INVESTIGATION OF EMBODIED LANGUAGE PROCESSING ON COMMAND-SWALLOW PERFORMANCE

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In the command swallow condition, which is routinely employed during videofluoroscopic examination of swallowing, patients commonly are told to hold a bolus in their mouth until they are told to swallow. Both components of the command swallow, bolus hold and swallowing in response to a command, could influence the act of swallowing. The focus of the current study was to examine the linguistic influences of the verbal command on swallowing. In fact, the language induced motor facilitation theory suggests the linguistic processes associated with the verbal command should facilitate the voluntary component of swallowing.

This study investigated whether language induced motor facilitation was evident under the command swallow condition as reflected in suprahyoid muscle activity measured by surface electromyography. During the experiment, 20 healthy young participants held a 5 ml liquid bolus in their mouth and swallowed the bolus after hearing 5 acoustic stimuli presented randomly: congruent action word (*swallow*), incongruent action word (*cough*), congruent pseudo-word (*spallow*), incongruent pseudo-word (*pough*), and non-verbal stimulus (1000 Hz pure-tone).

Swallow latencies following the congruent action word were shorter than swallows following the non-verbal stimulus, indicating that suprahyoid muscle activity occurred earlier for

following the word *swallow* than for the pure-tone. Longer latencies for the pseudo-words than real words also supported the language induced motor facilitation theory, but it was not clear whether the observed differences were due to reduced linguistic facilitation or longer processing-time associated with interference. Stronger support for the theory captured by lexical directionality was not evident when the words *swallow* and *cough* were compared. The facilitation effects of swallow-related action words may not have sufficient sensitivity and strength among effectors, and the incongruent word in the study may not have represented a true incongruent action against the act of swallowing. There also was no facilitation effect on peak suprahyoid muscle activity amplitude.

The evidence from this study advances our understanding of the links between language and movement for behaviors that are not entirely under voluntary control. Linguistic inducement of swallowing could be useful as a swallow compensatory technique for patients with difficulty initiating oropharyngeal swallows including patients with Parkinson's disease.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

PREFACE

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1.0 INTRODUCTION

Swallowing is defined as the entire act of placing food in the mouth and transporting food through oral, pharyngeal, esophageal structures and into the stomach (Logemann, 1998). It is a complex neuromuscular act that requires sensory and motor coordination and involves organized interactions of cortical, subcortical, brainstem and peripheral systems (Ertekin, 2003; Miller, 2008b). Any disruption of the neurophysiological pathways can result in swallow disorders or dysphagia (Robbins et al., 2008). In the United States, more than 18 million adults are suffering from dysphagia (Robbins et al., 2008).

Patients with dysphagia have a high risk of having dehydration, malnutrition, aspiration pneumonia, and reduction in quality of life (Harrison, Sessions, & Kies, 2014; Logemann, 1998). Aspiration pneumonia is associated with substantial morbidity and mortality with the highest case-mortality rate during hospitalization among all pneumonia diagnoses (Baine, Yu, & Summe, 2001). The financial impact of dysphagia is $1.3 billion dollars a year in the United States (Hsu, Siroka, Smith, Holodniy, & Meduri, 2011). To provide optimal swallow treatments to reduce such risks, carefully controlled swallowing studies are needed to enable the clinician to focus on the specific anatomical and physiological factors influencing swallow function. It is essential for the clinician to observe the patient swallowing under the conditions in which he/she routinely swallows when eating and drinking.

Videofluoroscopic examination of swallowing (VFSS) is considered a gold standard for diagnosis and evaluation of swallowing. It is widely used in the United States (Langmore, 2003; Molfenter & Steele, 2011). Typically during VFSS, the command swallow condition, in which a patient/participant holds a bolus while waiting for a verbal stimulus to initiate the swallow, is employed both for clinical and research purposes (Daniels, Schroeder, DeGeorge, Corey, & Rosenbek, 2007; Hiiemae & Palmer, 2003; Nagy et al., 2013). Normative swallowing data are based on previous research that has employed the command swallow condition (Daniels et al., 2007). However, recent studies provide evidence that the command swallow condition may impact swallow physiology. Based on the evidence, it has been debated whether to continue employing the command swallow condition during VFSS. If swallow physiology under the command swallow condition is different from those of normal swallows, it is crucial to re-establish the normative data of swallowing without the command swallow condition. To evaluate the use of the command swallow condition during the diagnosis and evaluation of swallowing, it is important to understand the impact of the command swallow condition on swallow physiology.

This dissertation document first reviewed the normal swallowing mechanism and physiology, evaluation of swallowing, and what was known about the impact of the command swallow condition on swallow physiology and neurophysiology. The following sections discussed the theoretical framework that supports the research questions. Then, the research questions, hypothesis, methods, data analysis, and results were summarized. The document concluded with a discussion based on the findings, contribution to the literature, limitations of this dissertation document, and future directions.

2.0 SWALLOW MECHANISM

2.1 SWALLOWING PHYSIOLOGY

2.1.1 Phases of swallowing: liquid swallowing

Traditionally, swallowing is divided into three or four sequential phases, such as (1) oral, (2) pharyngeal, and (3) esophageal phases (Dodds, 1989; Dodds, Stewart, & Logemann, 1990; Logemann, 1998). The oral phase is further subdivided into two phases: (1) oral preparatory phase, and (2) oral or oral transport phase (Logemann, Rademaker, Pauloski, Ohmae, & Kahrilas, 1998; Matsuo & Palmer, 2008). This four phase model was primarily developed based on the previous investigations of volitional liquid swallows (Hiiemae & Palmer, 1999), and it describes the physiology of volitional liquid swallows (Matsuo & Palmer, 2008).

2.1.1.1 Oral preparatory phase

After liquid is taken into the oral cavity, it is held on the tongue surface against the hard palate. Then, the liquid is mixed with saliva to form a cohesive mass that is referred to as a bolus, which has appropriate consistency and size for swallowing (Dodds, 1989; Dodds et al., 1990; Hiiemae & Palmer, 2003; Logemann, 1998). The oral cavity is sealed anteriorly by the upper and lower lips, posteriorly by the contact of the soft palate and the dorsum of the tongue, and laterally by the bilateral buccal and facial muscles to prevent the loss of portions of the liquid bolus (Dodds, 1989; Dodds et al., 1990; Hiiemae & Palmer, 2003; Logemann et al., 1998; Matsuo & Palmer, 2008; Shaw & Martino, 2013). The oral preparatory phase is modulated primarily by voluntary control (Logemann, 2007).

2.1.1.2 Oral phase of swallowing

The oral phase of swallowing is initiated when the bolus is propelled between elevating and retracting the tongue and the palate posteriorly along the palate by the tongue (Dodds, 1989; Dodds et al., 1990; Hiiemae & Palmer, 2003; Logemann et al., 1998; Matsuo & Palmer, 2008; Shaw & Martino, 2013). The phase ends when the pharyngeal swallow is triggered (Dodds, 1989; Dodds et al., 1990; Logemann, 1998). The oral phase is modulated by voluntary control (Logemann, 2007). Duration and onset of swallow physiological parameters in the oral phase can vary depending on sensory information coming from the oropharynx, such as bolus volume, consistency, texture, and temperature, as well as motivation, hunger, and consciousness (Ertekin, 2006; Logemann, 2007; Robbins et al., 2008).

2.1.1.3 Pharyngeal phase of swallowing

The next phase is the pharyngeal phase of swallowing. It is initiated when the pharyngeal swallow is triggered (Dodds, 1989; Dodds et al., 1990; Logemann, 1998). In healthy individuals, the pharyngeal swallow is triggered approximately when the bolus head passes any point between the anterior faucial arches and the point where the base of the tongue crosses the ramus of the mandible (Logemann et al., 1998). Once the pharyngeal swallow is triggered, sequential cascading neuromuscular events occur (Logemann et al., 1998). The soft palate is elevated to contact the posterior and lateral pharyngeal walls to close off the nasopharynx (Logemann, 1998; Logemann et al., 1998; Matsuo & Palmer, 2008). The hyoid and larynx are pulled superiorly and anteriorly by the supra-hyoid muscles and the larynx is shortened by the thyrohyoid muscles. This anterior displacement of the hyolaryngeal complex contributes to the airway closure (Steele, Thrasher, & Popovic, 2007). The airway is closed at three levels (i.e., inferiorly at the level of the true vocal folds, within the larynx with adduction of the false vocal folds, and superiorly through arytenoid cartilages tilting forward to contact the thickening of the epiglottic base together with the inversion of the epiglottis) (Logemann, 1998). The laryngeal closure is essential for safe swallowing, and particularly important for preventing foreign materials from entering into the airway (Kurosu & Logemann, 2010; Logemann, 1998). The upper esophageal sphincter (UES) also is opened by as a result of the anterior displacement of the hyolaryngeal complex along with the relaxation of the cricopharyngeal muscle and intrabolus pressure (Kahrilas, 1997; Logemann, 1998; Matsuo & Palmer, 2008). Finally, when the bolus tail reaches the tongue base, the space between the base of the tongue and posterior pharyngeal wall sequentially collapses from the top to bottom to propel the bolus downward (Logemann, 1998; Matsuo & Palmer, 2008).

The pharyngeal phase contains both voluntary and involuntary/reflexive components (Shaw & Martino, 2013) that can be augmented volitionally when swallow compensations are deployed (Humbert & German, 2013). Once the pharyngeal swallow is triggered, the pattern of the previously described cascade of events (i.e., velopharyngeal closure, hyoid elevation, laryngeal closure, and UES opening), cannot be altered (Ertekin, 2003). However, the onset time and duration of hyoid elevation, laryngeal closure, and UES opening, can vary depending on bolus characteristics, such as volume, temperature, consistency, and taste (Ding, Logemann, Larson, & Rademaker, 2003; Kahrilas & Logemann, 1993; Kurosu & Logemann, 2010; Logemann et al., 1995; Mendell & Logemann, 2007; Robbins et al., 2008; Shaw & Martino, 2013). In addition, the onset time and duration of hyoid elevation, laryngeal closure, and UES opening can be altered voluntarily by using swallow maneuvers, such as the supraglottic swallow, super-supraglottic swallow, and Mendelsohn maneuver (Kahrilas, Logemann, Krugler, & Flanagan, 1991; Ohmae, Logemann, Kaiser, Hanson, & Kahrilas, 1996).

2.1.1.4 Esophageal phase of swallowing

When the bolus enters the esophagus at the UES, the esophageal phase is initiated (Dodds, 1989; Dodds et al., 1990; Logemann, 1998). When the bolus passes through the UES, the bolus is carried proximally to distally by a sequential peristaltic wave through the lower esophageal sphincter (Dodds, 1989; Dodds et al., 1990; Logemann, 1998). The esophageal phase of swallowing is theorized to be under involuntary control (Logemann, 1998). It is considered to be mainly under the somatic and autonomic nervous system control (Ertekin, 2003).

2.1.2 Process model of feeding: solid food swallowing

The process model of feeding was developed to describe the physiology of volitional solid food swallowing (Hiiemae & Palmer, 1999; Matsuo & Palmer, 2008; Palmer, Rudin, Lara, & Crompton, 1992). This model divides swallows into three stages: (1) oral stage, (2) pharyngeal stage, and (3) esophageal stage (Hiiemae & Palmer, 1999; Matsuo & Palmer, 2008; Palmer et al., 1992). The oral stage is further divided into (1) stage I transport, (2) food processing, and (3) stage II transport (Hiiemae & Palmer, 1999; Matsuo & Palmer, 2008; Palmer et al., 1992). Swallow physiology of both pharyngeal and esophageal stages is identical to those of liquid swallows (Matsuo & Palmer, 2008).

During the stage I transport, after the solid food is placed in the oral cavity, the food is moved posteriorly to the molar region by the tongue (Hiiemae & Palmer, 1999; Matsuo & Palmer, 2008; Palmer et al., 1992). Then, the solid food is masticated and mixed with saliva until it becomes suitable for swallowing during the food processing (Hiiemae & Palmer, 1999; Matsuo & Palmer, 2008; Palmer et al., 1992). During the stage II transport, masticated food is placed on the tongue surface and propelled posteriorly (Hiiemae & Palmer, 1999; Matsuo & Palmer, 2008; Palmer et al., 1992). Then, the masticated food is accumulated in the upper oropharynx and/or valleculae before it is propulsed to the pharynx and beyond (Hiiemae & Palmer, 1999; Matsuo & Palmer, 2008; Palmer et al., 1992).

2.2 SWALLOWING MUSCULATURE

More than 30 muscles in the oral cavity, larynx, pharynx, and esophagus are activated during swallowing (Shaw & Martino, 2013). Most of the muscles involved in swallowing are striated muscles except the middle and distal esophagus, which are partially and completely smooth muscles (Shaw & Martino, 2013). Muscles involved in swallowing are innervated by cranial nerves, V (Trigeminal), VII (Facial), IX (Glossopharyngeal), X (Vagus), XII (Hypoglossal), the ansa cervicalis (C1-C3), and through the pharyngeal plexus by fibers from the cranial division of XI (Accessory) (Dodds et al., 1990; Logemann, 1998; Sessle & Henry, 1989; Shaw & Martino, 2013).

2.3 SWALLOWING NEUROPHYSIOLOGY

Until the early 1980's, swallowing was considered to be a purely reflexive act controlled primarily by the brainstem (Humbert et al., 2009; Robbins et al., 2008). However, most contemporary researchers agree that swallowing involves the complex interaction of voluntary and involuntary neuronal networks, such as the cortical, subcortical, brainstem and peripheral nervous system (Humbert et al., 2009; Logemann, 1998; Malandraki & Robbins, 2013; Martin & Sessle, 1993; Shaw & Martino, 2013). Yet, questions remain regarding the underlying neural mechanism(s) of swallowing (Humbert & German, 2013).

2.3.1 Infratentorium

Sensory information, such as temperature, touch, and pressure from sensory receptors and taste information from chemoreceptors in the oropharynx are sent to the cranial nerve V (Trigeminal), VII (Facial), IX (Glossopharyngeal), and X (Vagus) and transferred to various nuclei in the brainstem (Jean, 2001; Malandraki & Robbins, 2013). This information then travels through various pontomedullary pathways with their summated input producing motor output through cranial nerve V (Trigeminal), VII (Facial), IX (Glossopharyngeal), X (Vagus), and XII

(Hypoglossal) and the ansa cervicalis (C1-C3) to the muscles involved in swallowing (Jean, 2001; Malandraki & Robbins, 2013).

In the brainstem, the swallowing central pattern generator is believed to be located within the medulla oblongata (Jean, 2001; Malandraki & Robbins, 2013; Miller, 1993). The swallowing central pattern generator contains two main groups of swallow-related neurons: the dorsal swallowing group within and around the nucleus and tractus solitarius in the dorsolateral medulla, and the ventral swallowing group above the nucleus ambiguus in the ventrolateral medulla (Jean, 2001; Miller, 1993). Both peripheral and supramedullary inputs travel to the dorsal swallowing group which contains generator neurons that generate the motor control of swallowing (Jean, 2001; Miller, 1993). The dorsal swallowing group sends the motor signals to the ventral swallowing group, which contains switching neurons, and transmit the outputs from the dorsal swallowing group to motor neuron pools (Jean, 2001; Miller, 1993).

2.3.2 Supratentorium

Evidence from functional magnetic resonance imaging (fMRI) studies indicate that multiple bilateral cortical and subcortical areas are activated during swallowing (Babaei et al., 2010; Hamdy et al., 1999; Huckabee, Deecke, Cannito, Gould, & Mayr, 2003; Humbert et al., 2009; Humbert & Robbins, 2007; Humbert et al., 2010; Kawai et al., 2009; Kern, Jaradeh, Arndorfer, & Shaker, 2001; Li et al., 2009; Malandraki, Sutton, Perlman, & Karampinos, 2010; Malandraki, Sutton, Perlman, Karampinos, & Conway, 2009; Martin, Goodyear, Gati, & Menon, 2001; Mosier, Liu, Maldjian, Shah, & Modi, 1999; Paine, Conway, Malandraki, & Sutton, 2011; Peck et al., 2010; Toogood et al., 2005; Zald, 1999). The primary motor cortex, primary sensory cortex, insular cortex, anterior cingulate gyrus, supplementary motor area, premotor area, internal capsule, thalamus, basal ganglia, putamen, globus pallidus, and cerebellum (i.e., infratentorial) are all reported to be activated during swallowing (Malandraki, Johnson, & Robbins, 2011). Based on a systematic review, Humbert and Robbins (2007) indicated, among the previously reported structures involved in swallowing, the primary motor cortex, primary sensory cortex, insular cortex, and anterior cingulate cortex are consistently active during swallowing.

The cerebral cortex is involved in the initiation and regulation of swallowing (Martin & Sessle, 1993). However, since swallowing, speech, and respiration share some upper aerodigestive tract functions, it is difficult to tease out swallow specific activations and other non-swallow functions when interpreting neural signals on an fMRI image (Hamdy et al., 1999; Huckabee et al., 2003; Kern et al., 2001; Malandraki et al., 2011). Several studies identified that larger neural activation areas represent swallow-related innervation, such as face, tongue, larynx and pharynx, rather than swallowing function itself (Huckabee et al., 2003; Kern et al., 2001; Malandraki et al., 2011).

2.3.3 Reciprocity of central control in swallowing

Behavioral evidence indicates that swallowing behavior can be altered by bottom-up input (i.e., peripheral to cortical structures) (Humbert & German, 2013). For example, swallowing behavior can be modulated by sensory information coming from the oropharynx, such as bolus volume, consistency, temperature, and taste (Ding et al., 2003; Kahrilas, 1997; Kahrilas & Logemann, 1993; Logemann, 2007; 1984; Logemann et al., 1995; Robbins et al., 2008; Shaw & Martino, 2013). Swallowing behavior also can be altered by top-down input (i.e., cortical to peripheral structures) (Humbert & German, 2013). For example, employing volitional swallow maneuvers, such as supraglottic swallow, super-supraglottic swallow, and Mendelsohn maneuver, alters the onset time and duration of hyoid elevation, laryngeal closure, and UES opening (Kahrilas et al., 1991; Logemann, 2007; Ohmae et al., 1996).

2.3.4 Volitional swallow vs. spontaneous swallow

Volitional swallow (i.e., voluntarily initiated swallow) is initiated with a desire to swallow under a conscious and awake condition (Dodds, 1989; Hamdy et al., 1999; Huckabee et al., 2003; Kern et al., 2001; Martin et al., 2001; Mosier & Bereznaya, 2001; Palmer, Hiiemae, Matsuo, & Haishima, 2007; Satow et al., 2004; Suzuki et al., 2003). Volitional swallow is often contrasted to the spontaneous or reflexive swallow that occurs in unconscious states or without intention. Some researchers use the term voluntary swallow or voluntarily induced swallow synonymously with the term volitional swallow (Ertekin, 2011; Ertekin et al., 2001; Li et al., 2009; Maeda et al., 2004; Martin, Goodyear, Gati, & Menon, 2001; Toogood et al., 2005; Watanabe, Abe, Ishikawa, Yamada, & Yamane, 2004; Zald, 1999). Moreover, some other researchers use the term "command swallow" to refer to the volitional swallow (Yamawaki, 2012). In this case, the term command swallow is used to refer to any voluntarily initiated swallows regardless of the presence of an external swallow command presented prior to the initiation of swallowing. Recent studies have indicated that there is a physiological difference between volitional swallows with and without the command swallow (Daniels et al., 2007; Nagy et al., 2013; Palmer et al., 2007). Thus, caution should be observed when interpreting command swallow data. The physiological differences between swallows with and without the command swallow were discussed later in this review.

Spontaneous swallow, which is mostly saliva swallows, occurs subconsciously without a desire to swallow, such as during sleeping or between mealtimes (Dodds, 1989; Ertekin, 2011; Shaker et al., 1994). It is considered a reflexive action for preventing saliva and/or a piece of bolus from entering the airway (Shaker et al., 1994). Yet, recent fMRI studies have indicated the involvement of the cortex during spontaneous swallows (Martin et al., 2001). Spontaneous swallow is initiated when the volume of salivary film reaches a critical amount (Ertekin, 2011).

2.4 COORDINATION OF SWALLOWING AND RESPIRATION

Respiration is defined as the process of exchanging oxygen from inhaled air and releasing carbon dioxide via exhalation (Martin-Harris, 2006). A lack of the swallow-respiration coordination may cause aspiration and/or choking (Butler, Stuart, Pressman, Poage, & Roche, 2007). As such, the coordination of swallowing and respiration is essential for safe swallowing (Logemann, 1998). There is no airflow through the trachea or larynx during the airway closure, which is referred to as the swallow apnea period or swallow cessation (Hiss, Strauss, Treole, Stuart, & Boutilier, 2004; Hiss, Treole, & Stuart, 2001; Martin-Harris, 2008; Martin-Harris et al., 2005). The swallow apnea/swallow cessation period predominantly occurs during the expiratory phase of respiration in healthy adults (Butler et al., 2007; Charbonneau, Lund, & McFarland, 2005; Logemann, 1998; Martin-Harris, 2008; Martin-Harris et al., 2005). The pharyngeal swallow is predominantly initiated during the expiratory phase of respiration, and the swallow ends during the expiratory phase (Butler et al., 2007; Charbonneau et al., 2005; Logemann, 1998; Martin-Harris, 2008; Martin-Harris et al., 2005). The next commonly observed respiratory pattern is inspiration before the swallow and expiration after the swallow (Martin-Harris et al., 2005). The expiration before the swallow and inspiration after the swallow pattern is rarely observed (Martin-Harris et al., 2005). This swallowing-respiration pattern is advantageous to protect the airway (Martin, Logemann, Shaker, & Dodds, 1994). An exhalation after a swallow is helpful in clearing foreign materials that enter the airway (Martin et al., 1994). During the expiratory phase of respiration, the true vocal folds are more mediatized at the onset of the pharyngeal swallow (Martin et al., 1994).

3.0 EVALUATION OF SWALLOWING

There are several imaging and non-imaging studies for investigating swallow functions. Imaging studies include: videofluoroscopic examination of swallowing (VFSS), fiberoptic endoscopic evaluation of swallowing, ultrasound, and scintigraphy (Logemann, 1998). Non-imaging studies utilize: electromyography, electroglottography, and pharyngeal manometry (Logemann, 1998). Among imaging studies, VFSS is widely used for evaluation and diagnosis of oropharyngeal dysphagia in the United States (da Silva, Lubianca Neto, & Santoro, 2010; Kelly, Drinnan, & Leslie, 2007; Kelly, Leslie, Beale, Payten, & Drinnan, 2006; Langmore, 2003).

3.1 VIDEOFLUOROSCOPIC EXAMINATION OF SWALLOWING

The videofluoroscopic examination of swallow (VFSS) also called the modified barium swallow study, was first introduced by Logemann and colleagues in the early 1980s (Dodds et al., 1990; Hartnick, Rudolph, Willging, & Holland, 2001; Langmore, 2003; Logemann, 1998; 1993). The purposes of conducting VFSS are: (1) to identify abnormalities in swallow anatomy and physiology that are causing patients to have swallow symptom(s), and (2) to identify swallow treatment strategies (Langmore, 2003; Leder & Murray, 2008; Logemann, 1998; 1993).

