when feeding individuals who rely on feeding assistance and perhaps feeding techniques which maximize sensory input for the individual with dysphagia should be more widely utilized.

Additional Limitations

Limited sample. The sample size of the current study was relatively small with only 14 participants. Therefore, it may not have produced an accurate representation to draw inferences regarding the entire population from the obtained results. Additionally, 79% of the participants were speech-language pathology graduate students. Therefore, the participants had a high awareness of feeding and swallowing behaviors and their prior background knowledge may have influenced their behavior during the experiment. However, when comparing the results of speech-language pathology students and non-students, there appear to be no significant differences. Future studies should include a more varied participant range. The study was also limited by location as it only took place in Eugene, Oregon. While the limited geographical location may affect the ability of the results to be applied to the entire population, many of the participants were originally from different states and it is expected that geography would not significantly impact patterns of physiology.

Eating environment. After the completion of the trials, participants were asked follow-up questions including: “How did you feel about being fed” and “What cues did you rely on during the trials”. Often, participants reported that they felt “awkward” being fed by another person. Additionally, for some of the participants, the feeder was a professor and for others, the feeder was a classmate. Therefore, participant attitudes towards being fed and relationships outside of the study with the feeders may have influenced their feeding and swallowing behaviors during the study and responses during the follow-up interview. Thus, it may be useful to use feeders who have no relation to the participants in future studies. Further, although participants were asked to eat and drink as naturally as possible, participants were attached to numerous sensors (See Figure 3), which may have impacted their feeding and swallowing behaviors. Lastly, the study took place in a controlled lab setting which is not representative of eating and drinking in everyday life. However, as the study aimed to tightly control the available sensory cues during the conditions, the lab setting allowed to better be able to control these factors. But, perhaps a more natural setting would impact eating and drinking behaviors. These limitations are important considerations for future experiments.

Future Directions

Simulate increased sensory loss. During the current study, the only simulated sensory loss analyzed was proprioception. Therefore, individuals were still provided with visual and auditory stimuli. In future studies, it would be important to simulate different sensory loss (i.e., vision) as well as increased sensory loss across multiple domains (i.e., vision and proprioception). By doing so, this would provide us with information regarding what sensory cues may be most meaningful and important for swallowing. Increased sensory loss may impact the individual’s ability to anticipate the bolus arriving at their mouth. Exteroceptive and proprioceptive sensory loss in combination has been shown to impact feeding behaviors during assisted feeding (Shune et al., 2016). Thus, by simulating different/increased sensory loss in future studies, perhaps we may see an impact of this sensory loss on the centrally driven aspects of swallowing in addition to a greater impact on the more peripheral aspects (i.e., reach to grasp).

Use less "conscientious" feeders. The feeders in this study were a licensed speech-language pathologist and speech-language pathology students. Therefore, due to their coursework and training emphasizing pacing and bolus size, they were extremely conscientious when feeding participants. The yielded results found no significant difference during the "reach to feed" movements between the two conditions; however, this may be due to the fact that the feeders were highly trained and provided with specialized instruction. Feeding assistance is typically a task given to less trained staff members (Aziz & Campbell-Taylor, 1999; Chadwick et al., 2003). Future studies should utilize feeders with less feeding knowledge or specialized experience to determine the full effect of timing differences under more typical, "real-life," conditions. Further, if differences emerge in the results when using less trained feeders, this would have important implications for clinical practice patterns and training needs.

Clinical profiles. The inclusion criteria for the current study was for healthy individuals aged 18 to 30 years old. However, future studies should expand inclusion to include older adults (70+) and/or individuals across the age spectrum. Studies have suggested that age can influence aspects of the swallow such as swallow apnea duration as well as anticipatory mouth movements (Hiss et al., 2001; Shune et al., 2016). Thus, by expanding the criteria to include at least an older adult subset, it would allow us to gain systematic data of swallowing across the lifespan and to see if timing differences occur as individuals age. Further, only healthy young adults were utilized during this study, but future studies should include individuals who have dysphagia. Including individuals with dysphagia would be useful as it would provide a comparison group for the healthy young adults. Additionally, it would provide formal data regarding the timing of swallowing events for individuals with dysphagia. It is possible, and perhaps likely, that the timing of the swallowing events studied here may be impacted in individuals with dysphagia. Therefore, it is crucial to better understand differences that occur between the disordered and healthy populations to identify factors that can be utilized therapeutically to maximize patient outcomes.