The VFSS has several advantages. VFSS allows visualizing all phases of swallowing, such as the oral preparatory, oral, pharyngeal, and esophageal phases (Langmore, 2003; Logemann, 1998; 1993). During VFSS, it is possible to examine bolus flow throughout all phases (da Silva et al., 2010; Logemann et al., 1998), assess biomechanical function of the aerodigestive mechanism leading to abnormal bolus flow, and detect the presence, timing and severity of aspiration and laryngeal penetration before, during, and after the swallow (Logemann et al., 1998). Moreover, the severity of penetration and aspiration is quantifiable on VFSS by using the penetration-aspiration scale (Rosenbek, Robbins, Roecker, Coyle, & Wood, 1996), which is a validated measurement tool developed for VFSS (Nacci et al., 2008).

However, VFSS involves radiation exposure (Bonilha et al., 2013; Kim, Choi, & Kim, 2013; Langmore, Schatz, & Olsen, 1988; Logemann, 1993; Zammit-Maempel, Chapple, & Leslie, 2007), although the amount of radiation doses is minimal during the procedure (Bonilha et al., 2013; Zammit-Maempel et al., 2007). Additionally, bedridden patients who are unable to be transported to a fluoroscopy suite (i.e., patients in ICU or on monitors) are not eligible for VFSS (da Silva et al., 2010; Langmore et al., 1988; Langmore, Schatz, & Olson, 1991; Logemann, Lazarus, Keeley, Sanchez, & Rademaker, 2000; Martin-Harris, Logemann, McMahon, Schleicher, & Sandidge, 2000; Nacci et al., 2008; Rugiu, 2007). Patients are required to maintain sitting or semi-sitting positions during VFSS, which is not possible for every patient (Langmore et al., 1988; 1991; Rugiu, 2007). Patients who are not able to tolerate a small amount of aspiration are not eligible for VFSS (Langmore et al., 1988; 1991).

In spite of these disadvantages, because of the dynamic visualization of all the phases of swallowing, VFSS has become a gold standard tool for the diagnosis and evaluation of swallowing (Bonilha et al., 2013; Kelly et al., 2006; Langmore et al., 1991; Zammit-Maempel et al., 2007).

3.2 FIBEROPTIC ENDOSCOPIC EVALUATION OF SWALLOWING

Fiberoptic endoscopic evaluation of swallowing (FEES) was first formalized by Langmore and colleagues in 1988 (Langmore, 2003). Langmore and colleagues have developed FEES for patients who were not eligible for VFSS (Langmore et al., 1988). In fact, FEES is portable, thus, it can be performed as a bedside examination (Langmore et al., 1988; 1991; Nacci et al., 2008; Rugiu, 2007).

There are several advantages of FEES. It does not involve radiation exposure (Hiss & Postma, 2003; Langmore et al., 1988; 1991; Logemann et al., 1998) and provides superior visual images of the larynx and hypopharynx, including the vocal folds (Langmore et al., 1988; Logemann, 1998). The FEES also have been reported to have higher sensitivity on detecting aspiration, penetration and residue than VFSS (Hiss & Postma, 2003; Kelly et al., 2006; 2007; Langmore et al., 1991; Leder, Bayar, Sasaki, & Salem, 2007; Wu, Hsiao, Chen, Chang, & Lee, 1997), although some other studies have reported that there was no difference between FEES and VFSS on detecting aspiration, penetration and residue (Leder & Murray, 2008; Rao, Brady, Chaudhuri, Donzelli, & Wesling, 2003). Furthermore, other studies have indicated that FEES overestimates both airway penetration-aspiration and post-swallow pharyngeal residue (Kelly et al., 2006; 2007).

There also are disadvantages of FEES, namely it does not provide images of the oral phase of swallowing or function of the UES. Since a scope is placed transnasally rendering the beginning of the field of endoscopic view posterior to the oral cavity (Langmore et al., 1988), it is not possible to investigate the oral phase of swallowing by FEES (Langmore et al., 1988). Fiberoptic endoscopic evaluation of swallowing also does not visualize swallow events that occur during the pharyngeal stage, also known as the "white-out" period, when the pharynx collapses after the pharyngeal swallow is triggered (Langmore et al., 1988; Logemann, 1998; Logemann et al., 1998; Nacci et al., 2008). Logemann and colleagues (1998) indicated that the hyoid movement, airway entrance closure, the contact of the tongue base to the posterior pharyngeal wall, laryngeal elevation and UES opening are not visualized on FEES. Given the lack of visualization during the white-out period, FEES does not allow the investigation of swallow functions during the pharyngeal swallow (Bonilha et al., 2013; Langmore et al., 1988; Logemann, 1998). In addition, due to the placement of a scope, patients may experience discomfort, sensations of gagging or vomiting during the placement (Logemann et al., 1998; Nacci et al., 2008). Finally, there are no standardized scales to quantify aspiration and penetration for FEES (Nacci et al., 2008) in spite of an attempt to validate the penetration-aspiration scale for FEES (Colodny, 2002).

Fiberoptic endoscopic evaluation of swallowing also is considered a gold standard tool for diagnosis and evaluation of swallowing (da Silva et al., 2010; Hiss & Postma, 2003; Langmore, 2003; Rugiu, 2007). However, given the limitations described above, VFSS is employed when it is necessary to examine all the phases of swallowing and swallow physiology during the pharyngeal swallow (Bonilha et al., 2013; Logemann, 1998).

3.3 SURFACE ELECTROMYOGRAPHY

Surface electromyography (sEMG) is a non-imaging study, which is a widely used non-invasive technique to measure muscle electrical activity during swallowing (McKeown, Torpey, & Gehm, 2002). The sEMG is considered to be a reliable procedure for investigating the muscles involved in swallowing (Ding et al., 2003).

Although sEMG does not provide any images of swallow process or the bolus during swallowing, it does provide the timing and relative amplitude of muscle contraction patterns during swallowing (Ding, Larson, Logemann, & Rademaker, 2002). The sEMG does not provide information regarding the activity produced by specific muscles for swallowing. However, it is known that the geniohyoid, mylohyoid and the anterior belly of the digastric muscle contribute to the submental sEMG signals obtained during swallowing (Crary, Carnaby-Mann, & Groher, 2006). It is also known that submental sEMG signals are correlated with hyoid elevation and laryngeal movement (Crary et al., 2006). Therefore, sEMG has been accepted as an indirect measure of the duration of hyolaryngeal excursion that serves as a surrogate for the approximate duration of the pharyngeal swallow. Furthermore, submental sEMG signals also is inferenced by the tongue movements (Huckabee & Steele, 2006; Steele & Huckabee, 2007).

There are several advantages of employing sEMG to measure muscles for swallowing. Surface electromyography does not involve radiation exposure (Logemann, 1998). It is relatively less expensive compared to VFSS (Ding et al., 2002). The sEMG allows frequent recordings of swallow kinematics. Unlike intramuscular electromyography that uses needle electrodes placed directly into specific muscles, sEMG signals can be obtained from an electrode patch that can be placed on the skin with an adhesive (Crary et al., 2006). As such, the sEMG produces little or no discomfort (McKeown et al., 2002). Given these advantages, sEMG has been employed to investigate participants' reaction time measurements during swallowing (Brodsky, et al., 2012; Nakamura & Imaizumi, 2013).

4.0 COMMAND SWALLOW CONDITION

4.1 WHAT IS THE COMMAND SWALLOW CONDITION?

During VFSS the command swallow condition has been employed both for clinical and research purposes (Daniels et al., 2007; Palmer et al., 1992). The command swallow condition is a controlled condition developed in research protocols that has been widely adopted and employed by clinicians (Daniels et al., 2007; Nagy et al., 2013; Palmer et al., 2007). Under the command swallow condition, a patient/participant is asked to hold a liquid or solid bolus in the mouth, and wait to swallow the bolus until a verbal command, *swallow*, is given to the patient/participant (Hiiemae & Palmer, 2003). More specifically, under the command swallow condition, a barium bolus is placed in the mouth of a patient or participant with a syringe or spoon by a speech language pathologist (SLP), and the patient/participant is instructed to hold the barium bolus on his/her tongue until a verbal stimulus after which he/she can swallow the bolus (Logemann, 1998; 1993).

The swallow stimulus is uttered by an SLP during VFSS. Although Daniels and colleagues (2007) and Reimers-Neils and colleagues (1994) have reported the exact instructions for the command swallow condition in their studies (Daniels et al., 2007; Reimers-Neils, Logemann, & Larson, 1994), there is not a standard set of instructions used by clinicians performing the VFSS. Anecdotally, the instruction below is given before the swallow examinations (Reimers-Neils et al., 1994).

I am going to place a small amount of food in your mouth. I want you to hold it in your mouth until I tell you to swallow.

After the instruction is given, the verbal cue for the bolus hold, such as *hold it*, is given after a barium bolus is placed on a patient/participant's tongue (Daniels et al., 2007). Then the verbal stimulus is given after a radiologist or radiology technician turns on the radiation beam to start the swallow examination. For this stimulus, an action word *swallow* is uttered by the examiner. There are variations of the verbal stimulus among SLPs in the clinical settings. However, the impact of variations of the verbal stimulus has never been systematically investigated.

Originally, the command swallow condition was designed for minimizing the amount of radiation exposure both for SLPs and patients/participants (Daniels et al., 2007; Logemann, 1998; 1993; Nagy et al., 2013). Under the command swallow condition, the radiation beam is turned off while a SLP places a barium bolus in a patient or participant's mouth, and steps away from the radiation beam source. The radiation beam is turned on right before the verbal stimulus is given, and turned off after the bolus is propelled down to the esophagus (Daniels et al., 2007; Nagy et al., 2013). Moreover, the command swallow condition is used to capture the whole swallow event during VFSS: in order to make sure each swallow is not initiated before turning on the radiation beam, a patient/participant needs to hold a bolus on the tongue until the verbal stimulus is given (Nagy et al., 2013). The verbal stimulus is required to let a patient/participant know when to initiate swallowing (Logemann, 1993; Logemann, Pauloski, Rademaker, & Kahrilas, 2002).

4.2 THEORETICAL AND NEURAL PATHWAY FOR THE COMMAND SWALLOW CONDITION: DUAL STREAM MODEL

There have been no prior studies that have explored the theoretical and/or neural mechanisms responsible for how the verbal stimulus, *swallow,* is processed during the command swallow condition. However, the dual stream model for speech perception proposed by Hickok and his colleagues (2007) may explain possible mechanisms of the verbal stimulus processing with the command to *swallow*.

The dual stream model for speech perception is based on the fact that acoustic speech input should be linked both to semantic representations and the motor speech system (Hickok, 2012; Hickok & Poeppel, 2007). The model suggests that speech is processed concurrently on two time-scales by two separate streams, the dorsal and ventral stream. The ventral stream, which is bilaterally organized, is involved in processing auditory signals for comprehension. The dorsal stream, which is left dominant, is involved in translating the auditory signals into articulatory presentation (Hickok, 2012; Hickok & Poeppel, 2004; 2007; Poeppel, Emmorey, Hickok, & Pylkkänen, 2012).

More specifically, the acoustic speech signal is projected to the bilateral primary auditory cortex, which is Brodmann area 41 (BA41), secondary auditory cortex (BA42), and planum temporale for the spectrotemporal analysis. The signal is further projected to the middle-posterior superior temporal sulcus for the phonological level processing. The subsequent projections bifurcate into the ventral and dorsal steams.

In the ventral stream, the auditory signal is projected to the posterior middle temporal gyrus and posterior inferior temporal sulcus for lexical-semantic-grammatical processing. During this process, the phonological information of the auditory signal is linked to the semantic information. The auditory signal is further projected to the anterior middle temporal gyrus and anterior inferior temporal sulcus that are proposed to work as the “combinational network”. In the network, the linguistic information of the signal, such as phonological, semantic, lexical, and grammatical information is integrated to speech motor functions.

In the dorsal stream, the auditory signal is projected to the parietal-temporal junction, which is called the area SPT. The area is proposed to be the “sensorimotor interface”. During this process, the auditory signal is integrated into speech motor representations. Other sensory inputs also enter the SPT. Subsequently, the information is projected to the “articulatory network” which is located in the left posterior inferior frontal gyrus, premotor cortex, and anterior insula for speech production.

Based on the dual stream model, it is postulated that the verbal stimuli in the command swallow condition is processed concurrently in the dorsal and ventral streams. The auditory signal perhaps is projected to the “swallowing-related network” instead of the “articulatory network”. However, it is not clear whether the “swallowing-related network” is independent from the articulatory network. As previously noted, it is difficult to tease out the swallow specific activations and speech specific functions when interpreting neural signal data (Hamdy et al., 1999; Huckabee et al., 2003; Kern et al., 2001; Malandraki et al., 2011).

4.3 IMPACT OF THE COMMAND SWALLOW CONDITION ON SWALLOW PHYSIOLOGY

Normative swallowing data have been established based on the previous research that has employed the command swallow condition (Daniels et al., 2007; Hiiemae & Palmer, 1999). However, Hiiemae and colleagues (1999) have suggested that swallows under the command swallow condition do not represent natural swallowing behaviors in healthy individuals (Hiiemae & Palmer, 1999). Indeed, there are two unnatural behaviors under the command swallow condition that are not observed under natural swallowing, which are (1) bolus hold: bolus is held in the mouth intentionally while the patient awaits a command to swallow, and (2) the verbal command itself: the patient processes the verbal stimulus, *swallow,* prior to the swallow initiation and then swallows in response to the stimulus (Hiiemae & Palmer, 2003). Recent studies have begun to indicate evidence that the command swallow condition may influence some aspects of the swallow physiology.

4.3.1 Impact of the bolus hold

4.3.1.1 Alterations of bolus location

Previous VFSS studies have focused on investigating the impact of the bolus hold, and indicated that the bolus hold under the command swallow condition induces patients/participants to position a bolus more anteriorly at swallow onset regardless of bolus consistency and volume (Daniels et al., 2007; Nagy et al., 2013; Palmer et al., 2007). Table 1 displays the summary of the previous studies. Table 2 displays the definitions of onset and duration measurements in the previous VFSS studies.

Daniels et al. (2007) examined the effects of the command swallow condition during 5 ml liquid barium swallows in 12 healthy older participants. The researchers reported, in the command swallow condition, a bolus was consistently moved on the tongue while participants were holding the bolus, and the bolus was located more posteriorly at the onset of oral transit than seen in the non-command swallow condition. In the non-command swallow condition, the bolus remained at the anterior loading position at the onset of the oral transit, and the bolus was propelled to the back of the oral cavity and pharynx.

In the same study, Daniels et al. (2007) also reported that the bolus head was located more superiorly in the oropharynx (i.e., superior or adjacent to the ramus of the mandible) at the swallow onset in the command swallow condition while the bolus head was more frequently located more inferiorly in the valleculae, the laryngeal surface of the epiglottis and pyriform sinuses in the non-command swallow condition. Furthermore, Nagy and colleagues (2013) reported, during 10 ml liquid bolus swallows in 20 healthy young participants, the bolus head was located above the pyriform sinuses at the swallow onset in the command swallow condition while the bolus head was more frequently located in the pyriform sinuses in the non-command swallow condition.

In addition, Palmer et al. (2007) examined the bolus location during swallows of an 8-gram hard cookie in 8 healthy younger participants. The researchers reported that the bolus head was more superiorly positioned at the swallow onset for the command swallow condition than for the non-command swallow condition. In particular, the bolus head was located either in the oral cavity, upper oropharynx, or valleculae at the swallow onset in the command swallow condition while the bolus head was either in the upper oropharynx or valleculae at the swallow onset in the non-command swallow condition.

Previous studies concur with each other and indicate that the command swallow condition alters the bolus position at swallow onset. Regardless of the methodological differences among these studies (i.e., participant's age, bolus consistency, and bolus volume), the bolus was more superiorly located in the command swallow condition than in the non-command swallow condition.

Despite of the agreement with the data regarding the bolus locations, the previous studies have small sample sizes and a limited number of swallow trials. Daniels et al. (2007) had 12 participants and participants performed only two swallows for each condition. In the Nagy et al. (2013), participants only swallowed once in the command swallow condition. Palmer et al. (2007) had a total of 8 participants, but only 7 participants' data were used for the statistical analysis. Participants swallowed once in each command swallow condition in their study. Lof and Robbins (1990) investigated the test-retest variability during VFSS in healthy participants, and suggested that at least three repeated trials of swallows are needed in order to avoid variability and capture swallow nature during VFSS (Lof & Robbins, 1990). The small sample size and limited number of swallow trials in the previous studies may have caused variability in the results. As such, the results of previous studies may not represent the true nature swallows or impact of the bolus hold on bolus locations during liquid swallows.

Table 1 Summary of the previous studies investigating the effects of the command swallow condition

Authors	*Subjects*	*Swallow tasks*	*Swallow condition*	*Measurements*	*Results*
Daniels et al. (2007)	12 healthy older adults 6females +6males Mean age=68.8±7.7 yrs. Age range=56-78 yrs.	-5 ml -Liquid barium Swallow trials=2	-WC -NC Randomized order	1.Bolus location at: -OTT -Swallow onset 2. Duration: -OTT - STT - PTT - TSD 3.PAS	1. Bolus location: Bolus always moved in WC Posteriorly located at OTT in WC More anteriorly located at OTT in NC More superiorly located at swallow onset in WC More inferiorly located at swallow onset in NC 2. Duration: Shorter OTT, STT, PTT, & TSD in WC 3. PAS: No difference between WC and NC
Nagy et al. (2013)	20 healthy younger adults 10females+ 10males Mean age=31.5±5.7 yrs.	-10 ml -Liquid barium Swallow trials=3	-WC - NC Order NOT randomized	1.BLSO 2.Duration: -STD - PTT -PRD	1. BLSO: More superiorly located in WC 2. Duration: Shorter trend for STD in WC Longer PTT and PRD in WC
Palmer et al. (2007)	8 healthy young adults 4females+4 males Age range=21-25 yr. Median age=23 yr.	-8g -Solid food (cookie) Swallow trial=1	- WC - NC Order not randomized	1.Bolus location at: swallow onset 2.Duration: - Stage I transport -Processing - VAT - HTT	1. Bolus location: More superiorly located at swallow onset in WC 2. Duration: Shorter trend for the stage I transport and HTT in WC Longer processing in WC Shorter VAT in WC

Note: yrs.= years; WC= command swallow condition; NC = non-command swallow condition; OTT = Oral transit time; STT = Stage transit time; PTT = Pharyngeal transit time; TSD = Total swallow duration; PAS = Penetration aspiration scale; BLSO = Bolus location at swallow onset; STD = Stage transition duration; PRD = Pharyngeal response duration; VAT = Vallecular aggregation time; HTT = Hypo-pharyngeal transit time.

Table 2 Definitions of onset and duration measurements in the previous studies investigating the effects of the command swallow condition

Authors	*Bolus timing measure*	*Time interval between:*	*And:*
Daniels et al. (2007)	Swallow onset	Onset of the maximum hyoid elevation	
	Oral transit time (OTT)	Onset of the first bolus anterior or posterior movement	Passing of the leading edge of the bolus at the posterior angle of the ramus of the mandible
	Stage transit duration (STD)	Passing of the bolus head at the posterior angle of the ramus of the mandible	Onset of the hyoid maximum superior movement
	Pharyngeal transit time (PTT)	Passing of the leading edge of the bolus at the posterior angle of the ramus of the mandible	Bolus tail passes through the UES
	Total swallow duration (TSD)	Onset of the first bolus anterior or posterior movement	Bolus tail passes through the UES
Nagy et al. (2013)	Swallow onset	Onset of the antero-superior hyoid excursion	
	Stage transition duration (STD)	Passing of the bolus head at the posterior angle of the ramus of the mandible	Onset of the antero-superior hyoid motion
	Pharyngeal transit time (PTT)	Passing of the bolus head at the posterior angle of the ramus of the mandible	Passage of the bolus tail through the UES
	Pharyngeal response duration (PRD)	Onset of the antero-superior hyoid motion	Passage of the bolus tail through the UES
Palmer et al. (2007)	Swallow onset	Onset of rapid hyoid elevation	
	Stage I transport	Passing of food at the incisors	Onset of mastication
	Processing	Onset of chewing	Bolus reaches at the level of lower border of the mandible
	Vallecular aggregation time (VAT)	Passing of the lower border of the mandible	Passing of the bolus at the edge of the epiglottis
	Hypopharyngeal transit time (HTT)	Passing of the edge of the epiglottis	Passing of the trailing edge of the bolus through the UES

4.3.1.2 Alterations of the swallow durations

Previous studies also have indicated that differences in the location of the bolus due to the bolus hold leads to altered swallow durations. However, there is no consensus as to exactly how the bolus hold alters the duration parameters.

Daniels et al. (2007) reported the duration of the oral transit time during 5 ml liquid barium swallows was significantly shorter in the command swallow condition than in the non-command swallow condition. Since the bolus was more posteriorly located at the onset of the oral transit time in the command swallow condition, the bolus needs to travel a shorter distance to reach to the ramus of the mandible.

Daniels et al. (2007) also reported shorter stage transit duration, pharyngeal transit time, and total swallowing duration in the command swallow condition during 5 ml swallows in older participants. Nagy and colleagues (2013) reported shorter stage transit duration in the command swallow condition in the study with 10 ml bolus swallows in younger participants, but the difference did not meet statistical significance. They also indicated longer pharyngeal transit time and pharyngeal response duration, in the command swallow condition in the same study, the results of which are opposite to the results reported by Daniels et al. (2007).

Nagy et al. (2013) pointed out that there was large variability in all measurements in the study by Daniels and colleagues, which could be explained by the small sample size and swallow trial numbers in the study conducted by Daniels et al. (2007). In fact, Molfenter and Steele (2012) conducted a systematic review of healthy swallow physiology and reported that stage transit duration was more variable than other duration parameters. Nagy et al. (2013) also indicated several methodological differences that may have contributed to the disagreement between the two studies, such as participants' age, bolus volume, and presence of the order randomization of the swallow conditions. Daniels and colleagues (2007) examined swallows of 5 ml liquid boluses in older participants, whereas Nagy et al. (2013) tested 10 ml liquid swallows in younger participants. In addition, Nagy et al did not randomize the order of their swallow conditions. However, it is unknown how age and bolus volume difference might have influenced the results in the within subject design studies. Furthermore, the results from the two studies are not consistent with literature that has indicated age effects on swallow durations. Robbins, Hamilton, Lof, and Kempster (1992) reported that older individuals show longer swallow durations than younger individuals. Molfenter and Steele (2012) reported that there was a trend toward longer stage transit duration and pharyngeal transit time in older participants. Further studies are needed to clarify the reasons for the differences in findings between the studies.

In addition, the swallow command condition in the Nagy et al. (2013) study was different from that used in Daniels et al. (2007). In the study by Daniels et al, participants held a liquid bolus in their mouths, listened to the verbal stimulus to swallow and then swallowed the bolus. In contrast, in the Nagy et al. (2013) study participants held a bolus in their mouth, listened to an individual counting from 1 to 5, listened to the verbal stimulus to swallow, and then swallowed the bolus. The effects of the command swallow condition (e.g., differences in instructions, verbal stimulus, and duration of bolus hold) have never been systematically investigated. The difference in the methods of deploying the command swallow condition in the previous studies may explain the contradictory findings of the two studies.

Furthermore, Palmer et al. (2007) indicated a longer processing time and shorter vallecular aggregation time in the command swallow condition than in the non-swallow condition in the previously described study with a hard cookie in eight healthy younger participants. The researchers reported that the duration of the stage I transport and hypopharyngeal transit time were shorter in the command swallow condition, but these differences were not statistically significant. Palmer et al. postulated the longer processing time was due to the increase of the number of chewing cycles participants used in the command swallow condition. However, they did not count the number of chewing cycles during the experiment, and their reasons for suspecting the increase of chewing cycles are unknown. Moreover, the same researchers also speculated that the shorter vallecular aggregation time was caused by the inhibition of the valleculae aggregation under the command swallow condition. Yet, the bolus aggregation in the valleculae was observed in 3/7 participants in the study. The reasons for the short vallecular aggregation time are not clear. The inconsistent results in the study by Palmer and colleagues may have been due to the small sample size and swallow trial number in the study.

4.3.2 Alteration of palate-lingual contact duration

Nomura and colleagues (2011) examined the effect of the swallow condition on tongue movements in eight young male participants. They reported that the duration of the palate-lingual contact, measured by an ultrasound, was shorter during 3 ml liquid swallows in the command swallow condition than in the non-command swallow condition (Nomura et al., 2011). However, the sample size also was small in this study. The authors speculated that the short palate-lingual contact was related to the hyoid elevation difference between the two conditions. Yet, they did not measure the hyoid elevation in their study. Further studies are needed to clarify the impact of the command swallow condition on the tongue movements including the palate-lingual contact.

4.3.3 Possible impact on the oral-swallowing pattern

Dodds et al. (1989) observed two types of oral-swallowing patterns. One is the “tipper” type swallow: swallowing is initiated with the tongue tip against the incisors. The bolus is in a supra-lingual position with the tipper type swallow. Another is the “dipper” type swallow: the bolus is positioned in the anterior floor of mouth beneath the anterior part of the tongue at the swallow onset. The tongue tip needs to dip beneath the bolus in order to elevate the bolus to the lingual surface before the posterior motion of the tongue in the dipper type swallows. The tipper type swallow is most common, but both patterns are observed among healthy individuals. The dipper type swallow is more prevalent in healthy individuals over 60 years.

It is conceivable that the command swallow condition may alter the dipper type swallows if participants who ordinarily are dippers are instructed to hold the bolus on the tongue. In the previously described tongue movement study, Nomura and colleagues (2011) have examined the oral-swallowing pattern and reported that all of the eight healthy young male participants exhibited the tipper type swallow pattern both in the command swallow and non-command swallow condition. Because there were no participants who showed the dipper type in the non-command condition, the study result does not indicate the impact of the command swallow condition on the oral-swallowing pattern. Future studies with larger sample sizes that include participants with the dipper type swallow are needed to test whether the instruction of the command swallow condition inhibit the dipper type swallow.

4.3.4 Inhibition of swallow onset

Roubeau et al. (2008) compared the reaction time difference between swallowing with the command swallow condition and phonation (i.e., sustained phonation at constant voice pitch) following an acoustic stimulus. They measured the duration between the acoustic stimulus (i.e., 1000Hz pure-tone signal) and the onset of swallowing with electroglottogram. Electroglottogram is used to track the vocal fold movement as well as laryngeal elevation during swallowing (Ding et al., 2002; Perlman & Grayhack, 1991). They found that the duration was longer for swallowing than for phonation. Based on these results, Roubeau et al. (2008) postulated that the longer duration in the swallowing condition was because the bolus hold may have induced inhibition of swallow onset: it was required to overcome the inhibition process to initiate the onset of swallowing, and overcoming the inhibition caused delay in initiating oropharyngeal swallow. The postulation by Roubeau et al. has never been tested, and whether the bolus hold induces inhibition has remained an unanswered question.

4.3.5 Alteration of hyoid kinematics

Molfenter and Steele (2011) hypothesized that during the command condition, the hyoid is partially elevated before the onset of the swallow. Because the hyoglossus muscle, which is one of the supra-hyoid muscles, arises from the hyoid and enters the side of the tongue (McFarland, 2009), it is reasonable to hypothesize that elevating the tongue toward the palate to hold a bolus on the tongue causes earlier hyoid elevation. However, the hypothesis by Molfenter and Steele has never been tested. In the previous VFSS studies, the onset time of the hyoid elevation associated with swallowing was used to calculate some of the duration parameters (i.e., stage transit duration, pharyngeal response duration, and hypopharyngeal transit time). Yet, the hyoid onset time for the bolus hold were not examined in the previous studies.

4.3.6 Impact on the coordination of swallowing and respiration

The impacts of the command swallow condition on swallow-respiratory coordination have not been well documented. Previously reported VFSS studies did not account for swallow-respiratory coordination. However, there is some evidence that suggests the use of the command swallow condition may also alter the swallow-respiratory pattern during liquid swallows, although the altered pattern is not pathological.

Uysal, Kızılay, Ünal, Güngör, and Ertekin (2013) observed that when the verbal stimulus was given during the inspiratory phase, the pharyngeal swallow was forced to be initiated during the inspiratory phase. In their study, the verbal stimulus to swallow was unintentionally given both during the inspiratory or expiratory phase of respiration because they did not control for the swallow-respiratory pattern when they gave the verbal stimulus. Perlman, Ettema, and Barkmeier (2000) also reported that the number of inspiration episodes preceding a swallow apnea or swallow cessation tend to be increased under the command swallow condition, although the respiratory pattern is not necessary pathological. They speculated that the alteration of the swallow-respiratory pattern could have been due to the bolus hold while waiting for the verbal stimulus.

When pharyngeal swallow is initiated during the inspiratory phase, more suprahyoid muscle effort is produced (Sekikawa, Isoda, Iwamoto, Takahashi, & Inamizu, 2008). Healthy individuals find it difficult to swallow during the inspiratory phase. These respiratory patterns may impact the duration between the verbal stimulus onset and the hyoid elevation onset and/or the onset of oral transit. Individuals may wait to initiate the oral transit until the onset of the expiratory phase.

4.3.7 Summary

Previous VFSS studies have focused on investigating the impact of the bolus hold under the command swallow condition, and indicated that the bolus hold induces a more anterior location of the bolus at swallow onset regardless of bolus consistency and volume (Daniels et al., 2007; Nagy et al., 2013; Palmer et al., 2007). The bolus hold also induces a more posterior bolus location at oral transit onset (Daniels et al., 2007). These bolus location differences induce alteration of some of the swallow durations, such as oral transit time, stage transit duration, total swallow duration, pharyngeal transit time, pharyngeal response time, processing duration, and vallecular aggression time (Daniels et al., 2007; Nagy et al., 2013; Palmer et al., 2007). Yet, there is no consensus as to the specifics of how the bolus hold alters the duration parameters. Furthermore, alterations of palate-lingual contact duration, hyoid elevation, inhibition of the swallow onset, and swallow-respiratory coordination pattern change have been reported under the command swallow condition. The impact of the bolus hold under the command swallow condition on swallow physiology has been evaluated, although it is not fully understood at this time.

4.3.8 Impact of the verbal stimulus

Researchers investigating the effects of the command swallow condition have postulated that the verbal stimulus may impose greater volition, thus, may change some of the swallow dynamics (Daniels et al., 2007; Nagy et al., 2013). Nevertheless, the previous VFSS studies investigating the command swallow condition did not account for the impact of the verbal stimulus. None of the VFSS studies and other behavioral studies tested the effect of the verbal stimulus, independent of the effect of the bolus hold. To date, no studies have investigated the impact of the linguistic processing associated with the verbal stimulus on swallow physiology. It is unknown whether processing and responding to the verbal stimulus impacts natural swallow dynamics. However, several lines of evidence support examination of the role of verbal stimuli during the command swallow condition. In the next section, neural and behavioral evidence is addressed that may assist in examining the impact of verbal stimuli.

4.3.9 Evidence that supports the feasibility of testing the impact of the verbal stimulus

4.3.9.1 Alterations on swallow physiology that cannot be explained by the bolus hold

There are some alterations in swallow physiology during the command swallow condition that cannot be explained by the bolus hold alone. It has been reported that the onset of hyoid elevation at the swallow onset in relation to the timing when the bolus tail passes through upper esophageal sphincter is reported to be earlier (Daniels et al., 2007) and/or have an earlier trend (Nagy et al., 2013) under the command swallow condition than the non-command swallow condition. It is also reported that pharyngeal swallow is initiated when the bolus is at a higher location in the aerodigestive tract in the command swallow condition than in the non-command swallow condition (Nagy et al., 2013).

Multiple factors such as bolus taste, temperature, volume, and swallow-respiratory coordination, contribute to the initiation of pharyngeal swallow. The bolus location itself was not found to influence the triggering of pharyngeal swallow (Mendell & Logemann, 2007; Stephen, Taves, Smith, & Martin, 2005). Thus, earlier hyoid onset and triggering of the pharyngeal swallow in the command swallow condition cannot be explained solely by the anterior bolus location resulting from the bolus hold.

4.3.9.2 Modulation by top-down input

As described previously, swallowing is not a purely reflexive act controlled primarily by the brainstem (Humbert et al., 2009; Malandraki & Robbins, 2013; Martin et al., 2007; Shaw & Martino, 2013). Swallowing involves more complex neuronal networks, such as cortical, subcortical, brainstem and peripheral nervous system (Humbert et al., 2009; Malandraki & Robbins, 2013; Martin et al., 2007; Shaw & Martino, 2013). Importantly, some of the voluntary components of swallow behaviors can be modulated by top-down input, such as cortical to peripheral structures (Humbert, Lokhande, Christopherson, German, & Stone, 2012).

4.3.9.3 Stimulus characteristics and differences in neural activation

Neural evidence collected in prior studies suggests that neural activation patterns are different among swallows that are elicited by various stimuli (i.e., a tactile, light signal, and verbal stimuli) and swallows without stimuli. Nagasaki, Hashizume, Tanimoto, and Kurisu (2007) have reported that more cortical areas are recruited for volitional swallows when a light signal is used to signal the participant to swallow, compared to volitional swallows without the light signal (self-initiated swallows). The right temporal pole and medial and inferior frontal gyrus have been observed to be activated prior to the initiation of volitional swallows with the light signal, but not prior to the volitional swallows without the signal. Nagasaki and colleagues postulated that these neural activation differences may suggest differences in cognitive processing prior to the swallowing. The cognitive process difference may influence swallow physiology.

Moreover, the neural activation observed prior to swallows elicited by a written, verbal stimulus (i.e., *swallow* in Japanese) has demonstrated left hemispheric dominance compared to swallows without the verbal stimulus (Nagasaki et al., 2004). This cerebral activation asymmetry may suggest the involvement of language processing under the command swallow condition when the verbal stimulus is employed.

In language research, based on the evidence of neuroimaging studies, such as structural and functional MRI, magnetoencephalography, transcranial magnetic stimulation, and electroencephalography, researchers have actively investigated the neural activation associated with language functions including language processing. Neurophysiological and behavioral evidence in language research suggests the processing of the verbal stimulus under the command swallow condition may impact swallow physiology. More specifically, two theories derived from the embodiment theories, which are (1) the language induced motor activity theory, and (2) language induced motor facilitation theory, may assist in examining the impact of processing the verbal stimulus. In the following sections, the language induced motor activity and language induced motor facilitation theories are reviewed.

4.4 LANGUAGE INDUCED MOTOR ACTIVITY: EMBODIED LANGUAGE PROCESSING

The theories of embodiment, which have been investigated in cognitive neurosciences, philosophy, anthropology, and robotics (Jirak, Menz, Buccino, Borghi, & Binkofski, 2010), link low cognitive processes such as human sensorimotor behaviors, to higher cognitive functions such as human language processing. In neuroscience, numerous studies have reported a link between language and movements (Rabahi, Fargier, Rifai Sarraj, Clouzeau, & Massarelli, 2013).

4.5 LANGUAGE INDUCED MOTOR ACTIVATION THEORY: LINK BETWEEN LANGUAGE AND MOTOR CORTICAL AREAS

The language induced motor activation theory indicates there is a neural link between action words that involve body parts, such as feet/legs, hands/arms, and articulators/face, and motor cortical areas that are involved in the execution of the actions (Buccino et al., 2005; Fargier, Ménoret, Boulenger, Nazir, & Paulignan, 2012; Fischer & Zwaan, 2008; Hauk & Pulvermüller, 2004; Jirak et al., 2010; Meteyard, Cuadrado, Bahrami, & Vigliocco, 2012; Péran et al., 2010; Postle, McMahon, Ashton, Meredith, & de Zubicaray, 2008; Pulvermüller, 1999; 2005; 2013; Pulvermüller & Hauk, 2006; Pulvermüller, Hauk, Nikulin, & Ilmoniemi, 2005a; Pulvermüller, Härle, & Hummel, 2001; Pulvermüller, Shtyrov, & Ilmoniemi, 2005b; Tettamanti et al., 2005; Tomasino, Fink, Sparing, Dafotakis, & Weiss, 2008; Tomasino, Werner, Weiss, & Fink, 2007). Action words are defined as verbs that refer to physical movements by one's own body, that are perceived visually (Pulvermüller, 1999). For example, there are action words that express the act of throwing (e.g., *toss* or *fling*), creation (e.g., *assemble*, or *sculpt*), and ingesting (e.g., *eat*, *chew*, *dine*, or *swallow*) (Kemmerer, 2006).

The processing of action words that involve body parts, such as feet/legs, hands/arms, and articulators/face including ingesting words, activate motor cortical areas, such as the primary, supplementary motor, and premotor cortex, that are involved in the execution of actions (Buccino et al., 2005; Fargier, Ménoret, Boulenger, Nazir, & Paulignan, 2012a; Fischer & Zwaan, 2008; Hauk & Pulvermüller, 2004; Jirak et al., 2010; Meteyard et al., 2012; Péran et al., 2010; Postle et al., 2008; Pulvermüller, 2005; 2013; Pulvermüller et al., 2001; Pulvermüller & Hauk, 2006; Pulvermüller, Hauk, Nikulin, & Ilmoniemi, 2005a; Pulvermüller, Shtyrov, & Ilmoniemi, 2005b; Tettamanti et al., 2005; Tomasino et al., 2007; 2008). Data from fMRI studies have suggested that a link between action words and motor cortical areas is developed early in one's life (James & Maouene, 2009), and the link persists in adulthood (Boulenger & Nazir, 2010). James and colleagues (2009) indicated that the motor activation in response to action words which were hand and leg-related words, was observed in children aged between 4 and 5 years old (James & Maouene, 2009).

4.5.1 Semantic somatotopy model: Somatotopical organization of the cortical activation by action words

Neuroimaging studies indicate that action word processing activates motor cortical areas in a somatotopic way without the execution of the actions (Buccino et al., 2001; James & Maouene, 2009; Jirak et al., 2010; Pulvermüller, 1999; 2005; Pulvermüller & Hauk, 2006; Pulvermüller, Shtyrov, & Ilmoniemi, 2005b; Scorolli & Borghi, 2007; Tettamanti et al., 2005). For example, Hauk and colleagues (2004) reported that during passive reading of action words related to arm, leg or face actions (e.g., *pick*, *kick*, or *lick*), activations of the premotor and primary motor cortex were observed. The activation areas were overlapped and/or adjacent with the areas that are activated by actual fingers, foot, or tongue movements. More specifically, arm-related action words activated bilateral middle frontal gyrus. Leg-related action words activated right superior frontal gyrus, left precentral gyrus and postcentral gyrus, and left dorsomedial frontal region. Face-related action words were found to activate bilateral inferior frontal gyrus, respectively.

4.5.2 Temporal aspects of the language induced motor activity

Results from neurophysiological recording techniques with high temporal resolutions, such as electroencephalography and magnetoencephalography, indicate that action words lead to the somatotopic activation of the motor cortical areas quickly. The cortical activation occurs approximately 200 ms after the written action word stimuli are presented (Boulenger et al., 2006; Hauk & Pulvermüller, 2004; Pulvermüller et al., 2001; Pulvermüller, Shtyrov, & Ilmoniemi, 2005).

In addition, Pulvermuller (2001, 2005) indicated that articulators-/face-related auditory and written action words (e.g., *eat* and *chew*) activated the motor cortical areas more quickly and stronger when the activation is compared to the motor cortical activation by a leg-related action word (e.g., *kick*). This result may suggest the processing of the action word *swallow*, which has similar semantic meaning to *eat*, may induce a fast, strong cortical activation.

4.5.3 Types of action word stimuli

The activation of the motor cortical areas elicited by action words can be observed during several types of word processing tasks, including during passive listening (Buccino et al., 2005; James & Maouene, 2009; Pulvermüller, Shtyrov, & Ilmoniemi, 2005b; Raposo, Moss, Stamatakis, & Tyler, 2009; Tettamanti et al., 2005), silent reading (Boulenger, Hauk, & Pulvermüller, 2009; Hauk & Pulvermüller, 2004; Hauk, Johnsrude, & Pulvermüller, 2004; Kana, Blum, Ladden, & Ver Hoef, 2012; Kemmerer, Castillo, Talavage, Patterson, & Wiley, 2008; Postle et al., 2008; Pulvermüller et al., 2001; Pulvermüller, Kherif, Hauk, Mohr, & Nimmo-Smith, 2009; Raposo et al., 2009; Tomasino et al., 2007; Willems, Hagoort, & Casasanto, 2010), action word picture naming (Saccuman et al., 2006), action word recalling (Oliveri et al., 2004), imagery of actions (Kosslyn, Ganis, & Thompson, 2001; Tomasino et al., 2007; Willems et al., 2010), and even observing actions by others (Aziz-Zadeh, Wilson, Rizzolatti, & Iacoboni, 2006; Hauk et al., 2004; Kana et al., 2012).

The motor area activation that occurs after presentation of action word stimuli is not limited to single-word level stimuli. Motor area activation has been reported during the processing of action words with literal meaning (Hauk et al., 2004; Hauk & Pulvermüller, 2004; James & Maouene, 2009; Kemmerer et al., 2008; Postle et al., 2008; Pulvermüller et al., 2001; 2009; Pulvermüller, Shtyrov, & Ilmoniemi, 2005b; Raposo et al., 2009; Willems et al., 2010), sentences that include action-related words with literal meanings (Kana et al., 2012; Raposo et al., 2009; Tettamanti et al., 2005), and sentences with action-related words that include idiomatic meanings (Boulenger et al., 2009; Boulenger & Nazir, 2010; Boulenger, Shtyrov, & Pulvermüller, 2012).

4.5.4 Theories explain the causes of the link between action words and motor cortical areas

4.5.4.1 Hebbian theory of learning

There has been no consensus on how the link between action words and the motor cortical areas has been established. Some researchers have hypothesized that the neural link between action words and the motor cortical areas is developed through Hebbian associative learning experiences (Fargier, Ménoret, Boulenger, Nazir, & Paulignan, 2012a; Pulvermüller, 1999; 2005; Pulvermüller et al., 2009).

The acquisition of action words in childhood are often associated with the execution of actions (Fargier, Ménoret, Boulenger, Nazir, & Paulignan, 2012a.) and/or the contexts of the execution of actions (Fargier, Ménoret, Boulenger, Nazir, & Paulignan, 2012; Goldfield, 2000; Pulvermüller, 2005). Language areas are activated as a result of the processing of action words understanding during action word acquisition. Simultaneously, the motor cortical areas involved in actions are activated as a result of the execution of actions. Thus, synaptic connections between neurons in both areas become stronger (Pulvermüller, 1999; 2005). Furthermore, the simultaneous activations of neurons in the two areas lead to the generation of cell assemblies, and, thus, these neurons become linked (Pulvermüller, 1999; Pulvermüller et al., 2009; Pulvermüller, Shtyrov, & Ilmoniemi, 2005b). Given the formation of the cell assemblies, whenever an individual perceives an action words, the motor cortical areas responsible for action execution of that action are activated simultaneously (Jirak et al., 2010; Pulvermüller, Shtyrov, & Ilmoniemi, 2005).

4.5.1.2 Motor imagery hypothesis

It should be noted that some researchers disagree with the Hebbian learning theory and hypothesize that the motor cortical activation that occurs during the processing of action words is due to the mental simulation of the movements (i.e., motor imagery) associated with action words during the process of action word comprehension (Boulenger & Nazir, 2010; Postle et al., 2008; Tomasino et al., 2008; Zwaan & Taylor, 2006). There is neural evidence indicating the motor imagery of finger-, foot- and tongue-related movements activate motor cortical areas, such as the supplementary motor area, premotor cortex, and primary motor cortex (Ehrsson, Geyer, & Naito, 2003; Orr, Lacourse, Cohen, & Cramer, 2008; Scorolli & Borghi, 2007; Sharma, Pomeroy, & Baron, 2006). Ehrsson and colleagues reported that motor imagery activates the primary motor cortex in a somatotopic manner (Ehrsson et al., 2003).

However, Boulenger and Nazir (2010) pointed out that motor imagery occurs after language comprehension, and the earlier cortical activation by action words cannot be explained by motor imagery which occurs post-lexically. Yet, it is still an open question whether the language induced motor activity is due to the mechanisms of the cell assemblies, motor imagery, or possibly both in some associated manner.

4.5.5 Mirror neuron system

4.5.5.1 Mirror neuron in monkeys

Researchers investigating the neurophysiological evidence of language induced motor activity have postulated that mirror neurons are responsible for the mediation of action words and motor cortical areas responsible for the action execution (Glenberg & Gallese, 2012; Jirak et al., 2010; Kemmerer, 2006; Liepelt, Dolk, & Prinz, 2012). Mirror neurons are activated when individuals perform motor actions and when individuals observe motor actions performed by others (Fabbri-Destro & Rizzolatti, 2008; Rizzolatti & Craighero, 2004).

Originally, mirror neurons were found in the ventral premotor cortex (Area F5) bilaterally in monkeys (Bergen, Lau, Narayan, Stojanovic, & Wheeler, 2010; Cattaneo & Rizzolatti, 2009; Gallese, Fadiga, Fogassi, & Rizzolatti, 1996; Kohler et al., 2002; Liepelt et al., 2012; Pulvermüller, Shtyrov, & Ilmoniemi, 2005b). Mirror neurons are activated when monkeys perform object-related actions by their hands and mouth, such as grasping, placing, holding, and breaking food (Gallese et al., 1996). Mirror neurons also are activated when monkeys observe similar objects related to actions by another individual (e.g., another monkey or a human experimenter) (Gallese et al., 1996). Ferrari, Gallese, Rizzolatti, and Fogassi (2003) and colleagues found the ingestive mouth mirror neurons that were activated particularly by performing or observing ingestive actions by the mouth.

Mirror neurons in monkeys also are activated when monkeys hear action-related sounds, such as paper ripping and object breaking sounds, made by other individuals (Keysers et al., 2003; Kohler et al., 2002). These specific mirror neurons are called audio-visual mirror neurons (Keysers et al., 2003; Kohler et al., 2002) and have been implicated in integrating sounds as well as actions (Buccino et al., 2005; Jirak et al., 2010; Keysers et al., 2003; Kohler et al., 2002). Hauk, Shtyrov, and Pulvermüller (2008) indicated the discovery of the audio-visual mirror neurons further support the existence of the neural link between action words and motor cortical areas in humans.