Respiratory phase patterns (exhale-exhale). Respiratory phase patterns have been explored in various studies (e.g., Hiss et al., 2001; Martin, Logemann, Shaker, & Dodds, 1994). Some researchers have suggested that respiratory phase patterns can be influenced by proprioception; however, there is limited data into this subject matter currently (Hiss et al., 2001). Currently, exhale-exhale (exhale prior to swallow, exhale after swallow) is considered the "gold standard" and safest phase pattern to prevent aspiration and penetration. Martin-Harris (2008) found that respiratory phase can be utilized clinically and trained patients who had dysphagia secondary to head and neck cancer to utilize this pattern. The results indicated that by utilizing this phase pattern, there were less aspiration and penetration events. Therefore, phase pattern may be a clinically useful tool. However, less is known regarding the relationship between phase pattern and proprioception. Therefore, it is possible that proprioception could influence phase pattern under typical patterns. Future studies should explore if there is a relationship between proprioception and phase pattern as any observed differences should be considered in therapy programs.

Proprioception and other aspects of the swallow. The current study only examined proprioception in relation to swallow apnea and the pharyngeal swallow. However, future studies should expand to look at other peripheral (or more volitional) swallowing events such as initial jaw lowering and lip rounding. Previous studies have indicated that proprioception may impact these events (Shune et al., 2016). As the results of the current study suggest that proprioception has little to no effect on the centrally driven (or more automatic) aspects of the swallow, it would be of interest to gain more systematic data regarding other peripheral events. As the current study supported that swallow apnea is a more centrally driven phenomenon not impacted by proprioception while previous research has suggested that other swallow-related actions such as mouth opening are impacted by proprioception, it is important to gain more systematic data regarding which swallow related events *are* influenced by proprioception. By gaining a deeper understanding of the swallow related events that are peripherally versus centrally driven, it can determine if and how they can be modified to optimize swallow safety.

Use of surface EMG. The current study utilized surface EMG in combination with video to estimate when the pharyngeal swallow occurred. Surface EMG may not be the most exact marker for the pharyngeal swallow given the large number of muscles it picks up information from. Future studies should utilize a more exact measurement, such as videofluroscopy, to obtain the exact onset of the pharyngeal swallow and visualize all swallow-related events. This would provide a more accurate measure to determine when the onset of these events occurred to strengthen results of the data.

Summary

This study was designed to determine whether proprioception influences the onset of swallow apnea and how it impacts other peripheral swallow-related events. The current study supports that proprioception has little to no impact on the onset of the swallow apnea period. However, the current study did find that the length of time to reach for the item to eat/drink was longer during assisted feeding. An overall goal of this study was to begin to provide systematic data regarding the timing of swallowing events in young adults. Additionally, the study sought to obtain data to better understand and determine what differences exist when comparing assisted and self-feeding. This information alone can better help clinicians determine what is the safest and most effective approach when feeding individuals who require feeding assistance. By gaining a better understanding the physiological impact assisted feeding has on individuals throughout the lifespan, we can best serve individuals who rely on feeding assistance and optimize swallow safety.

APPENDIX

ADULT INFORMED CONSENT DOCUMENT

Project Title:	**Anticipatory sensorimotor cues to promote swallow safety**
Principle Investigator:	Samantha Shune, PhD, CCC-SLP sshune@uoregon.edu / (541) 346-7494 Communication Disorders and Sciences

This consent form describes the research study to help decide if you want to participate. This form provides important information about what you will be asked to do during the study, about the risks and benefits of the study, and about your rights as a research participant.

- If you have any questions about or do not understand something in this form, you should ask the research team for more information.
- You should discuss your participation with anyone you choose such as family or friends.
- Do not agree to participate in this study unless the research team has answered your questions and you decide that you want to be a part of this study.

Introduction

- You are being asked to be in a research study about eating and swallowing patterns.
- You were selected as a possible participant because you are healthy and have no history of a speech-language, neurological, or psychiatric condition.
- We ask that you read this form and ask any questions that you may have before agreeing to be in the study.

Purpose of Study:

- The purpose of this study is to better understand typical eating and swallowing patterns across the lifespan.
- Up to 60 people will take part in this study, 30 between the ages of 18 and 30 and 30 between the ages of 70 and 90.