4.5.5.2 Mirror neurons in humans

In humans, the area F5 in monkeys is equivalent to the pars opercularis of the inferior frontal gyrus (BA44) which is a part of Broca's area (BA44 and 45) (Aziz-Zadeh et al., 2006; Buccino et al., 2001; Cattaneo & Rizzolatti, 2009; Gallese et al., 1996; Iacoboni et al., 2005; Jirak et al., 2010; Liepelt et al., 2012; Nishitani, Schürmann, Amunts, & Hari, 2005; Pulvermüller, Shtyrov, & Ilmoniemi, 2005b; Rizzolatti et al., 1996). Mirror neurons are found bilaterally in the ventral premotor cortex, inferior parietal lobule, posterior part of the inferior frontal gyrus, a part of which overlaps with the Broca's area in humans (Aziz-Zadeh et al., 2006; Fabbri-Destro & Rizzolatti, 2008; Iacoboni et al., 2005; Lametti & Mattar, 2006). It has been suggested that mirror neurons in humans are activated during action word comprehension (Kemmerer, 2006; Liepelt et al., 2012; Pulvermüller, Shtyrov, & Ilmoniemi, 2005b; Tettamanti et al., 2005), action understanding (Rizzolatti & Craighero, 2004; Rizzolatti, Fogassi, & Gallese, 2002), action imagery (Kosslyn et al., 2001; Nyberg et al., 2001), and action imitation (Heiser, Iacoboni, Maeda, Marcus, & Mazziotta, 2003; Nishitani et al., 2005).

Tettamanti et al. (2005) indicated, during an action-related sentence comprehension task in their fMRI study, Broca's area was the only region that was conjointly activated by foot/legs, hands/arms, and articulators/face words. Given these results, they postulated that Broca's area is particularly crucial for action word understanding. In addition, Pulvermüller (2005) postulated that speech and action production areas overlap in Broca's area, and that this overlap makes it possible for one to influence each other.

4.5.6 Language induced motor activation in swallowing

The motor areas responsible for articulators-/face-related actions also are activated by auditory ingesting-action words, such as *chew*, *munch*, and *swallow* (Pulvermüller, Shtyrov, & Ilmoniemi, 2005b; Tettamanti et al., 2005). These findings indicated that articulators-/face-related action words (i.e., *eat* and *chew*) activated the motor cortical areas faster and stronger when the activation is compared to the motor cortical activation by a leg-related action word (i.e., *kick*).

More specifically, Pulvermuller et al. (2005b) employed one of the ingesting action words *eat* in their megnetoencephlographic study, and indicated the inferior fronto-central area activation by silent listening of the word stimuli. Tettamanti et al. (2005) used the action word *swallow* along with *chew* and *munch* as one of the articulators-/face-related word stimuli in their fMRI study. The researchers reported that when healthy participants listened silently to sentences containing articulators-/face-related words including the word *swallow* activated the pars opercularis in the left inferior frontal gyrus more dorsally, rostrally, and ventrally. The inferior frontal gyrus is known to be activated by the articulators-/face-related motor actions (Hauk et al., 2004). However, all articulators-/face-related neural activation data were combined when the data were analyzed. Tettamanti and colleagues did not report the cortical activation pattern associated with the word *swallow* alone.

In a related study, Kawai et al. (2009) had 12 healthy adults listen to human swallowing sounds independent of executing a swallow and found that the supplementary motor area (BA6, associated with swallowing) and the left primary auditory area (BA42) were activated. In addition, the left primary auditory area (BA42) was activated. Similarly, Barros-Loscertales et al. (2012)

reported that passive reading of taste-related words activated the primary and secondary gustatory cortices along with the language areas in 59 healthy adults. More specifically, there were activations of the anterior insula, frontal operculum, and orbitofrontal gyrus, along with left inferior frontal gyri, posterior middle and superior temporal gyri. These authors did not provide the details of the stimuli used in these studies, however, they indicated a possible neural link between swallow-related sounds and motor cortices, and taste-related words and gustatory cortices, respectively.

There also is evidence suggesting that motor imagery of swallowing induces hemodynamic changes in the brain areas that are associated with the execution of liquid swallowing. Kober and Wood (2014) examined hemodynamic changes in healthy adults with near-infrared spectroscopy and reported that both liquid swallowing and motor imagery of liquid swallowing without suprahyoid muscle activations resulted in hemodynamic changes in the premotor, supplementary motor, and pars opercularis (Kober & Wood, 2014). As noted previously, some researchers have suggested that the link between actions words and motor cortical areas is due to motor imagery during the execution of actions associated with the words (Ehrsson et al., 2003; Orr et al., 2008; Scorolli & Borghi, 2007; Sharma et al., 2006). If so, the study results of Kober and Wood (2014) may indirectly suggest that the motor cortical areas related to swallowing could be activated by the swallow verbal stimulus.

4.5.7 Summary

The language induced motor activation theory indicates there is a substantive neural link between action words that involve body parts, such as feet/legs, hands/arms, and articulators/face including ingesting words, and the motor cortical areas that are involved in the execution of the actions. The link between action words and the motor cortical areas develop early in childhood, possibly developed through the Hebbian associative learning experiences. The link persists in adulthood. Researchers investigating language induced motor activation have postulated that mirror neurons are responsible for the neural link between action words and motor cortical areas responsible for the execution of the actions. The previous studies also indicated the processing of the ingesting action words (i.e., *eat, swallow*, *chew* and *munch*), swallow-related sounds, and taste-related words, also activate motor cortical areas.

Taken together, the evidence from the language induced motor activation suggests that there also is a neural link between the verbal stimulus, *swallow,* and motor cortical areas involved in swallowing. Motor cortical areas involved in swallowing are activated during the processing of the verbal stimulus prior to the initiation of swallowing under the command swallow condition during videofluoroscopic examination of swallowing.

4.6 LANGUAGE INDUCED MOTOR FACILITATION: FACILITATION EFFECTS OF ACTION WORDS ON MOTOR PERFORMANCE

Language induced motor activity theory does not indicate whether the motor cortical area activation by action words has any impact on the peripheral systems. There are no studies that have conducted concurrent neuroimaging and behavioral studies to investigate the impact of the processing of action words on actions described by action words. However, the language induced motor facilitation theory, which is based on behavioral evidence, suggests the motor area activation by action words (language induced motor activation) influences the control of some of the actions (Gentilucci, 2003). Behavioral evidence indicates, depending on the temporal relationship between action words and actions described by the action words, the processing of action words induces both facilitation (language induced motor facilitation) and interference (language induced motor interference) effects on actions (Aravena et al., 2010; Boulenger et al., 2006; Buccino et al., 2005; Dalla Volta, Gianelli, Campione, & Gentilucci, 2009; Frak, Nazir, Goyette, Cohen, & Jeannerod, 2010; Gentilucci, 2003; Nazir et al., 2008; Sato, Mengarelli, Riggio, Gallese, & Buccino, 2008; Scorolli & Borghi, 2007).

4.6.1 Language induced motor facilitation

Language induced motor facilitation theory indicates that presenting body-part-related action words such as hand- and foot-related action words (e.g., *lift, grasp*, *place*, and *press*), that (1) describe the subsequent actions, and (2) are presented prior to the initiation of the actions (e.g., pressing a button, and reaching and grasping an object) selectively facilitate the control of the subsequent actions (Aravena et al., 2010; Boulenger et al., 2006; Dalla Volta et al., 2009; Frak et al., 2010; Gentilucci, 2003).

The facilitation effect by action words has been reported with several types of tasks, such as passive listening of action words (Aravena et al., 2010; Boulenger et al., 2006; Dalla Volta et al., 2009; Frak et al., 2010; Gentilucci, 2003) and silent and oral reading of the action words (Grossi, Maitra, & Rice, 2007; Scorolli & Borghi, 2007), although outcome measurements, (e.g., latency between the stimuli onset and the movement onset, movement peak amplitude and velocity, and movement duration) vary across studies.

For instance, Rabahi et al. (2013) reported that passive listening of the leg-related action word *jump* prior to the squat-vertical-jump resulted in increased jump height compared to that with passive listening of non-related action words (i.e., *lick*, *pinch*, and *jump* when presented in Chinese) to 16 healthy native English speakers who did not speak or understand Chinese (Rabahi et al., 2013). In the study by Grossi et al. (2007), written action words *reach*, *grasp*, *lift*, *place*, and *return* were presented prior to the task of reaching, grasping, lifting, placing, and returning a bottle-shaped object in 28 healthy participants. The participants' reach movement duration was significantly shorter and the peak velocity of reaching was increased with the written action word *reach* than those without action words. Boulenger et al. (2006) also have examined the effects of several types of written action words (i.e., hand-related, leg-related action, and mouth-related words) and nouns on the reaching and grasping of a cylindrical object in nine young adults. The researchers indicated that a wrist acceleration peak, which indicated that the initiation of muscular contractions, occurred earlier for the condition in which written action words were presented prior to the movement than the condition in which written noun words were presented.

4.6.2 Effector specific modulation

Facilitation effects by action words are effector specific. That is, presentation of arm/hand action words related to hand actions result in faster hand-related actions, whereas processing of foot-related action words results in faster foot-related actions (Gentilucci, 2003; Grossi et al., 2007; Scorolli & Borghi, 2007). For example, in the study by Scorolli and Borghi (2007), 40 healthy participants received both hand- and mouth-related action word sentences prior to the mouth-related action performance (e.g., saying yes with a microphone). When the written mouth-related action sentences were presented prior to the mouth-related action, the response time for the action was faster than that when the hand-related action word sentences were presented. In the same study, Scorolli and Borghi tested the effect of written hand- and foot-related action sentences on the foot-related action (e.g., pressing a pedal with one's foot). The participants pressed the pedal with their feet faster when the foot-related action word sentences were presented prior to the pressing action than that when hand-related action word sentences were presented.

It is not clear, however, whether the facilitation effect by the action words have equally strong sensitivity among effectors (Rabahi et al., 2013). It has been reported when hand-related action words or sentences, (e.g., *reach*), were presented prior to the sequential hand action (e.g., reach-lift-place action) the hand-related action word facilitates not only the action that is congruent to the action word, but also other hand movements which are part of the sequence of the hand action. For example, in the previously described study by Grossi and colleagues (2007), the lift and place movements were influenced not only by the *lift* and *place* words, but also by the *reach* word: the movement duration was shorter and peak lift velocity was increased with written action words *lift*, *place,* and *reach* than those without any action words (Grossi et al., 2007). In addition, Gentilucci (2003) presented hand-related written action words, *place* and *lift*, adjectives, *high* and *lateral*, and a pseudo-word in Italian, prior to the hand-related sequential action (i.e., (1) reach, (2) grasp a target object with the thumb and index finger, and (3) place the object on a table) in the study with 16 healthy participants. Gentilucci reported that presenting adjectives and the pseudo-word did not change any peak velocity, maximal finger aperture, and maximal height of wrist path during any of the three movements. Likewise, presenting action words, *place* and *lift*, did not change any of the measurements during the grasping movement. However, the peak velocity of finger aperture during the reach movement was increased when the word *place* was presented.

The peak velocity, vertical peak velocity and maximal height of the wrist path during the place movement also were increased with the presentation of the word *lift*. To explain the discrepancy, Gentilucci has postulated that the facilitation effect for *place* and *lift* occurred on the previous motor acts. That is, the effect occurred on the reach and place actions due to the consequence of urging the execution of the place and lift actions.

The facilitation effect of action words on subsequent actions was observed when the action words were compared with nouns (Boulenger et al., 2006), non-related action words (e.g., leg-/foot-related words on the reach and grasp movements) (Boulenger et al., 2006; Rabahi et al., 2013; Scorolli & Borghi, 2007), congruent action word in a foreign language (Rabahi et al., 2013), and without any words (Grossi et al., 2007). The facilitation effect of action words on subsequent actions also were observed when the action words were compared with pseudo-words (Gentilucci, 2003), which also activate the lexical networks via their phoneme and syllable features, without stored lexical representations (Cibelli, 2012; Hickok & Poeppel, 2007).

In addition, language induced motor facilitation also was observed when the congruent action word was compared with an incongruent or contradicting action word (e.g., *fall* and *stop* on a jump movement) (Rabahi et al., 2013). This result is consistent with the action sentence compatibility effect that is addressed in the following section. It has been suggested that the slower responses with incongruent action sentences were due to the interference effect and/or inhibition during the incongruent sentence processing (Bergen, Narayan, & Feldman, 2003; Schaller, Weiss, & Müller, 2015).

4.7 ACTION SENTENCE COMPATIBILITY EFFECT

The action sentence compatibility effect (ACE) relates to the interaction between a sentence direction and performance of an action such as moving toward vs. away or up vs. down (Borreggine & Kaschak, 2006; Glenberg & Kaschak, 2002). Glenberg and Kaschak (2002) indicated that ACE provides strong behavioral evidence that indicates a link between linguistic processing and the motor systems.

For instance, Borreggine and Kaschak (2006) asked healthy participants to listen to sentences that described actions occurring either toward the body or away from the body, and then judge whether each sentence made sense. They reported that responses with moving a hand toward the body to press a keypad were faster when the sentences that described action toward the body (e.g., “Mark dealt the cards to you.”) (congruent condition) compared to the sentences that described action away from the body (e.g., “You dealt the cards to Mark.”) (incongruent condition). Likewise, responses associated with moving a hand away from the body to press a keypad were faster when the sentences described action away from the body.

It is unknown whether ACE is observed in sentence judgment tasks with swallow-related action words. It also is unknown whether there is any directional relationship (e.g., toward vs. away, or congruent vs. incongruent) between swallow-related action words and any motor performance. If there is no directional relationship between swallow-related action words and any motor performance, the interference effect may not be observed in swallowing.

4.8 THEORIES EXPLAIN THE CAUSES OF THE LANGUAGE INDUCED MOTOR FACILITATION

Reasons for facilitation effects of actions performed by hand- and foot-related action words remain to be elucidated (Boulenger et al., 2006; Dalla Volta et al., 2009; Rueschemeyer, Lindemann, van Rooij, van Dam, & Bekkering, 2010). However, there are a few theories that may explain the causes of language induced motor facilitation.

4.8.1 Semantic priming during the processing of action words

Researchers investigating language induced motor facilitation suggest that the facilitation effect is the result of the "semantic priming" by the processing of action words prior to the subsequent actions (Aravena et al., 2010; Borghi & Scorolli, 2009; Boulenger et al., 2006; Rueschemeyer et al., 2010). Priming is defined as a behavioral change based on the previous stimuli (Stoykov & Madhavan, 2015). Pulvermuller and Berthier (2008) suggested that motor behavior is easier to be elicited than that without action words because the motor system is automatically facilitated by the processing of action words prior to the execution of the motor behavior.

4.8.2 Corticospinal excitability by motor imagery

On the other hand, some researchers have suggested that facilitation effects are due to motor imagery, particularly kinesthetic imagery, imagery of kinesthetic sensation of actions, during the process of action word understanding (Gianelli & Dalla Volta, 2014; Papeo, Vallesi, Isaja, & Rumiati, 2009).

It has been reported that motor imagery of hand and leg movement without the execution of the movements results in increased corticospinal excitability (Bakker et al., 2008; Fadiga et al., 1999). For instance, Fadiga et al. (1998) have used transcranial magnetic stimulation during kinesthetic imagery of the flexing and extending the right forearm in healthy participants to test the effect of motor imagery. Motor evoked potentials were recorded from the bicepts brachialis and opponens pollicis during the kinesthetic imagery task. The bicepts brachialis is an agonist muscle for elbow flexion that is a task-related muscle. The opponens pollicis is an intrinsic hand muscle that is a non-task-related muscle. Fadiga and colleagues (1998) have reported that the kinesthetic imagery of the forearm movement resulted in increased bicepts brachialis motor evoked potentials but not in opponens pollicis.

In addition, Bakker et al. (2008) have used transcranial magnetic stimulation over the primary motor cortex during kinesthetic imagery of foot dorsiflexion task in healthy participants. Motor evoked potentials were recorded from the foot muscles, the tibialis anterior as a task-related muscle and the first dorsal interosseous as non-task-related muscle, during the kinesthetic imagery. They found that kinesthetic imagery resulted in increased activity of the motor evoked potential areas both the tibialis anterior and first dorsal interosseus muscle, with the larger increase in the tibialis anterior muscle.

4.8.3 Difference between self-initiated and externally triggered movements

There is abundant evidence indicating there are neural and behavioral differences between self-initiated or internally triggered movements (i.e., actions that are not elicited by external stimuli) and externally triggered movements (i.e., actions that are elicited by external stimuli) such as a visual, tactile, and beep stimuli (Ballanger et al., 2006; Cunnington, Windischberger, Deecke, & Moser, 2002; Jahanshahi et al., 1995; Jenkins, Jahanshahi, Jueptner, Passingham, & Brooks, 2000; Obhi & Haggard, 2004; Yazawa et al., 1997). Both the internally triggered and externally triggered movements involve activation of common neural areas for the organization and control of voluntary movements. However, the internally triggered movements are associated with earlier and stronger activation of the supplementary motor area, which is considered to be associated with motor preparation (Cunnington et al., 2002).

Behavioral evidence indicates that the duration of hand movements (e.g., index finger press and a button press) is shorter when the movement is elicited by external stimuli than that observed in self-initiated movement (Ballanger et al., 2006; Obhi & Haggard, 2004). For instance, Ballanger et al. (2006) conducted a button press movement study both with healthy participants and patients with Parkinson's disease. Patients performed a button-pressing task either in response to an external acoustic stimulus (i.e., a beep stimulus) or voluntarily without any stimulus. Their results indicated that the interval between the onset of the hand release from a start position and the contacting of the button was shorter in the externally triggered condition than in the self-initiated condition. Obhi and Haggard (2004) examined electromyographic (EMG) activity recorded from the first dorsal interosseous muscle, a task-related muscle, during the index finger press of a metal lever with and without the presentation of a tactile stimulus. They reported that

EMG activity duration following the tactile stimulus had shorter trend than that during the self-initiated finger press movement in healthy participants. Moreover, Obhi and Haggard have reported that, in the same study, the internally triggered movement resulted in significantly greater EMG activity in the first dorsal interosseous muscle than that of externally triggered movement.

Taking the neural and behavioral evidence together, Obhi and Haggard have postulated the longer movement duration in the internally triggered condition was due to the earlier cortical activation in this condition while the greater EMG activity in the internally triggered movement was due to the greater preparatory processing of the condition (Obhi & Haggard, 2004).

Studies that have tested the self-initiated and externally triggered movements did not employ any action word stimuli. However, it is reasonable to question whether or not the observed neural differences between the self-initiated and externally triggered conditions also may account for the facilitation effects by action words on subsequent actions.

4.9 IS THE LANGUAGE INDUCED MOTOR FACILITATION "LANGUAGE-SPECIFIC"?

It is unknown whether the observed facilitation effects on the hand- and foot-related actions in the language induced motor facilitation are language-specific. There have been no studies that employed non-verbal stimuli, such as a pure-tone, along with verbal stimuli.

Rabahi et al. (2013) speculated that attention and/or intention also may play a role in language induced motor facilitation: giving action words prior to the actions make participants have more attention and emotion toward the motor acts. If attention plays a role, non-verbal stimuli may also facilitate subsequent actions.

Because phonological, lexical, semantic, and grammatical processing is not necessary for non-verbal stimuli, non-verbal stimuli may produce shorter reaction time than that with action words. It is essential to employ both verbal and non-verbal stimuli to test whether the observed facilitation effects in the language induced motor facilitation literature are language-specific.

4.10 LANGUAGE INDUCED MOTOR FACILITATION IN SWALLOWING

There have been no behavioral studies that have tested the effects of the auditory processing of the verbal stimulus, *swallow*, on swallow physiology. However, there are few behavioral studies that reported the effects of auditory cues on swallow physiology more generally.

4.10.1 Swallow-related auditory cues: Name of drinks

Nakamura and Imaizumi (2013) employed sEMG to test the impact of swallow-related verbal cues presented auditory cues acoustically. In their study, the names of the drinks (i.e., *water*, *apple juice*, and *grass juice*, in Japanese) were presented in a congruent manner prior to the initiation of swallows by 24 younger and older healthy participants. Suprahyoid muscle activity was measured during the swallows of 5 ml of water, apple juice and grass juice. The participants were instructed to listen to the drink names, imagine the flavor of the drink, hold the liquid bolus in their mouth for 5 to 7 seconds, and then swallow when they hear the verbal stimulus, *swallow* (in Japanese).

The researchers reported that the maximum suprahyoid muscle activity was stronger in swallows associated with drink names compared to swallows without the names, regardless of the participant ages. Nakamura and Imaizumi postulated that the swallow-related drink names caused a priming effect and induced the anticipation of swallowing, and thus caused an enhancement of the suprahyoid muscle activity.

However, they also reported significant latency differences (duration between the verbal stimulus onset and the peak suprahyoid muscle activity onset) between swallows with and without the drink names. Nevertheless, the verbal stimulus was given both in the acoustic cue and non-cue conditions. According to the language induced motor facilitation theory, the processing of the verbal stimulus, *swallow*, given after the drink names should facilitate the latency both in the conditions. It is feasible to have not difference between the two swallow conditions.

4.10.2 External non-verbal auditory cue unrelated to swallowing

Nonaka et al. (2009) used sEMG to examine suprahyoid muscle activity differences between saliva swallows when elicited with and without a 105 dB SPL acoustic cue. The acoustic cue was not described except for presentation intensity level and was presented to ten healthy young male participants. The researchers reported no difference in mean suprahyoid muscle activity between the two swallow conditions. The lack of differences and the limited information about the acoustic cue used in this study makes it difficult to relate the results to any type of language impact on participant swallows.

Regarding non-verbal acoustic stimuli, there is evidence that that an intense acoustic stimulus (e.g., >124 dB SPL, 1000 Hz tone) produces a reflexive startle response but can also elicit faster voluntary actions when participants are ready to initiate a motor behavior (Alibiglou & MacKinnon, 2012; Carlsen, Maslovat, & Franks, 2012). This facilitation effect is known as the startle reflex, and has been observed in healthy participants as well as patients with Parkinson's Disease (Carlsen et al., 2012). However, the acoustic stimulus used by Nonaka et al. (2009) may not have been sufficiently intense to produce the startle reflex.

Furthermore, the experimental methodology employed in the study may explain why there was no suprahyoid muscle activity difference between the two swallow conditions. Participants were instructed to inhibit the oral lingual movement prior to the swallow onset, and then used a supraglottic swallow (SGS)-like maneuver regardless of the swallow condition. More specifically, participants were instructed to hold their breath for four seconds prior to the swallow onset in both conditions. In the external sound cue condition, the sound cue was presented after the SGS-like breath-hold task. The SGS, which is designed to produce airway closure at the true vocal fold level before and during the swallow (Logemann, 1998), alters some of the swallow physiology (Bodén, Hallgren, & Witt Hedström, 2006; Donzelli & Brady, 2004; Kasahara, Hanayama, Kodama, Aono, & Masakado, 2009; Ohmae et al., 1996). Indeed, true vocal fold closure was achieved when healthy participants were instructed to have an easy breath-hold prior to the swallow onset (Donzelli & Brady, 2004). This causes the earlier inhibition of respiration (Ertekin, 2006). The hyoid starts to elevate when performing the breath-hold task prior to the swallow onset during SGS in healthy adults (Bülow, Olsson, & Ekberg, 1999; Ohmae et al., 1996). The earlier onset of the laryngeal elevation results in prolonged laryngeal elevation and UES opening during SGS (Bülow et al., 1999; Ohmae et al., 1996), although a recent study failed to meet the statistical significance regarding the longer UES opening (Bodén et al., 2006).

In addition, both superior and anterior displacement of the hyoid was significantly greater and longer during the SGS (Kasahara et al., 2009). Nonaka et al. (2009) measured the suprahyoid muscle activity during the onset and end of the muscle electrical discharge. Therefore, the suprahyoid muscles were perhaps activated and deactivated at the same time in the cue and non-cue conditions. Thus, there might have been no suprahyoid muscle activity difference between the two swallow conditions. In fact, Nonaka et al. reported that, regardless of the swallow conditions, the onset of the suprahyoid muscle activation was earlier than any of other muscle activations, such as eye, tongue and face-related muscle activations in their study.

4.11 LANGUAGE INDUCED MOTOR FACILITATION: SUMMARY

The language induced motor facilitation theory suggests that the processing of foot-/leg- and hand-/arm-related action words, which are (1) related to actions described by the action words, (2) presented prior to the actions, have facilitation effects on subsequent actions described by the action words, although it is unknown whether the facilitation is language-specific. Taken together, the evidence from the language theory suggests the processing of the verbal stimulus that is a congruent action word prior to the initiation of swallowing under the command swallow condition may also facilitate some of the swallow physiological parameters that are under voluntary control.

Nevertheless, the effects of the action word, *swallow,* on swallow physiology have never been investigated. None of the previous studies that have tested the language induced motor facilitation have employed the action word, *swallow*. In order to clarify whether giving the verbal stimulus under the command swallow condition imposes any artifacts on swallow physiology, it is critical to investigate whether the language induced motor facilitation can be observed during swallowing.

4.12 STIMULUS ONSET ASYNCHRONY: LANGUAGE INDUCED MOTOR INTERFERENCE

Depending on the temporal relationship between the presentation of action words and motor tasks, the processing of action words can also interfere the subsequent actions (Boulenger et al., 2006). When hand- and foot-related auditory or written action words are presented concurrent or 50 to 200 ms after the initiation of hand- and foot-related actions, interference effects on the hand- and foot-related actions were observed (Boulenger et al., 2006; Buccino et al., 2005; Frak et al., 2010; Nazir et al., 2008; Sato et al., 2008). For instance, Buccino et al. (2005) reported that, in their study with healthy young participants, listening to sentences with hand- or foot- related action words, such as *sew* and *cut*, or *kick* and *jump*, while executing hand- and foot- related actions resulted in slower hand and foot reactions.

Sato et al. (2008) postulated the interference effects by auditory and written concurrent action word stimuli on actions described by action word stimuli were due to the simultaneous competition for the motor system between action word processing and action execution. Other researchers have suggested that language induced motor interference is due to the inhibition of the actions or can possibly planning of actions while simultaneously processing the action words (Boulenger et al., 2006; Dalla Volta et al., 2009). However, reasons for language induced motor interference remain to be elucidated.

Given the fact that actions word can facilitate or interfere with the subsequent actions depending on the temporal relationship between the presentation of action words (Boulenger et al., 2006), stimulus onset asynchrony, the time interval between the onset of cues and actions, becomes an important factor for investigating language induced motor facilitation. In order to avoid having influences by the effects of the language induced motor interference, the action words should be presented prior to the actions.

4.13 FEASIBILITY OF APPLYING THE LANGUAGE INDUCED MOTOR FACILITATION IN SWALLOWING

The language induced motor facilitation theory has only been tested in foot/leg, hand/arm actions. In this section, the feasibility of applying the language induced motor facilitation theory in swallowing was addressed. The majority of the previous studies investigating language induced motor facilitation and interference examined the reaction time of the hand-related actions, such as pressing a button, reaching and grasping an object, and reaching-grasping-lifting an object, or a foot-related actions, such as pressing a pedal or jumping (Aravena et al., 2010; Boulenger et al., 2006; Buccino et al., 2005; Dalla Volta et al., 2009; Frak et al., 2010; Gentilucci, 2003; Nazir et al., 2008; Sato et al., 2008; Scorolli & Borghi, 2007). Among the hand-related actions, the reaching and grasping of an object task has been frequently employed in the literature. Thus, this section focused on the reaching and grasping (RG) movements.

RG movement is considered to be a multi-segment motor action (Olivier, Hay, Bard, & Fleury, 2007; Rizzolatti, Cattaneo, Fabbri-Destro, & Rozzi, 2014). The reaching movement involves the transport of the hand, and change in position of the hand over time to reach the desired object (Olivier et al., 2007; van Vliet, Pelton, Hollands, Carey, & Wing, 2013). Visual and proprioceptive information, such as distance and direction of an object, is used to plan and activate the reaching movement (van Vliet et al., 2013). The grasping movement involves the pre-shaping, opening and closure of the hand (Olivier et al., 2007). Visual and proprioceptive information, such as size, shape, orientation, and estimated weight of an object, is used to guide the grasping movement appropriately (van Vliet et al., 2013). Moreover, in order to complete the RG task, the coordination of these two movements is required (Olivier et al., 2007).

There are several similarities between swallowing and the RG movements. Table 3 displays the summary of the comparison between swallowing and the RG movements. For instance, both swallowing and the RG movement contain a series of motor actions (Olivier et al., 2007; Rizzolatti et al., 2014; van Vliet et al., 2013). Striated muscles are used for voluntary aspects of swallowing (i.e., swallow events prior to the triggering of pharyngeal swallow) (Shaw & Martino, 2013), and the RG movements (Taylor & Schwarz, 1955). Coordinated muscle movements are required to complete both swallowing and the RG movements, although different types of sensory information are used to alter the movements (van Vliet et al., 2013). Information of temperature, touch, pressure, and taste information including bolus characteristics from the oropharynx is used for swallowing (Miller, 2008a). On the other hand, visual, proprioceptive information, and information of a weight of an object is used for the RG movements (Olivier et al., 2007; van Vliet et al., 2013).

Moreover, the information of voluntary motor control for swallowing and the RG movement is carried by the pyramidal tracts, which are descending pathways that arise from the cerebral cortex and terminate either in the brainstem or spinal cord (Siegel & Sapru, 2010). The corticobulbar tract sends information of voluntary motor control from the cortex to the most of the muscles involved in swallowing (i.e., the geniohyoid and infrahyoid muscles receive information via the corticospinal tract) (Shaw & Martino, 2013). The corticospinal tract sends information of voluntary motor control from the cortex to the muscles for the RG movements and the geniohyoid and infrahyoid muscles (Siegel & Sapru, 2010). The corticobulbar and corticospinal tracts serve as upper motor neurons, and have similar descending trajectory except for the terminations of upper motor neurons. The corticobulbar tract arise from the primary motor cortex and are directed to the cranial nerve motor nuclei in the brainstem (Siegel & Sapru, 2010). The corticospinal tract arises from the primary motor, primary somatosensory, supplemental motor, and premotor cortex, and descends through the spinal cord (Siegel & Sapru, 2010).

Given these similarities between swallowing and the RG movement, it is feasible to apply the language induced motor facilitation that has been tested in the RG movements to swallowing.

Table 3. Summary of the comparison between swallowing and the RG movement

	Swallowing	Reaching-grasping movement
Action type	Series of motor action	Series of motor action
Sensory feedback	Temperature, touch, pressure, and taste information	Visual, proprioceptive information, and a weight of an object
Muscles	Muscles of face, mastication, tongue, soft palate, pharyngeal, suprahyoid, larynx, infrahyoid, and upper esophagus	Muscles of arm and hand, wrist, and fingers, shoulder, and torso
Muscle types	Striated muscles except the middle and distal esophagus	Striated muscles
Descending pathway	Pyramidal tracts: Corticobulbar + Corticospinal	Pyramidal tracts: Corticospinal
Information carried	Voluntary movements of the muscles for swallowing	Voluntary movements of upper limbs
Neuron type	Upper motor neurons	Upper motor neurons
Origin	Primary motor cortex Branchial primarily	Primary motor cortex, primary somatosensory cortex, supplemental motor area, and premotor area
Termination of UMNs	Motor nuclei in brainstem	Motor nuclei in the Spinal cord
Projections	-Corona radiata -Internal capsule -Cerebral peduncles -Pons -Motor nuclei in Medulla	-Corona radiata -Internal capsule -Cerebral peduncles -Pons -Medulla -Spinal cord
UMN Fiber type	Pyramidal	Pyramidal

Note: UMNs=upper motor neurons

5.0 SUMMARY AND SPECIFIC AIMS

5.1 SUMMARY

Swallowing is a complex neuromuscular act that requires sensory and motor coordination (Ertekin, 2006; Miller, 2008b). It involves organized interactions between cortical, subcortical, brainstem, and peripheral systems (Ertekin, 2006; Miller, 2008b). Any disruption in these neurophysiological pathways can result in swallow disorders or dysphagia (Robbins et al., 2008). Patients with dysphagia have a high risk of dehydration, malnutrition, aspiration pneumonia, and reduction in quality of life (Harrison et al., 2014; Logemann, 1998). In order to provide optimal swallow treatments to reduce such risks, during swallow evaluations, it is essential to observe the patient swallowing under the conditions in which he/she routinely swallows.

For diagnosis and evaluation of swallowing, VFSS is widely used in the U.S. (Langmore, 2003). During VFSS, the command swallow condition, in which a patient/participant holds a bolus in his/her mouth while waiting for a verbal stimulus, *swallow,* that indicates the timing to initiate the swallow, is commonly employed (Daniels et al., 2007; Nagy et al., 2013; Palmer et al., 2007). However, the command swallow condition imposes two unnatural conditions that are: (1) the bolus is held on the tongue intentionally while the patient awaits the verbal stimulus, and (2) the patient processes the verbal stimulus prior to the swallow initiation and then swallows in response to the stimulus (Hiiemae & Palmer, 2003).

Recent studies have indicated the bolus hold induces the anterior location of the bolus at swallow onset under the command swallow condition regardless of bolus consistency and volume (Daniels et al., 2007; Nagy et al., 2013; Palmer et al., 2007). The alteration of some of the swallow durations, such as oral transit time, stage transit duration, total swallow duration, pharyngeal transit time, pharyngeal response time, processing duration, and vallecular aggression time, were also observed in the bolus hold (Daniels et al., 2007; Nagy et al., 2013; Palmer et al., 2007). However, there is no consensus as to how the bolus hold alters the duration parameters. Also, shorter palate-lingual contact duration (Nomura et al., 2011), and inhibition of the swallow onset (Roubeau et al., 2008) due to the bolus hold have been reported. However, the majority of studies had small sample sizes and swallow trial repetitions. Study results may not represent the true nature of swallows or effects of the command swallow condition. The effects of the bolus hold under the command swallow condition on swallow physiology are not fully understood.

The impact of the processing of the verbal stimulus under the command swallow condition has never been investigated. It is unknown whether or not and to what extent language processing impacts natural swallowing physiology.

There are several lines of evidence that may assist in examining the impact of the verbal stimulus. Swallowing is not a purely reflexive act. Voluntary components of swallowing can be modulated by verbal instructions (Humbert & German, 2013). Neural activation prior to swallows elicited by a written verbal stimulus has left hemispheric dominance (Nagasaki et al., 2004). This may suggest the involvement of language processing in the command swallow condition and supports applying theoretical approaches.

The language induced motor activation theory indicates that there is a tight neural link between foot/leg-, hand/arm-, and articulator-/face-related action words and motor cortical areas that are involved in the execution of the actions (Buccino et al., 2005; Fargier, Ménoret, Boulenger, Nazir, & Paulignan, 2012a; Fargier, Paulignan, Boulenger, Monaghan, Reboul, & Nazir, 2012b; Fischer & Zwaan, 2008; Hauk & Pulvermüller, 2004; Jirak et al., 2010; Meteyard et al., 2012; Péran et al., 2010; Postle et al., 2008; Pulvermüller, 1999; 2005; 2013; Pulvermüller et al., 2001; Pulvermüller & Hauk, 2006; Pulvermüller, Hauk, Nikulin, & Ilmoniemi, 2005a; Pulvermüller, Shtyrov, & Ilmoniemi, 2005b; Tettamanti et al., 2005; Tomasino et al., 2007; 2008). Action word processing activates motor cortical areas in a somatotopic manner without the execution of the actions (Buccino et al., 2005; James & Maouene, 2009; Jirak et al., 2010; Pulvermüller, 1999; 2005; Pulvermüller, Hauk, Nikulin, & Ilmoniemi, 2005a; Pulvermüller, Shtyrov, & Ilmoniemi, 2005b; Tettamanti et al., 2005).

The language induced motor facilitation theory suggests the processing foot/leg-, hand-/arm-related words presented prior to the initiation of the related actions facilities the control of the subsequent actions (Aravena et al., 2010; Boulenger et al., 2006; Gentilucci, 2003). Yet, it is unknown whether the observed facilitation effects are narrowly defined by linguistic and motor parameters, or more general.

Taken together, these theories suggest that processing the verbal stimulus, *swallow,* under the command swallow condition alters some of the swallow events that are considered to be under voluntary control. To clarify whether processing the verbal stimulus under the command swallow condition imposes any artifacts on swallow physiology, it would be useful to investigate whether the language induced motor facilitation effect can be observed during swallowing.

5.2 SPECIFIC AIMS

The current study investigated whether the language induced motor facilitation effect is evident under the command swallow condition as reflected in the onset of suprahyoid muscle activity and duration of suprahyoid muscle activity relative to the verbal stimulus onset as measured from sEMG. Differences in latency, peak amplitude, and duration were compared between conditions. The conditions included a congruent verbal stimulus (*swallow*), incongruent verbal stimulus (*cough*), congruent pseudo-word stimulus (*spallow*), incongruent pseudo-word stimulus (*pough*), as well as a non-verbal acoustic stimulus (1000 Hz speech-shaped pure-tone). The specific aims are listed below.

Specific aim 1: Determine if there was a significant difference on the delays between stimulus onset and the suprahyoid muscle activity onset (sEMG latency), the duration of suprahyoid muscle activity (sEMG duration), peak suprahyoid muscle activity amplitude (sEMG peak amplitude), and delays between stimulus onset and the peak suprahyoid muscle activity amplitude (sEMG latency) for swallows following the congruent action word like *swallow* and a non-verbal stimulus (1000 Hz pure-tone) after controlling for swallow-respiratory pattern at the stimulus onset.

Specific aim 2: Determine if there was a significant difference in the sEMG latency, sEMG duration, sEMG peak amplitude, and sEMG peak latency in swallows following the congruent action word, *swallow,* and the congruent pseudo-word, *spallow*, after controlling for swallow-respiratory pattern at the stimulus onset.

Specific aim 3: Determine if there was a significant difference in the sEMG latency, sEMG duration, sEMG peak amplitude, and sEMG peak latency in swallows following the word *swallow* as compared to the incongruent action word *cough,* after controlling for swallow-respiratory pattern at the stimulus onsets.

Specific aim 4: Determine if there was a significant difference in sEMG latency, sEMG duration, sEMG peak amplitude, and sEMG peak latency for swallows following the incongruent word *cough* and the incongruent pseudo-word *pough* after controlling for the swallow-respiratory pattern at stimulus onset.

Specific aim 5: Determine whether there were sEMG latency pattern differences for the swallows produced after the five different stimuli (*swallow*, *cough*, *spallow*, *pough,* and 1000 Hz pure-tone) after controlling for the swallow-respiratory pattern at stimulus onset.

5.3 HYPOTHESES

Specific aim 1:

H_0: There was no significant difference in the sEMG latency, sEMG duration, sEMG peak amplitude, and sEMG peak latency for swallows following the congruent action word *swallow* and those following a non-verbal (1000 Hz pure-tone) stimulus.

H_1: The sEMG latency, sEMG peak latency, and sEMG duration of swallows following the congruent action word *swallow* were significantly shorter than for a 1000 Hz pure-tone. The sEMG peak amplitude was greater for the word *swallow* than for a 1000 Hz pure-tone.

Findings of this type suggest that swallowing is facilitated by the linguistic information in the swallow command and simply not a response to an acoustic stimulus.

H_2: The sEMG latency, sEMG peak latency, and sEMG duration of swallows following the 1000 Hz pure-tone were significantly shorter than for the congruent action word. The sEMG peak amplitude was greater for a 1000 Hz pure-tone stimulus than for the word *swallow*.

Findings of this type suggest that a simple non-verbal stimulus requires less processing and activates a swallowing response more directly than a verbal command.

Specific aim 2:

H_0: There was no significant difference in the sEMG latency, sEMG duration, sEMG peak amplitude, and sEMG peak latency for swallows following the congruent action word *swallow* as compared to the congruent pseudo-word *spallow*.

H_1: The sEMG latency, sEMG peak latency, and sEMG duration of swallows following the word *swallow* were significantly shorter than following the pseudo-word *spallow*. The sEMG peak amplitude for swallows following the word *swallow* was greater than for the word *spallow*.

Findings of this type are consistent with pseudo-words creating interference in language processing and is consistent with presence of language-induced motor facilitation.

Specific aim 3:

H_0: There was no significant difference in the sEMG latency, sEMG duration, sEMG peak amplitude, and sEMG peak latency for swallows following the congruent action word *swallow* and the incongruent action word *cough*.

H_1: The sEMG latency, sEMG peak latency, and sEMG duration of swallows following the word *swallow* were significantly shorter than for the word *cough*. The sEMG peak amplitude for swallows following the word *swallow* was significantly greater than for the word *cough*.

Findings of this type are consistent with the language induced motor facilitation theory in that semantic directionality influences the swallow response and suggests that command semantics can facilitate and interfere with the act of swallowing.

Specific aim 4:

H_0: There was no significant difference on the sEMG latency, sEMG peak latency, and sEMG duration for swallows following the incongruent action word *cough* and the incongruent pseudo-word *pough*.

H_1: The sEMG latency, sEMG peak latency, and sEMG duration of swallows following the word *pough* were shorter than for the word c*ough*. The sEMG peak amplitude of swallows following the word *pough* was greater than for those following the word *cough*.

Findings of this type are consistent with pseudo-words creating interference on language tasks and that the interference extends beyond that created by an incongruent command. This pattern is consistent with language influencing the motor act of swallowing, and therefore supports the language induced motor facilitation theory.

Specific aim 5:

H_0: There was no significant relative pattern for swallow latencies across the congruent action word *swallow*, non-verbal pure-tone, incongruent action word *cough*, congruent pseudo-word *spallow*, incongruent pseudo-word *pough*, and 1000 Hz pure-tone.

H_1: The sEMG latency of swallows following the congruent action word *swallow* was shorter than for the other four stimuli and there was a relative influence of interference across incongruent words and pseudo-words.

Findings of this type are consistent with the language induced motor facilitation theory in that the congruent word *swallow* facilitates the motor act of swallowing, whereas incongruent and pseudo-words show signs of interference. The 1000 Hz pure-tone does not have a facilitative effect because it is not verbal.

H_2: The sEMG latency of swallows following the 1000 Hz pure-tone was shorter than the five stimuli.

Findings of this type suggest non-verbal stimuli produce shorter response times than that with verbal stimuli because linguistic processing is not necessary and the motor system is activated directly.

6.0 METHODS

6.1 EXPERIMENTAL DESIGN

The study employed a repeated measures within subject design. The dependent variables for the study were: (1) the delay between the onset of each stimulus and the onset of suprahyoid muscle activity as measured by sEMG (sEMG latency), (2) the duration of suprahyoid muscle activity as reflected in the duration between onset and offset of sEMG activity (sEMG duration), (3) the peak suprahyoid muscle activity amplitude as reflected in the sEMG maximum (sEMG peak amplitude), and (4) the delays between the onset of each stimulus and the sEMG peak latency (sEMG peak latency). The independent variable for the study was the stimulus type (five levels).

The swallow-respiratory coordination pattern (the expiratory phase, inspiratory phase, or zero flow) at stimulus onset was added into the mixed model as a random effect, along with the acoustic stimulus types which were fixed effects.

6.1.1 Participant demographics, recruitment and screening

Twenty monolingual, native speakers of American English with normal swallowing function were recruited from the University of Pittsburgh and surrounding area. The demographic information of the participants is summarized in Table 4. This study protocol was approved by the University of Pittsburgh Institutional Review Board (Appendix A), and all participants provided oral and written informed consent prior to any study procedures. The inclusion and exclusion criteria are summarized in Table 5. They included known allergies or sensitivity to skin adhesive products used to secure surface electrodes, facial hair in the submandibular region (submental geniohyoid-mylohyoid-anterior digastric region) that could interfere with adhesion of the electrodes used to record the sEMG (Brodsky et al., 2012), hearing loss, and vision loss. Participants who had difficulty breathing from the nose due to the presence of nasal congestion or blockage also were excluded from the study. In addition, participants who used any medications that could affect swallowing functions (Balzer, 2000) were excluded. Table 6 lists medications that may induce swallowing difficulty.

The participants were first screened with a background questionnaire (Appendix B) followed by hearing and vision screens. The hearing screening was applied to each ear separately using 500, 1000, 2000, and 4000 Hz pure-tones presented at 25 dB HL (ASHA, 2005). Testing was done in a quiet laboratory space using a diagnostic audiometer (Beltone 120). A vision screening was completed with the standard Snellen chart (Bailey & Lovie, 1980) administered under the binocular condition with/without correction to ensure that participants were able to see the visual stimuli used in the study. The participants needed 20/20 vision for inclusion.

Table 4. Demographic information of the participants

Variable		
Age (years)	*Mean* ± *SD*	23.18 ± 4.6
	Range	18-35
sex	Male	10
	Female	10
Race/ethnicity	Asian	4
	African-American	1
	Caucasian	15

Table 5. Summary of the inclusion and exclusion criteria of the study

Inclusion	*Exclusion*
− Healthy adults − Age between 18 and 35 years − English is the first language	− History of swallowing problems or of health issues that affect swallowing − Known allergies or sensitivity to skin adhesives − Facial hair in the submandibular region − History or presence of hearing loss − Visual acuity worse than 20/20 − Presence of nasal congestion − Taking medications that may affect swallowing

Table 6. List of the medications that may induce swallow difficulty

Type	*Name*
Medications with anticholinergic or anti-muscarinic effect	Benztropine mesylate
	Oxbutynin
	Propantheline
	Tolterodine
Medications that cause xerostomia	ACE inhibitors
	Antiarrythmic
	Antiemetics
	Antihistamines and decongestants
	Calcium channel blocker
	Diuretics
	Selective serotonin reuptake inhibitors

Table 6. continued

Antipsychotic/Neuroleptic medications	Chlorpromazine
	Clozapine
	Fluphenazine
	Haloperidol
	Lithium
	Loxapine
	Olanzapine
	Quetiapine
	Risperidone
	Thithizene
	Trifluoperazine
Medications depress the central nervous system	Antiepilepitc drugs
	Benzodiazepines
	narcotics
	Skeletal muscle relaxants

6.1.2 Sample size calculation

The sample size was based on a power analysis conducted using PASS 14 (NCSS, Kaysville, Utah) and G*power to calculate the number of participants needed for multilevel modeling with a power of .80, an alpha offset at .05, a medium effect size of .50, repeated measurement of 20, alpha level of .05, and the variance (*SD*=663 ms) observed in the Brodsky et al. study (2012). It was estimated that a total of 20 participants were needed for sufficient power to find differences among experimental conditions.