Description of the Study Procedures:

- If you agree to take part in this study, your involvement will last for approximately one hour.
- During the study, you will be asked to eat and drink different foods and liquids that vary in volume and type.
- While eating and drinking these items, muscle activity and body movements will be recorded via small sensors that will be attached to your face and arm/elbow. These sensors will be attached to your skin using either double-sided tape or medical grade tape, which can be removed easily at the end of the session, attached via a Velcro strap placed around your chest/abdomen, and/or attached to your face via a nasal cannula.

- During one portion of the study, you will be asked to feed yourself as you typically would. During other portions of the study, you will be fed by a researcher assistant and/or you will eat while being blindfolded.
- Video recordings will be made during the study. These recordings help us analyze performance on our study measures No portion of the video recording will be heard or seen outside of the research team without first obtaining your explicit, written permission.
- You will be free to stop any of the testing at any time.
- The results will be confidential, but we are happy to discuss any of them with you. If you would like to be notified of this study's findings, please initial here and we will contact you when they are available: _________.

Risks/Discomforts of Being in the Study:

- You may experience one or more of the following risks or uncomfortable conditions during the course of this study. In addition to these, there may be other unknown risks, or risks that we did not anticipate, associated with being in this study.
- As with all daily meals, the consumption of foods and liquids may result in coughing or choking and this risk may be slightly increased when being fed by the examiner while blindfolded (food/drink 'going down the wrong way'). Additionally, you may find periods of successive swallowing to be tiring; however, you may take a break as needed during the testing. You may find the adhesives on your skin potentially uncomfortable or irritating. There is also a risk of loss of confidentiality of your study-related information.

Benefits of Being in the Study:

- You will not benefit from being in this study.
- We hope that, in the future, other people might benefit from this study because the results may help us better understand the process of swallowing and how swallowing problems occur, allowing for the development of better treatment options for individuals with swallowing problems.

Payments:

- You will receive a $10 gift card for your participation in this study.

Costs:

- There is no cost to you to participate in this research study.

Confidentiality:

- We will keep your participation in this research study confidential to the extent permitted by law. All records will be maintained for ten years for data analysis and publication purposes.
- The records of this study will be kept private. In any sort of report we may publish, we will not include any information that will make it possible to identify any participant. All records will be identified only by a code number.
    - With explicit, written permission, video recordings may be used for educational purposes (e.g., classroom teaching). Please indicate if you release your video for non-research staff viewing (circle one): Yes / No

    - If “yes”, we would notify you prior to any non-research use. Please include the best way to contact you here: _________________________.
- All paper/hard copy records will be maintained in locked filing cabinets in a laboratory that is always locked unless a member of the research team is present.
- All electronic information (including video recordings) will be coded and secured on password-protected computers.
- Access to the records will be limited to the researchers; however, please note that regulatory agencies, and the Institutional Review Board and internal University of Oregon auditors may review the research records.

Voluntary Participation/Withdrawal:
- Your participation is voluntary. If you choose not to participate, it will not affect your current or future relations with the University.
- You are free to withdraw at any time, for whatever reason.
- There is no penalty or loss of benefits for not taking part or for stopping your participation. Not taking part or stopping your participation will not risk loss of present or future faculty/school/University relationships. If you withdraw from the study early, payment will be pro-rated accordingly.

Contacts and Questions:
- We encourage you to ask questions.
- If you have any questions about the research study itself, please contact: Samantha Shune, Communication Disorders and Sciences, 249 HEDCO, (541) 346-7494, or email sshune@uoregon.edu.
- If you believe you may have suffered a research related injury, contact Samantha Shune at (541) 346-7494 who will give you further instructions.
- If you have any questions about your rights as a research subject, you may contact: Research Compliance Services, University of Oregon at (541) 346-2510 or ResearchCompliance@uoregon.edu

Copy of Consent Form:
- You will be given a copy of this form to keep for your records and future reference.

Statement of Consent:
- I have read (or have had read to me) the contents of this consent form and have been encouraged to ask questions. I have received answers to my questions. I give my consent to participate in this study. I have received (or will receive) a copy of this form.

Signatures/Dates

____

Study Participant (Print Name)

Participant Signature **Date**

Signature of Research Team Member (who obtained consent)

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