6.2 STIMULI

Six acoustic stimuli and two visual stimuli were used in the study. The acoustic stimuli included the bolus hold instruction; "*hold it"*, which instructed participants to hold a bolus after they sipped water from a cup. This was followed by one of five acoustic stimuli to signal the swallow. The visual stimuli included the start cue to signal the beginning of each trial, and the sip cue to instruct the participants to sip water from a cup. Both acoustic and visual stimuli were presented via SuperLab 5.0, a laboratory experiment administration software (Cedrus, Phoenix, AZ).

6.2.1 Acoustic stimuli

The five acoustic stimuli used to signal the command swallow included: (1) congruent action word, *swallow*, (2) incongruent action word, *cough*, (3) congruent pseudo-word, *spallow,* (4) incongruent pseudo-word, *pough*, and (5) a non-verbal, 1000 Hz pure-tone.

Efforts were made to match the stimuli on acoustic and sublexical parameters. The database from the Washington University English Lexicon project was used to generate the words (Balota et al., 2007). The sublexical parameters used for selection are listed in Table 7 and the decision process follows.

Table 7. Summary of each acoustic stimulus

Acoustic stimuli	Pronunciation	Word-frequency	Word length	Phoneme number	Syllable number	Morpheme number
swallow	sw"A.lo	8.066	7	5	2	1
cough	k"Of	7.703	5	3	1	1
spallow	sp"A.lo	NA	7	5	2	NA
pough	p"Of	NA	5	3	1	NA

Note: Word frequency was based on the log-transformed HAL (Hyperspace Analogue to Language) frequency norms; Word length was the number of letters in the word (Balota et al., 2007); NA=Not applicable.

Congruent action word stimulus

The word *swallow* was used as the congruent action word because it corresponds directly with the target action and is typically used clinically under the command swallow condition.

Incongruent action word stimulus

The incongruent word *cough* was selected because it was associated with a motor activity that propels materials or air in the opposite direction of *swallow* and has a similar word-frequency. There are physiological similarities between swallow and cough actions, although substances in the aerodigestive tract travel in the opposite direction during swallowing and coughing (Ludlow, 2015). Both swallowing and coughing are upper airway responses to stimulation and both involve laryngeal and respiratory system functions. However, the function of swallowing is to propel liquid or solid boluses down to the esophagus, whereas, the function of cough is to expel substances from the trachea. Swallowing actively suppresses respiration, closes the true vocal folds and laryngeal entrance so that liquid or solid boluses are not propelled to the airway. Cough starts with an inspiration, closure of the false and true vocal folds, followed by forceful and rapid air expulsion in order to open the true vocal folds, and expel substances from the trachea.

Syllable numbers and word-frequency can influence reaction time and movement duration and should be matched when possible (Abrams & Balota, 1991; Balota & Abrams, 1995; Bangert, Abrams, & Balota, 2012; Johns, Gruenenfelder, Pisoni, & Jones, 2012). There were only a limited number of words that described an action incongruent to swallow (e.g., *cough*, *spit*, *vomit*, and *gag*). The word *vomit* had the same syllable numbers and a similar word-frequency as *swallow*, but was not selected because it has strong negative emotional connotations that could impact the results of the proposed study (Larsen, Mercer, & Balota, 2006). The word *cough* was selected because it has a similar word-frequency as *swallow* and its directional connotation.

Pseudo-word stimuli

The pseudo-words were generated relative to the congruent action word *swallow* and the incongruent action word *cough*. Each pseudo-word was created to match the length, consonant-vowel structure, and phoneme numbers, and syllable number of the corresponding real word. In order to form a closely matched pseudo-word for the congruent action word, the first consonant blends of the congruent action word cue were switched (i.e., /sw/ →/sp/). Likewise, the first initial consonant of the incongruent action word cue (i.e., /c/→/p/) was switched to have a closely matched pseudo-word form for the incongruent action word.

Because it was not possible to control the syllable numbers between the congruent and incongruent action words, both pseudo-word stimuli were used as a comparison condition. Specifically, statistical results of the pseudo-word conditions were compared to those of the congruent and incongruent conditions to determine whether the outcomes of the study were influenced by the syllable number difference between the congruent and incongruent action words. The possible outcomes were addressed in the data analysis section of this paper.

Non-verbal stimuli

The 1000 Hz pure-tone was selected based on a previous study that tested swallowing reaction times after the presentation of a 1000 Hz tone (Roubeau et al., 2008). It also was included to provide a non-verbal acoustic control. The tone duration (600 ms), amplitude (average RMS) and envelope were matched to the congruent action word *swallow*.

6.2.2 Acoustic stimuli recording

All the acoustic stimuli, including the bolus hold instruction, were produced by a native English male speaker. The recordings were done in a sound-treated booth with a Shure 33-3043 microphone (Shure, Niles, IL) routed out to a desktop computer. The stimuli were recorded at 44,100 Hz, 32 bit-rate with a digital audio editing program, Adobe Audition CS5.5 (Adobe system, San Jose, CA), and saved in a wav audio file format.

During the recordings, the speaker repeated each of the words 10 times at a natural rate within the context of "*1, 2, 3*, <u>target word</u>" (i.e., "*1, 2, 3, hold it*", "*1, 2, 3, swallow*", "*1, 2, 3, cough*", "*1, 2, 3, spallow*" and "*1, 2, 3, pough*"). This context was used to control the speaking context and co-articulation. The same talker also was asked to repeat each word 10 times in a slightly faster and slower speed than his normal conversational speech rate to help with later matching of stimulus durations. From the recordings, a single sample of each word/phrase was selected based on clarity and naturalness. These sound files were edited and matched for amplitude and duration. The intelligibility of each stimulus was validated by 25 volunteers who correctly identified each stimulus across 40 presentations (Brodsky, 2006). The detail of the validation procedure was described in the section below. The non-verbal stimulus was extracted from a pre-existing 10 sec, 1000 Hz pure-tone.

6.2.3 Acoustic stimuli manipulation

The four acoustic word stimuli (i.e., *swallow*, *cough*, *spallow*, and *pough*) were edited with Adobe Audition CS5.5. The background noise during the recording was reduced from all the stimuli, and a 50-ms silence was added at the beginning and end of each stimulus file to control timing. Then the duration and amplitude of the incongruent and pseudo-words were matched to *swallow* so that the cues and sound files were of equal length. The 1000 Hz pure-tone was constructed to match *swallow*. An example of the congruent action word and the non-verbal stimulus are shown in Figure 1 and 2.

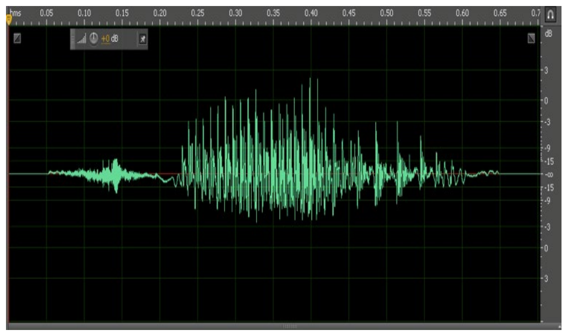

Figure 1. An example of the congruent action word

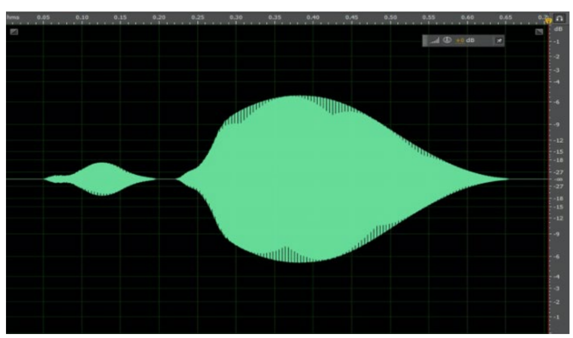

Figure 2. An example of the non-verbal 1000 Hz tone

Note: The x-axis (horizontal ruler) indicates time in seconds, and the y-axis (vertical ruler) indicates a software-based relative amplitude in dB, not dB SPL or HL. Word amplitude was matched on average RMS rather than peak amplitude.

6.2.4 Acoustic stimuli intelligibility verification

To verify the intelligibility of the verbal acoustic stimuli, the four words *swallow, spallow, cough*, and *pough* were presented to 25 volunteers in sound field at 65 dB SPL, as measured at the level of the pinna. The volunteers were over 18 years of age, native English speakers, had normal hearing (per ASHA 2005), and naïve to the purposes of the study. Each stimulus was presented 10 times (40 words total), in random order. After each word was presented, the volunteers indicated which of the four words they heard. Twenty-four of the volunteers identified all the stimuli with 100% accuracy, and one volunteer correctly identified the stimuli with 98% accuracy. The latter listener selected *cough* for *pough* 1 out of 10 trials. A priori criterion level of 70% correct was used (Brodsky, 2006), so all of the stimuli were deemed intelligible.

Prior to implementing the experiment, the directionality of the congruent and incongruent words was assessed in preliminary studies with procedures similar to those used by Borreggine and Kaschak (2006). This ACE-related procedures required a manual response and did not verify directionality and failed to replicate previous studies by Kaschak and colleagues. See Appendix C-F.

6.2.5 Visual stimuli

As previously noted, there were two visual stimuli used in the study – the start cue and the sip cue. The start cue consisted of a cross symbol in black 60-point Times New Roman font on a white background. The start cue indicated the beginning of each swallow trial. The sip cue was a colored photograph of a female person sipping from a cup. The photograph (800 x 500 pixels) was on a white background and signaled participants to sip water from a cup. Both visual stimuli were presented on a computer monitor in front of the participants at approximately 74 cm.

6.3 INSTRUMENTATION

A Kay Digital Swallowing Workstation (Model 7200, KayPENTAX, Lincoln Park, NJ) and Swallowing Signals Laboratory (Model 7120, KayPENTAX, Lincoln Park, NJ) were used as a multi-functional system to simultaneously record sEMG, nasal airflow, and the acoustic stimuli. The Swallowing Signals Lab system had a custom external module with a PC interface card and five channels for specific transducers. For the current study, one of the sEMG channels (sEMG1), the nasal channel, and an auxiliary channel (AUX1) were used.

Submental sEMG signals were recorded in this study. A 6-cm diameter adhesive patch with three-point electrodes (two recording electrodes and one reference) and a 10-mm edge-to-edge inter-electrode distance was used (Dura Stick EMG electrodes, Part 42109: Chattanooga Group, Inc, Hixson, TN). All of the sEMG signals were recorded at a 250 Hz sampling rate. The raw signal was automatically band-pass filtered, integrated, rectified and digitally recorded by the Kay Digital Swallowing Workstation.

Nasal airflow signals were recorded with a standard 210 cm nasal cannula straight tip 7' with oxygen tubing (Unomedical Inc, McAllen, TX). Nasal airflow signals also were recorded at a sampling rate of 250 Hz.

The acoustic stimuli were presented via SuperLab 5.0 (Cedrus, Phoenix, AZ) experimental software installed on the notebook computer. The acoustic stimuli were presented at 65 dB SPL from two loudspeakers (Multi-media SL-80) placed to the sides of the computer monitor situated in front of the participants at a distance of approximately 74 cm. The presentation level of the acoustic stimuli was calibrated at the level of each subject's pinna with a portable sound level meter (Larson-Davis 824, Larson Davis, Depew, NY) using speech-shaped white noise with the an average RMS for the acoustic stimuli. The computer monitor (Dell E2211HC: 21.5-inch display, 1920 x 1080 resolution) was connected to the notebook computer and used to present the visual stimuli (i.e., the instruction, start cue, and sip cue). This overall configuration made it possible to simultaneously record sEMG signals, nasal airflow signals and acoustic stimuli, and to present both the acoustic and visual and stimuli during the experiment. The notebook computer was used to record the onset time of each acoustic and visual stimulus during the experiment. Figure 3 displays the instrumentation configuration.

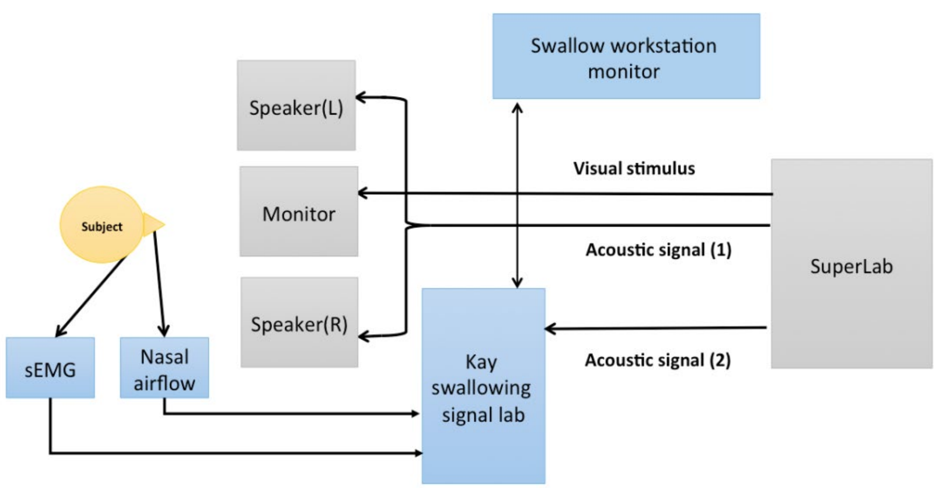

Figure 3. Instrumentation configuration.

6.4 EXPERIMENTAL PROCEDURE

6.4.1 Experimental configuration

The experiment was conducted in a quiet laboratory space in the Department of Communication Science and Disorders in Forbes Tower at the University of Pittsburgh. The participants sat in front of a table where the Kay Digital Swallowing Workstation, notebook computer, computer monitor, and loud speakers for the study were located. Figure 4 displays the experimental configuration.

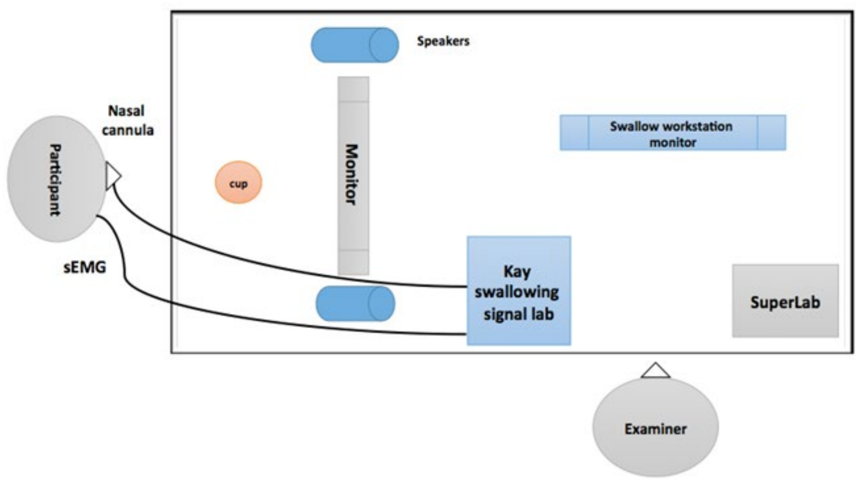

Figure 4. Experimental configuration

6.4.2 Preparation procedure: Electrode and nasal cannula placement

Prior to the experiment, the participant's submandibular area (submental geniohyoid-mylohyoid-anterior digastric region) was prepared with isopropyl alcohol impregnated prep pads (Dynarex 1113 Latex Free Sterile Alcohol Prep Pad, USA) to remove skin oil (Brodsky, 2006). Electrode jell was placed on the electrode surface of a self-adhering patch that contained three electrodes. The adhering electrode patch was placed 1 cm posterior to the midline of the posterior surface of the mandible (i.e., roughly 1 cm posterior to the inferior mental processes). Figure 5 displays sEMG electrode and nasal cannula placement. A 100-cm lead wire was attached to the electrode patch, and connected to the Swallowing Signals Lab via the sEMG1 input channel. The nasal cannula was placed into the nasal cavities of the participant. The cannula was positioned at the nares entrance and was threaded behind the ears and connected to the Swallowing Signals Lab system via the nasal input channel.

In order to test whether sEMG and nasal airflow signals were properly recorded by the Kay Digital Swallowing Workstation, participants were asked to perform spontaneous swallows of water from a cup. This was done several times at their own pace and self-selected bolus volume. This integrity check was conducted prior to the administration of the main experiment.

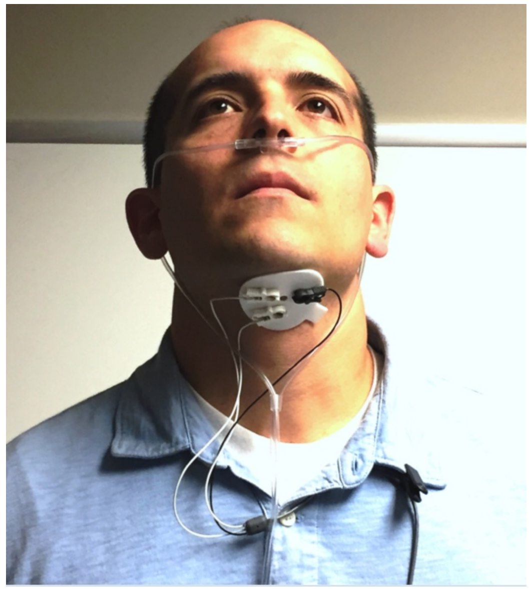

Figure 5. sEMG electrode and nasal cannula placement

6.4.3 Main experimental procedure

Five swallow conditions were measured, including swallows following (1) the congruent action word, *swallow*, (2) the incongruent action word, *cough*, (3) the congruent pseudo-word, *spallow,* (4) the incongruent pseudo-word, *pough*, and (5) a 1000 Hz pure-tone. The 5 stimuli were presented 20 times each in random order. The 100 trials were presented in 4 blocks of 25 swallow trials with 5-minute break between the blocks.

During the experiment, each participant was asked to sip 5 ml of water from a cup and hold the liquid in their mouth until he/she heard sound, and then swallow as soon as they heard the sounds. The water was premeasured with a syringe by the investigator prior to each swallow block of trials. The bolus volume was selected because it was clinically relevant, less likely to cause aspiration in healthy individuals (Martin-Harris et al., 2000), and used in the previous reaction time studies with sEMG in swallowing (Brodsky et al., 2012a; Brodsky et al., 2012c; Nakamura

& Imaizumi, 2013). The bolus hold condition was included in the procedure to replicate the command swallow condition during videofluoroscopic examination of swallowing.

After the physical preparations, the participants were seated comfortably in a chair facing the computer monitor and asked to read the following written instruction. The instructions were presented on the computer monitor, in black 30-point, Times New Roman font on a white background:

At the beginning of each trial, you'll see a "+" in the middle of the screen. This will be followed by a picture of a female sipping water from a cup. When you see the picture, sip the water from the cup and hold the water in your mouth. After you sip, you will hear the words "hold it". Please be very still while holding the water in your mouth. Then, you will hear some words or sounds. Drink the water in your mouth as soon as you hear the end of each word or sound. After you are finished drinking, place the cup on the desk. Are you ready?

To begin each trial, a start cue was presented on the middle of the computer monitor for 3000 ms, followed by the sip cue. With the sip cue, participants sipped 5 ml of water from a medicine cup that was placed on the table in front of them. The investigator placed the cup of water in front of the participants prior to each trial. After the participants sipped the water, the bolus hold cue was presented. It was presented after participants released the cup from their mouths after the sip. The timing of the bolus hold cue was manually controlled by the investigator to ensure that participants sipped the water prior to the bolus hold cue. The sip cue disappeared as soon as the bolus hold cue, *"hold it"*, was presented.

After the bolus hold cue was presented, one of the five acoustic stimuli, *swallow*, *cough*, *spallow, pough* or 1000 Hz pure-tone, was presented. The acoustic stimulus was randomly presented within a 3000 to 5000 ms window following the bolus hold command so that participants were less able to anticipate when to initiate each swallow. Prior research has indicated that language induced motor interference is evident when action words are presented concurrently or with a 50 to 200 ms delayed to the initiation of the related actions (Boulenger et al., 2006; Buccino et al., 2005; Nazir et al., 2008; Sato et al., 2008). In this study, all of the swallow stimuli were given prior to the initiation of swallowing. Figure 6 displays the flow chart of the procedure for each swallow trial.

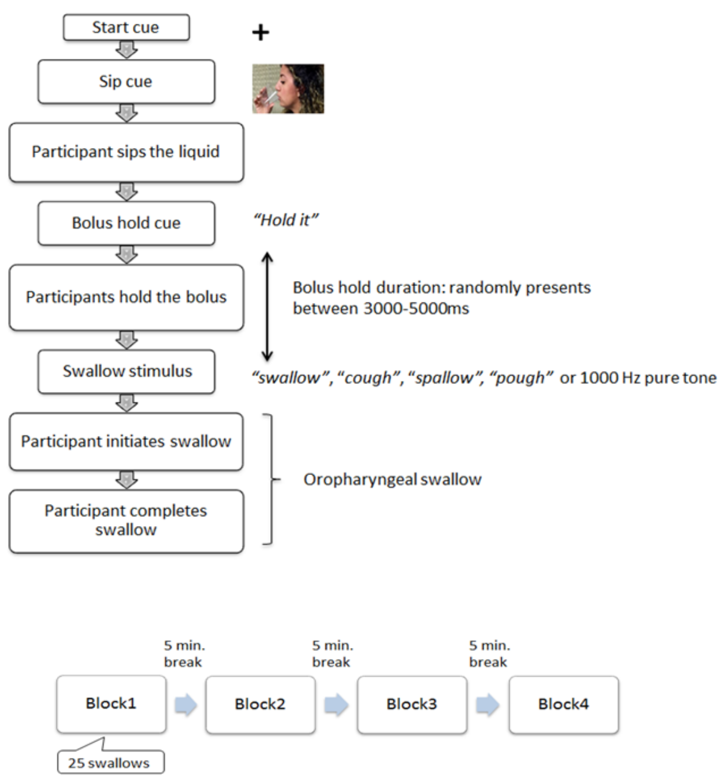

Figure 6. Flow chart of the procedure for each swallow trial

6.4.4 Stimulus preference self-report

After the main experimental procedures were completed, the participants were asked their preference among the stimuli they heard during the experiment (i.e., "Do you have any preference among the words and sounds you heard?"). When participants expressed preference for only one stimulus, they were asked what word(s) they liked the best and least.

6.5 MEASUREMENTS

Each swallow was detected by the increase in sEMG signals along with the presence of the respiratory secession identified on the nasal airflow signal and the observation of the laryngeal elevation by the investigator during the experiment (McFarland, Martin-Harris, Fortin, Humphries, Hill & Armeson, 2016). Several measurements were made from the sEMG recording: sEMG latency, sEMG duration, sEMG peak amplitude, and sEMG peak amplitude. The swallow-respiratory pattern (i.e., inspiratory phase, expiratory phase, or zero flow) at stimulus onset and sEMG onset also were measured from the nasal airflow signals via the nasal cannula, which allowed for the detections for airflow direction and magnitude at the nares (Lee, Steele, & Chau, 2011). Each swallow-respiratory pattern was coded as: +1=expiratory phase, 0=zero flow, and−1= inspiratory phase.

The sEMG latency was defined as the delay between stimulus onset and the suprahyoid muscle activity onset. The sEMG duration was defined as the duration between onset and offset of sEMG activity. The onset of the sEMG activity was defined as the point when the suprahyoid activity value (μV) exceeded two standard deviation (*SD*) above the baseline mean activity. The offset of sEMG activity was defined as the point when the suprahyoid activity returned to within 2 *SD* of the baseline mean level (Crary & Baldwin, 1997). It preceded any structural movement during swallow including hyoid elevation (Kim et al., 2015).

The baseline sEMG activity was taken from the duration between the stimulus onset and just 1000 ms prior to the stimulus onset. Originally, it was defined as the duration between the offset of the "*hold it*" bolus hold command and the onset of each acoustic cue for the swallow. However, due to sEMG activity associated with the bolus hold, the sEMG levels using the original baseline definition were found to be too high to capture the onset of the sEMG activity associated with oropharyngeal swallows, and thus, the measurement rules were revised.

The offset of sEMG was defined as the point when sEMG activity returned to within 2 *SD* of the baseline mean (Fujiwara, Fujiu-Kurachi, Hori, Maeda, & Ono, 2017). The sEMG offset indicates the time when the hyoid returns to the resting position after the completion of swallowing. As indicated previously, the sEMG peak amplitude was defined as the highest amplitude point of the sEMG trace during swallowing (Crary et al., 2006) and indicates the maximum myoelectric activity during swallowing (Kim et al., 2015). Figure 7 displays an example of the sEMG measurements and nasal airflow measurement (Details of the sEMG measurement rules, see Appendix G).

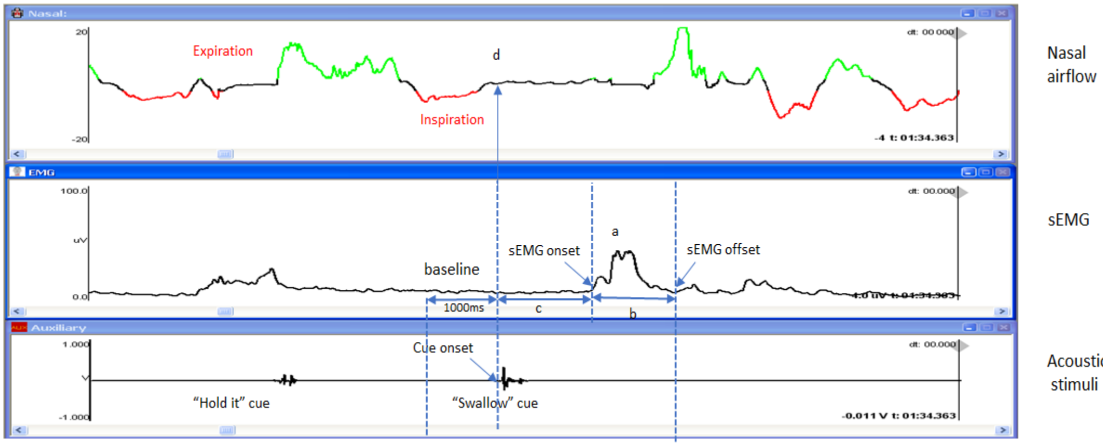

Figure 7. An example of the sEMG and nasal airflow measurements

Note: a=sEMG peak amplitude; b= sEMG duration (duration between sEMG onset and sEMG offset); c=sEMG latency (duration between cue onset and sEMG onset); d=swallow-respiratory pattern at cue onset

Stimulus onset, sEMG onset, sEMG offset, and the swallow-respiratory pattern at the stimulus onset were manually identified by the investigator through visual inspections on the acoustic, sEMG, and nasal airflow tracings. The sEMG peak amplitude and onset of sEMG peak amplitude were automatically selected by the Swallowing Signals Lab System after entering the sEMG onset and sEMG offset information for each swallow.

A total of 200 swallows (10% of the data) were randomly selected, and stimulus onset, sEMG onset, sEMG offset, sEMG peak amplitude, sEMG peak amplitude onset, and swallow-respiratory pattern at stimulus onset were re-measured for intra-examiner and inter-examiner reliability to ensure a lack of measurement drift and accuracy respectively. The investigator re-measured the swallows for intra-examiner reliability and inter-examiner reliability was conducted with an automated signal analysis algorithm. The same swallows that were selected for intra-examiner reliability were used for the inter-rater reliability. Inter- and intra-examiner agreement for stimulus onset and sEMG measurements were calculated using intraclass correlation coefficients (*ICC*). The SPSS v. 25.0 statistical package (IBM Corporation, Armonk, NY) was used for the analyses. The *ICC* both for the intra- and inter-rater reliability was 1.0 which indicates excellent agreement. Inter- and intra-examiner agreement for nasal airflow signals were calculated using Cohen's *Kappa* correlation. The *Kappa* for the intra-examiner reliability for the nasal airflow signals was .969, and .73 for the intra-examiner reliability, respectively. Both results indicated good to strong agreement. Table 8 shows the reliability result for each variable.

Table 8. Intra- and inter-examiner reliability results

	Variables / Tests	Stimulus onset (ms)	sEMG onset time (ms)	sEMG offset time (ms)	sEMG peak amplitude (µV)	Nasal airflow at stimulus onset (-1,0,1)	sEMG peak onset time (ms)
Intra-rater reliability	Mean difference between 1st and 2nd rating	-0.2	1.5	2.2	0.1	NA	0
	ICC	1.0	1.0	1.0	1.0	NA	1.0
	Kappa	NA	NA	NA	NA	0.969	NA
Inter-rater reliability	Mean difference between 1st and 2nd raters	-134.8	-198.3	26.8	-254.3	NA	86.76
	ICC	1.0	1.0	1.0	0.994	NA	1.0
	Kappa	NA	NA	NA	NA	0.73	NA

6.6 OUTCOME MEASURES

6.6.1 Independent variables

There were three independent variables of interest in the study. Stimulus type had five levels: (1) congruent action word, *swallow*, (2) incongruent action word, *cough*, (3) congruent pseudo-word, *spallow,* (4) incongruent pseudo-word, *pough*, and (5) 1000 Hz pure-tone. Swallow-respiratory pattern at stimulus onset (inspiratory phase, expiratory phase, or zero flow) was of interest because it was a potential confounding factor. The last variable was order of presentation over time (stimuli multiple exposures effect) as a possible confounding factor.

6.6.2 Dependent variables

The dependent variables for the study were: (1) The delays between stimulus onset and the suprahyoid muscle activity onset measured by sEMG (sEMG latency), (2) The duration of suprahyoid muscle activity (sEMG duration), (2) The peak suprahyoid muscle activity amplitude (sEMG peak amplitude), and (4) The delays between stimulus onset and the peak suprahyoid muscle activity amplitude measured by sEMG (sEMG peak latency).

7.0 DATA ANALYSIS

7.1 STATISTICAL ANALYSIS OUTLINE

Mixed effects models were used to test all the specific aims. The stimulus type, which was the independent variable of the study, was added into the mixed models as fixed effects. The swallow-respiratory pattern at stimulus onset, swallow-respiratory pattern at sEMG onset, and order of swallows in each block also were added into the mixed effect model as a fixed effect. The models included a random effect for intercept (i.e., each participant has a different intercept) for the sEMG measures.

Mixed effects models were used because, unlike analysis of covariance, this type of statistic allowed for the inclusion of the swallow-respiratory pattern that was a categorical variable with random effects (i.e., the swallow-respiratory pattern may vary within a participant as a predictor) and treatment of the swallow-respiratory pattern as a covariate (Blozis & Traxler, 2007; Marinus & de Jong, 2010). Furthermore, mixed effects models handled incomplete data, i.e., missing data, which was advantageous when assessing reaction time data (Blozis & Traxler, 2007; Marinus & de Jong, 2010).

7.2 POSSIBLE OUTCOMES FOR THE SPECIFIC AIM 5

There were four possible outcomes for swallows following the four verbal stimuli. The first two patterns support the language induced motor facilitation in swallowing. Figures 8 through 11 indicate the possible pattern differences. The pure-tone outcomes were not considered in these patterns.

7.2.1 Lexical effect without syllable number effect on swallows following action and pseudo words

The first possible pattern (Figure 8) indicates a lexical effect without a syllable number effect on swallows following the action and pseudo-words. In this pattern, the sEMG latency of swallows following the congruent action word *swallow* is statistically shorter than swallows following any other stimuli. The sEMG latency of swallows following the incongruent action word *cough* is statistically longer than swallows following the word *swallow* and the incongruent pseudo-word *spallow.* The sEMG latency of swallows following the congruent pseudo-word *spallow* is longer than those following the incongruent pseudo-word cue *pough*, but the difference may or may not be statistically significant. This outcome pattern supports the language induced motor facilitation in swallowing.

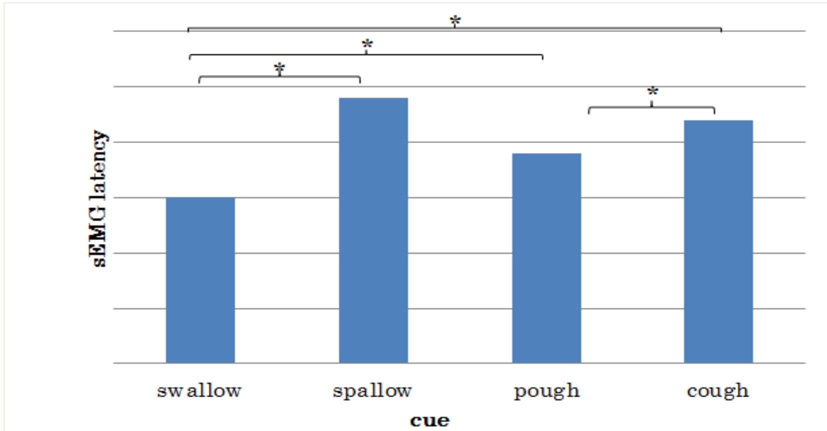

Figure 8. Possible outcomes on sEMG latency that indicates the lexical effect with syllable number effect

7.2.2 Lexical effect with syllable number effect on swallows following action words: cancellation effect

A second possible pattern (Figure 9) indicates lexical and syllable number influence on swallows following the action words. In this pattern, there are no differences on the sEMG latency between swallows following the word *swallow*, and those following *cough,* due to the cancellation effect between the lexical and syllable number effects. On the other hand, the sEMG latency of swallows following the congruent pseudo-word *spallow*, is longer than swallows following the incongruent pseudo-word pough. This outcome pattern also supports the language induced motor facilitation in swallowing.

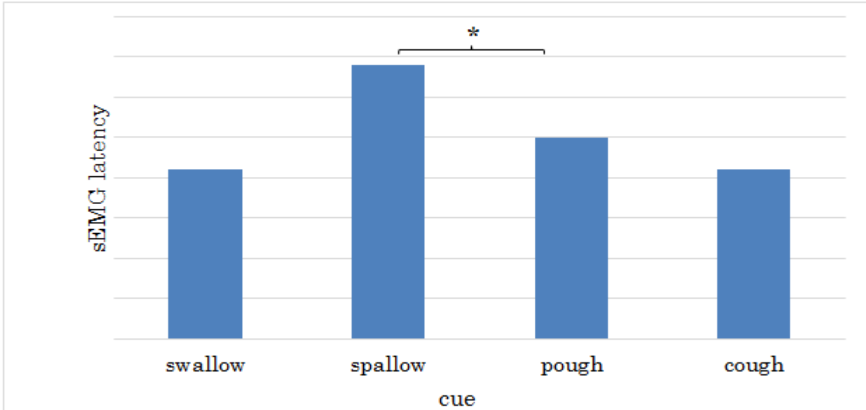

Figure 9. Possible outcomes on sEMG latency that indicates the lexical effect with the syllable number effect.

7.2.3 Syllable number effect without lexical effect

A third possible pattern (Figure 10) includes a syllable number effect without a lexical effect. In this pattern, the sEMG latency for swallows following the word *swallow*, as well as the pseudo-word *spallow*, is longer than swallows following *cough* and the incongruent pseudo-word, *pough*. This outcome pattern is inconsistent with the language induced motor facilitation in swallowing.

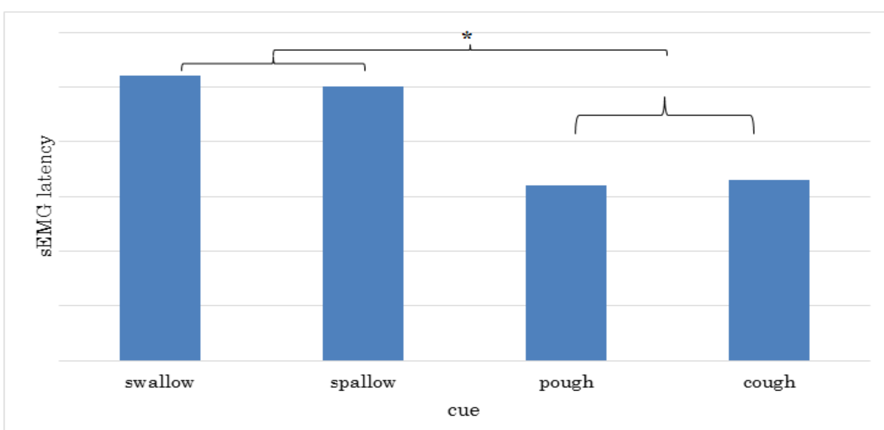

Figure 10. Possible outcomes on sEMG latency that indicates the syllable number effect without lexical effect.

7.2.4 No lexical effect or no syllable number effect

The fourth possible pattern (Figure 11) shows no lexical effect or syllable number effect. In this pattern, there is no difference on sEMG latency among swallows following any words. This outcome pattern also rejects language induced motor facilitation in swallowing.

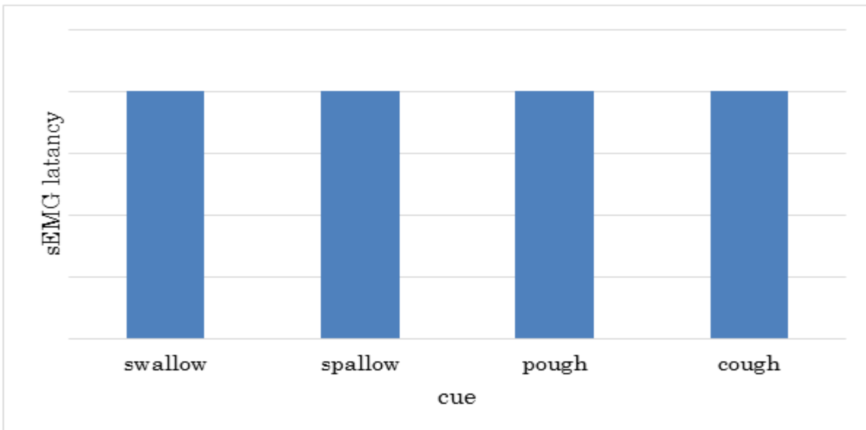

Figure 11. Possible outcomes on sEMG latency that indicates no lexical effect or no syllable number effect

8.0 RESULTS

8.1 DATA CLEANING: IDENTIFICATION OF OUTLIERS

Prior to statistical analysis, any swallows with sEMG activity onset occurring before the stimulus onset and swallows with errors related to the experimental procedures and equipment (e.g., electrode failure, computer operational errors, participants dropping a cup) were removed. Then outliers, identified with a criterion of +/- 2 *SD* from the mean for each dependent variable (i.e., sEMG latency, sEMG duration, sEMG peak amplitude, and sEMG peak latency), were removed. Swallows with sEMG latencies shorter than 50 ms also were removed. Outliers were identified for each dependent variable, resulting in 9% of the data (180/2000 swallows) being removed.

8.2 SEMG LATENCY

8.2.1 sEMG latency model building

Once multilevel models were built, the assumption of normality was tested for sEMG latency. Normality of the residuals was visually inspected because a large number of the observed swallows in the study could overpower the formal tests for significance of normality, such as Shapiro-Wilk test. After removing 6 swallows with residuals below -3 *SD* and 9 swallows with residual above +3 *SD* (1805 swallows remaining), the assumption of normality, linearity and homoscedasticity were met. A Shapiro-Wilk test indicated that normality in random intercepts was met, W=.926, p<.127.

Multiple model comparisons were conducted to determine an optimally fitted final model for each dependent variable (Pinheiro & Bates, 1995). Stata 15.0 statistical analysis package (Stata Corp, 2017) was used for all of these analyses. Table 9 summarizes the fit statistics.

The first step was to test the random intercept. Intra-class correlation (*ICC*=.274) indicated that 27% of the variance in sEMG latency was due to between-person variation amongst participants. A Likelihood Ratio (*L-R*) test with alpha set to $p \leq .05$ indicated that adding a random intercept for participants (i.e., level 2 random intercept) significantly improved model fit over the null model, $\chi^2(1)=401.59$, $p=.02482\text{x}10^{-87}$. Thus, a random intercept for participants was added to the model.

After adding a random intercept, the order effect was tested by adding the block order (i.e., block 1-4) in the model. A L-R test indicated that including block order did not significantly improve the model fit, $\chi^2(1)=1.01$, $p=.314$. However, when the order of swallows within each block was added to the model, it appeared to have an effect in inducing decline in sEMG latency (B=-.004). A L-R test indicated a significant improvement in the model upon accounting for order within blocks, $\chi^2(1)=26.77$, $p=.02292\text{x}10^{-5}$. Therefore, order within blocks was added to the model.

Moreover, the influences of swallow-respiratory pattern at stimulus onset (nasal airflow at cue onset) as well as sEMG onset (nasal airflow at sEMG onset) were tested. A L-R test indicated a significant improvement in the model upon accounting for nasal airflow at sEMG onset, $\chi^2(2)$ = 9.62, p=.008. Adding the nasal airflow at cue onset also significantly improved the model fit over the model with nasal airflow at sEMG onset, $\chi^2(2)$=6.47, p=.039. However, there was a significant interaction between nasal airflow at cue onset and nasal airflow at sEMG onset, L-R $\chi^2(4)$=83.11, p=.03818x10^{-15}. The sEMG latencies were shorter when the swallow-respiratory pattern at cue onset was matched to that at sEMG onset relative to those that were in zero-flow phase both at cue and sEMG onset (*Mean Difference*=-155.31, *SE*=31.78, z=-4.89, p=.0260x10^{-4} when nasal airflow at cue and sEMG onset were inspiratory; *Mean Difference*=-137 ms, *SE*=30.04, z=-4.56, p=.05.10x10^{-4} when nasal airflow at cue and sEMG onsets were expiratory). Given these results, nasal airflow at cue onset, nasal airflow at sEMG onset, and the interaction between nasal airflow at cue onset and nasal airflow at sEMG onset were added to the model.

Finally, stimulus type (i.e., congruent action word, incongruent action word, congruent pseudo-word, incongruent pseudo-word, and 1000 Hz pure-tone) was tested. A L-R test indicated stimulus type had a significant overall improvement of the model fit, $\chi^2(4)$=155.59, p= .0129+10^{-30}. Table 10 lists the complete tests results for sEMG latency.

Table 9. Summary of the fit statistics

#	*Variable*	χ^2	*df*	*p-value*
1	Random intercept	401.59	1	.02482x10^{-87}**
2	Block #	1.01	1	.314
3	Order within block	26.77	1	.02292x10^{-5}**
4	Nasal airflow at sEMG onset	9.62	1	.008**
5	Nasal airflow at cue onset	6.47	1	.039*
6	Nasal airflow at cue onset * nasal airflow at sEMG onset	83.11	4	.03818x10^{-15}**
7	Cue	155.59	4	.0129x10^{-30}**

Table 10. Results from final model for sEMG latency (in ms).

Fixed Effects	*Coefficient*	*Standard Error*	*z*	*p*	*95% confidence interval*	
					Lower	*Upper*
Cue: *spallow* vs. *swallow* (γ_{01})	79.030	15.304	5.160	.024x10^{-5}**	49.034	109.026
Cue: *cough* vs. *swallow* (γ_{02})	11.515	15.355	.750	4.53	-18.580	41.610
Cue: *pough* vs. *swallow* (γ_{03})	107.823	15.254	7.070	.160x10^{-10}**	77.926	137.720
Cue: tone vs. *swallow* (γ_{04})	158.617	15.118	10.490	.094x10^{-26}**	128.986	188.248
Order within block (γ_{05})	-3.334	.678	-4.920	.087x10^{-5}**	-4.663	-2.006
Nasal airflow at sEMG onset: inspiration vs. zero-flow (γ_{06})	25.044	23.077	1.090	.280	-20.186	70.275
Nasal airflow at sEMG onset: expiration vs. zero-flow (γ_{07})	19.915	24.214	.820	.410	-27.543	67.373
Nasal airflow at cue onset: inspiration vs. zero- flow (γ_{08})	44.938	19.860	2.260	.240	6.014	83.862
Nasal airflow at cue onset: expiration vs. zero- flow (γ_{09})	87.736	17.776	4.940	.080x10^{-5}**	52.895	122.577
Nasal airflow at sEMG onset (inspiration) * Nasal airflow at cue onset (inspiration) (γ_{10})	-154.641	32.916	-4.700	.026x10^{-4}**	-219.154	-90.128
Nasal airflow at sEMG onset (inspiration) * Nasal airflow at cue onset (expiration) (γ_{11})	22.807	34.244	.670	.505	-44.310	89.923
Nasal airflow at sEMG onset (expiration) * Nasal airflow at cue onset (inspiration) (γ_{12})	19.793	40.210	.490	.623	-59.017	98.602
Nasal airflow at sEMG onset (expiration) * Nasal airflow at cue onset (expiration) (γ_{13})	-137.034	30.035	-4.560	.051x10^{-4}**	-195.902	-78.166
Grand mean γ_{00}	517.816	32.203	16.08	.035x10^{-56}**	454.7	580.932
Random Effects	*Estimate*	*Standard Error*			*95% confidence interval*	
intercept (u_{00})	15727.05	5124.40			8304.19	29784.98
residual (ε_{it})	41747.32	1397.42			39096.33	44578.06

Note: *=significant at p<0.5; **=significant at p<.01.

The first and second levels of the model shown below were based on the above model fitting procedures. The level 1 predictor was observation (i.e., swallow) while the level 2 predictor was participant. The combined model contains both levels into one equation. In the level 1 model, the β_{0i} indicates the intercept that has random components. The $B_{1\text{-}4}$ indicates the fixed effect for stimulus type. The B_5 indicates the fixed effect for order within block. The $B_{6\text{-}7}$ indicates the fixed effect for nasal airflow at cue onset. The $B_{8\text{-}9}$ indicates the fixed effect for nasal airflow at sEMG onset, and the $B_{10\text{-}13}$ indicates the interaction terms for nasal airflow at cue onset and nasal airflow at sEMG onset. The ε_{it} indicates the level 1 residual error in the level 2 model, and γ_{00} is the grand mean intercept. The u_{0i} is the random intercept for individual participants.

Equation 1: Level 1

sEMG latency$_{it}$ = β_{0i} + $\beta_{1\text{-}4}$ (cue)$_{it}$ + β_5 (order within block)$_{it}$ + $\beta_{6\text{-}7}$ (nasal airflow at cue onset)$_{it}$ + $\beta_{8\text{-}9}$ (nasal airflow at sEMG onset)$_{it}$ + $\beta_{10\text{-}13}$ (nasal airflow at cue onset)$_{it}$ * (nasal airflow at sEMG onset)$_{it}$ + ε_{it}

Equation 2: Level 2

$$\beta_{0i} = \gamma_{00} + u_{0i}$$

$$\varepsilon_{ij} \sim N(0, \sigma^2)$$

$$u_{0i} \sim N(0, \sigma^2)$$

Combined model:

$$\text{sEMG latency}_{it} = (\gamma_{00} + u_{0i}) + \beta_{1\text{-}4}\,(\text{cue})_{it} + \beta_5\,(\text{order within block})_{it} + \beta_{6\text{-}7}\,(\text{nasal airflow at cue onset})_{it} + \beta_{8\text{-}9}\,(\text{nasal airflow at sEMG onset})_{it} + \beta_{10\text{-}13}\,(\text{nasal airflow at cue onset})_{it} * (\text{nasal airflow at sEMG onset})_{it} + \varepsilon_{it}$$

8.2.2 sEMG latency stimulus type comparisons

After the model was built, the data were added into the same multilevel mixed model to further examine the pattern difference for sEMG latency among cue levels. Table 11 lists the complete model results for sEMG latency. Table 12 summarizes the model-based means and standard errors, and 95% confidence intervals on sEMG latency for each cue. The results relative to the specific aims follow.

Table 11. Model results for sEMG latency among cues

Cue 1	*Cue* 2	*Coefficient*	*Standard Error*	*z*	*p*	*95% confidence interval* lower	*95% confidence interval* upper
swallow	*spallow*	79.030	15.304	5.160	$.024\text{x}10^{-5}$**	49.034	109.026
	cough	11.515	15.355	.750	4.53	-18.580	41.610
	pough	107.823	15.254	7.070	$.016\text{x}10^{-10}$**	77.926	137.720
	tone	158.617	15.118	10.490	$.094\text{x}10^{-24}$**	128.986	188.248
spallow	*cough*	-67.515	15.404	-4.380	$.012\text{x}10^{-3}$**	-97.707	-37.323
	pough	28.793	15.307	1.880	.06	-1.208	58.794
	tone	79.587	15.170	5.250	$.016\text{x}10^{-5}$**	49.854	109.321
cough	*pough*	96.308	15.358	6.270	$.036\text{x}10^{-8}$**	66.206	126.410
	tone	147.102	15.201	9.680	$.038\text{x}10^{-20}$**	117.308	176.896
pough	tone	50.794	15.090	3.370	$.076\text{x}10^{-2}$**	21.218	80.370

Note: **=significant at p<.01; *=significant at p<0.5.

Table 12. Predicted marginal mean, standard error, and 95% confidence intervals on sEMG latency for each cue.

Cue	*Mean(ms)*	*Standard Error*	*95% confidence interval*	
			lower	*upper*
swallow	485.822	30.047	426.931	544.712
spallow	564.852	30.074	505.907	505.907
cough	497.337	30.098	438.347	556.327
pough	593.645	30.040	534.767	652.523
tone	644.439	29.969	585.700	703.177

8.2.3 sEMG latency results

Specific aim 1:

Specific aim 1 was to determine if there was a significant difference on sEMG latency for swallows following the congruent action word *swallow* and a non-verbal stimulus (1000 Hz pure-tone) after controlling for swallow-respiratory pattern. The sEMG latency for swallows following *swallow* was significantly shorter than for swallows following the 1000 Hz pure-tone (B=158.617ms, SE=15.118, z=10.49, p=.094x10^{-24}).

Specific aim 2:

Specific aim 2 was to test if there was a significant difference in sEMG latency in swallows following the congruent action word *swallow,* and the congruent pseudo-word *spallow* after controlling for swallow-respiratory pattern. The sEMG latency for swallows following *swallow* was significantly shorter than for swallows following *spallow* (B=79.30, SE=15.304, z=5.16, p=.024x10^{-5}).

Specific aim 3:

Specific aim 3 was to determine if there was a significant difference on sEMG latency in swallows following the word *swallow* as compared to the incongruent action word *cough,* after controlling for swallow-respiratory pattern. There was no statistical difference on sEMG latency between swallows following *swallow* and those following *cough* (B=11.515, SE=15.355, z=.75, p=.453).

Specific aim 4:

Specific aim 4 was to determine if there was a significant difference in sEMG latency for swallows following the incongruent word *cough* and the incongruent pseudo-word *pough* after controlling for the swallow-respiratory. The sEMG latency for swallows following *cough* was significantly shorter than for swallows following *pough* (B=96.308, SE=15.358, z=6.27, p=.036x10^{-8}).

Specific aim 5:

Specific aim 5 was to test whether there were sEMG latency pattern differences for the swallows produced after the five different stimuli (*swallow*, *cough*, *spallow*, *pough,* and a 1000 Hz pure-tone) after controlling for swallow-respiratory pattern at stimulus onset. There were significant pattern differences among the five conditions. The sEMG latencies for swallows following the 1000 Hz pure-tone were significantly longer than those following all other stimuli (*swallow*, *spallow*, *cough*, and *pough*). The sEMG latency for swallows following *swallow* was significantly shorter than for swallows following other stimuli except *cough* (i.e., *spallow*, *pough*, and 1000 Hz pure-tone). The sEMG latency for swallows following *spallow* was significantly longer than for swallows following *swallow* and *cough* (B=67.515, SE=15.404, z=-4.38, p=.012x10^{-3}). There was no statistical difference on sEMG latency between swallows following *spallow* and those swallows following *pough* (*B*=28.79, *SE*=15.307, *z*=1.88, *p*=.06). Figure 12 indicates the predictive marginal mean and standard error on sEMG latency for each cue.

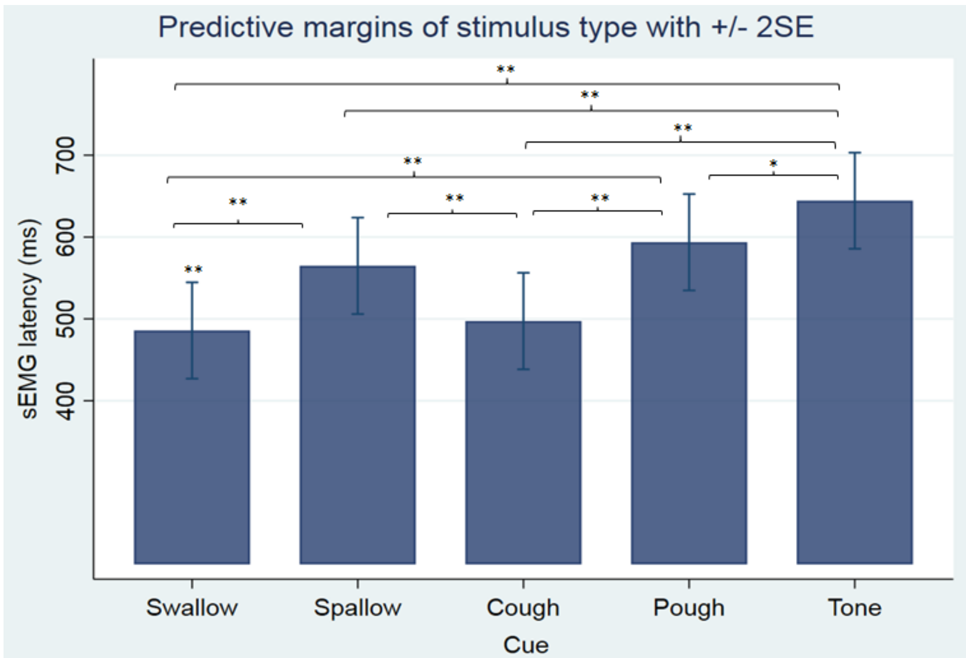

Figure 12. Predictive marginal mean and standard error on sEMG latency for each cue

Note: *=significant at $p<.05$; **=significant at $p<.01$.

8.3 SEMG DURATION

8.3.1 sEMG duration model building

Once multilevel models were built, the assumption of normality was tested for sEMG duration. Normality of the residuals was visually inspected. After removing one swallow with a residual below -3 *SD* and 31 swallows with residuals above +3 *SD* (*n*=1788), the assumptions of normality and linearity were met. However, there was potential concern with heteroscedasticity, with greater spread in the upper range, implying that longer durations were being more poorly predicted than shorter durations. Robust standard errors were incorporated into analysis to remediate this issue. Shapiro-Wilk test indicated that Normality in random intercepts was met, W=.926, p<.127.

Table 13 summarizes the fit statistics. An intra-class correlation (ICC=.412) indicated that about 41% of the variance in sEMG duration was due to differences among individual participants. A L-R test indicated that adding a random intercept to account for variance explained by differences in sEMG duration among participants improved model fit over the null model, $\chi^2(1)=728.34$, $p=.02057\text{x}10^{-158}$. A L-R test indicated that accounting for blocking did not significantly improve the model: $\chi2(1)=3.34$, p=.07, nor did order within the block, $\chi^2(1)$ =.52, p=.471. As a consequence, these variables were not added to the model. There was no significant improvement by adding nasal airflow at sEMG onset, $\chi^2(2)$ .65, p=.722 or nasal airflow at cue onset, LR $\chi^2(2)$=.82, p=.662. A L-R test indicated cue had a significant overall effect on sEMG duration, $\chi^2(4)$=10.64, p=.031. Table 14 lists the complete tests results for sEMG duration.

Table 13. Summary of the fit statistics for sEMG duration

#	*Variable*	χ^2	*df*	*p-value*
1	Random intercept	728.34	1	$.02057\text{x}10^{-158}$**
2	Block #	3.34	1	.314
3	Order within block	.52	1	.471
4	Nasal airflow at sEMG onset	.65	2	.722
5	Nasal airflow at sEMG onset	.82	2	.662
6	Cue	10.64	4	.031**

Table 14. Results from final model for sEMG duration (in ms).

Fixed Effects	*Coefficient*	*Robust standard error*	*z*	*p*	*95% confidential Interval*	
sEMG duration: *spallow* vs. *swallow* (γ_{01})	-96.830	45.817	-2.11	.035**	-186.631	-7.030
sEMG duration: *cough* vs. *swallow* (γ_{02})	14.291	57.196	.25	.803	-97.811	126.392
sEMG duration: *pough* vs. *swallow* (γ_{03})	-114.619	57.055	-2.01	.045**	-226.445	-2.792
sEMG duration: tone vs. *swallow* (γ_{04})	-150.877	53.972	-2.8	.005**	-256.660	-45.093
Grand mean γ_{00}	1980.806	141.558	13.99	$.017 \times 10^{-42}$**	1703.357	2258.255
Random Effects	*Estimate*	*Robust standard error*			*95% confidential Interval*	
intercept (u_{00})	344563.7	100072.7			195008.0	608816.8
residual (ε_{it})	491471.4	75106.1			364265.9	663098.3

Note: *=significant at $p<0.5$; **=significant at $p<.01$.

The first and second levels of the model based on the above fitting procedures are listed below. The B_{0i} indicates the intercept that has random components. The $\beta_{1\text{-}4}$ indicates the fixed effect for cue. The ε_{it} indicates the level 1 residual error. The γ_{00} represents the grand mean intercept, and the u_{0i} is the random intercept.

Equation 1: Level 1

$$\text{sEMG duration}_{it} = \beta_{0i} + \beta_{1\text{-}4}\,(\text{cue})_{it} + \varepsilon_{it}$$

Equation 2: Level 2

$$\beta_{0i} = \gamma_{00} + u_{0i}$$

$$\varepsilon_{ij} \sim N(0, \sigma^2)$$

$$u_{0i} \sim N(0, \sigma^2)$$

Combined model:

$$\text{sEMG duration}_{it} = (\gamma_{00} + u_{0i}) + \beta_{1\text{-}4}\,(\text{cue})_{it} + \varepsilon_{it}$$

8.3.2 sEMG duration: cue comparisons

After the model was built, the data were added into the same multilevel mixed model to further examine the pattern difference on sEMG duration among the cue levels. Table 15 lists the complete model results for sEMG duration. Table 16 summarizes the model-based means and standard errors, and 95% confidence intervals on sEMG duration for each cue. The results relative to the specific aims follow.

Table 15. Model results for sEMG duration among cue

Cue		*Coefficient*	*Robust Standard Error*	*z*	*p*	*95% confidence. Interval*	
1	2					*lower*	*upper*
swallow	*spallow*	-96.830	45.817	-2.110	.035**	-186.631	-7.030
	cough	14.291	57.196	.250	.803	-97.811	126.392
	pough	-114.619	57.055	-2.010	.045**	-226.445	-2.792
	tone	-150.877	53.972	-2.800	.005**	-256.660	-45.093
spallow	*cough*	111.121	46.844	2.370	.018*	19.308	202.934
	pough	-17.788	34.255	-.520	.604	-84.928	49.351
	Tone	-54.046	40.355	-1.340	.180	-133.141	25.049
cough	*pough*	-128.909	40.412	-3.190	.0014**	-208.115	-49.703
	Tone	-165.167	52.311	-3.160	.0016**	-267.694	-62.640
pough	Tone	-36.258	51.963	-.700	.485	-138.104	65.588

Note: *=significant at p<0.5; **=significant at p<.01.

Table 16. Predicted marginal mean, standard error, and 95% confidence intervals on sEMG duration for each cue

Cue	*Mean(ms)*	*Robust standard error*	*95% confidence interval*	
			lower	*upper*
swallow	1980.806	141.558	1703.357	2258.255
spallow	1883.976	131.793	1625.666	2142.285
cough	1995.097	154.506	1692.271	2297.922
pough	1866.187	142.250	1587.382	2144.993
tone	1829.929	124.914	1585.103	2074.756

8.3.3 sEMG duration results

Specific aim 1:

Specific aim 1 was to determine if there was a significant difference on sEMG duration for swallows following the word *swallow* and the pure-tone. The sEMG duration for swallows following *swallow* was significantly longer than for swallows following the pure-tone (B=-150.877, *Robust SE*=55.972, z=-2.80, p=.005). Figure 13 indicates the predictive marginal mean and standard error on sEMG duration for each cue.

Specific aim 2:

Specific aim 2 was to test if there was a significant difference in sEMG duration in swallows following the word *swallow,* and the congruent pseudo-word *spallow*. The sEMG duration for swallows following *swallow* was significantly longer than for swallows following *spallow* (B=-96.830, *Robust SE*=45.817, z=-2.11, p=.035).

Specific aim 3:

Specific aim 3 was to determine if there was a significant difference on sEMG duration in swallows following the word *swallow* as compared to the incongruent action word *cough*. There was no statistically significant difference on sEMG duration between swallows following *swallow* and swallows following *cough* (*B*=14.291, *Robust SE*=57.196, *z*=.25, *p*=.803).

Specific aim 4:

Specific aim 4 was to determine if there is a significant difference between sEMG duration for swallows following the word *cough* and the pseudo-word *pough*. The sEMG duration for swallows following *cough* was significantly longer than for swallows following *pough* (*B*=-128.909, *Robust SE*=40.412, *z*=-3.19, *p*=.0014).

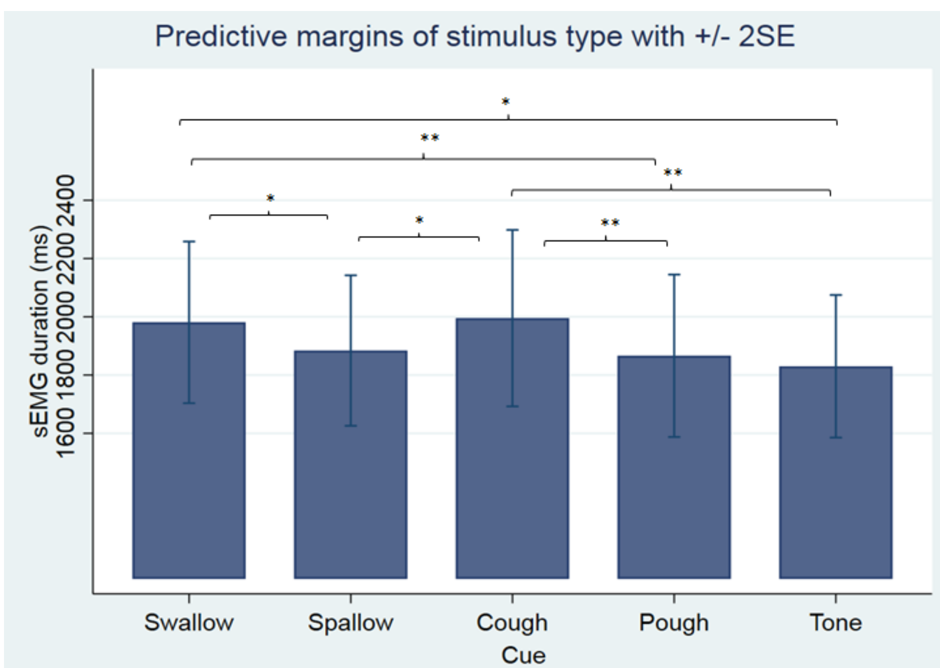

Figure 13. Predictive marginal mean and standard error on sEMG duration for each cue

Note: *=significant at *p*<.05; **=significant at *p*<.01.

8.4 SEMG PEAK AMPLITUDE

8.4.1 sEMG peak amplitude model building

The assumption of normality was tested for sEMG peak amplitude after multilevel model building. After dropping one swallow with a residual below -3 *SD* and 26 swallows above +3*SD* (n=1793), the assumption of linearity as well as homoscedasticity were met. Normality in random effects also was met, Shapiro-Wilk W=.922, p=.107.

Table 17 summarizes the fit statistics. Intra-class correlation (*ICC*=.8427) indicated that about 84% of the variance in sEMG peak amplitude was due to differences among individual participants. Adding a random intercept significantly improved the model over the model with fixed intercept alone, $\chi^2(1)=2797.85$, $p=0.01\text{x}10^{-20}$. Adding block order also significantly improved model fit over the random intercept model, $\chi^2(1)=6.42$, p=.011. Order within blocks did not improve model fit, $\chi^2(1)$ =.01, p=.937. Thus, only block order was included in subsequent model fitting. Nasal airflow at sEMG onset did not significantly improve model fit, $\chi^2(2)=1.65$, p=.438. Also, there was no significant improvement on model fit by adding nasal airflow at cue onset, $\chi^2(2)$ =.19, p=.910.

For peak amplitude, cue had no significant overall effect, $\chi^2(4)=3.25$, p=.517. Table 18 lists the complete tests results for sEMG peak amplitude.

Table 17. Summary of the fit statistics for sEMG peak amplitude

#	*Variable*	χ^2	*df*	*p-value*
1	Random intercept	2797.85	1	0.01x10^{-20}**
2	Block #	6.42	1	.011*
3	Order within block	.01	1	.937
4	Nasal airflow at sEMG onset	1.65	2	.438
5	Nasal airflow at cue onset	.19	2	.910
6	Cue	3.25	4	.517

Table 18. Results from final model for sEMG peak amplitude (μV)

Fixed Effects	*Coefficient*	*Standard Error*	*z*	*p*	*95% confidential Interval*	
Block (γ_{01})	788.13	195.557	4.030	.056x10^{-3}**	405.84	1171.41
sEMG peak amplitude: *spallow* vs. *swallow* (γ_{02})	-127.35	694.90	-.180	.855	-1489.34	1234.64
sEMG peak amplitude: *cough* vs. *swallow* (γ_{03})	605.49	699.45	.870	.387	-765.41	1976.38
sEMG peak amplitude: *pough* vs. *swallow* (γ_{04})	682.94	692.94	.990	.324	-675.21	2041.09
sEMG peak amplitude: tone vs. *swallow* (γ_{05})	-301.86	682.95	-.440	.685	-1639.35	1035.64
Grand mean (γ_{00})	51225.96	4835.71	10.590	.032x10^{-24}**	41748.15	60703.77
Random Effects	*Estimate*	*Standard Error*			*95% confidential Interval*	
intercept (u_{00})	.0458x10^{-6}	0.145x10^{-6}			.0246x10^{-6}	.0852x10^{-6}
residual (ε_{it})	.0855x10^{-5}	.0287x10^{-4}			.0801x10^{-5}	.09.3x10^{-5}

Note: *=significant at p<0.5; **=significant at p<.01.

Levels 1 and 2 models based on the above fitting procedures for sEMG peak amplitude are listed below. In the level 1 model, β_{0i} indicates the intercept that has a random component. The β_1 indicates the fixed effect for block order, the $\beta_{2\text{-}5}$ represents the effects for cue, and ε_{it} indicates the level 1 residual error. In the level 2 model, γ_{00} is the grand mean intercept, and u_{0i} is the variance components for random intercepts.

Equation 1: Level 1

$$\text{sEMG peak amplitude}_{it} = \beta_{0i} + \beta_1 \text{ (block)}_{it} + \beta_{2\text{-}5} \text{ (cue)}_{it} + \varepsilon_{it}$$

Equation 2: Level 2

$$\beta_{0i} = \gamma_{00} + u_{0i}$$

$$\varepsilon_{ij} \sim N(0, \sigma^2)$$

$$u_{0i} \sim N(0, \sigma^2)$$

Combined model:

$$\text{sEMG peak amplitude}_{it} = (\gamma_{00} + u_{0i}) + \beta_1 \text{ (block)}_{it} + \beta_{2\text{-}5} \text{ (cue)}_{it} + \varepsilon_{it}$$

8.4.2 sEMG peak amplitude cue comparisons

As previously noted, there were no significant effects for cue on sEMG peak amplitude. Table 20 summarizes the predictive marginal means and standard errors, and 95% confidence intervals on sEMG peak amplitude for each cue. The results relative to the specific aims follow.

Table 19. Predictive marginal means and standard errors, and 95% confidence intervals on sEMG peak amplitude for each cue

Cue	*Marginal mean (µV)*	*Standard Error*	*95% Confidence interval*	
			lower	*upper*
swallow	53.209	4.811	43.780	62.638
spallow	53.081	4.811	43.652	62.511
cough	53.814	4.812	44.384	63.245
pough	53.892	4.811	44.463	63.320
tone	52.907	4.809	43.481	62.333

8.4.3 sEMG peak amplitude results

Specific aim 1-4

There were no statistically significant differences amongst cues for sEMG peak amplitude. Figure 15 indicates the predictive marginal mean and standard error on sEMG peak amplitude for each cue.

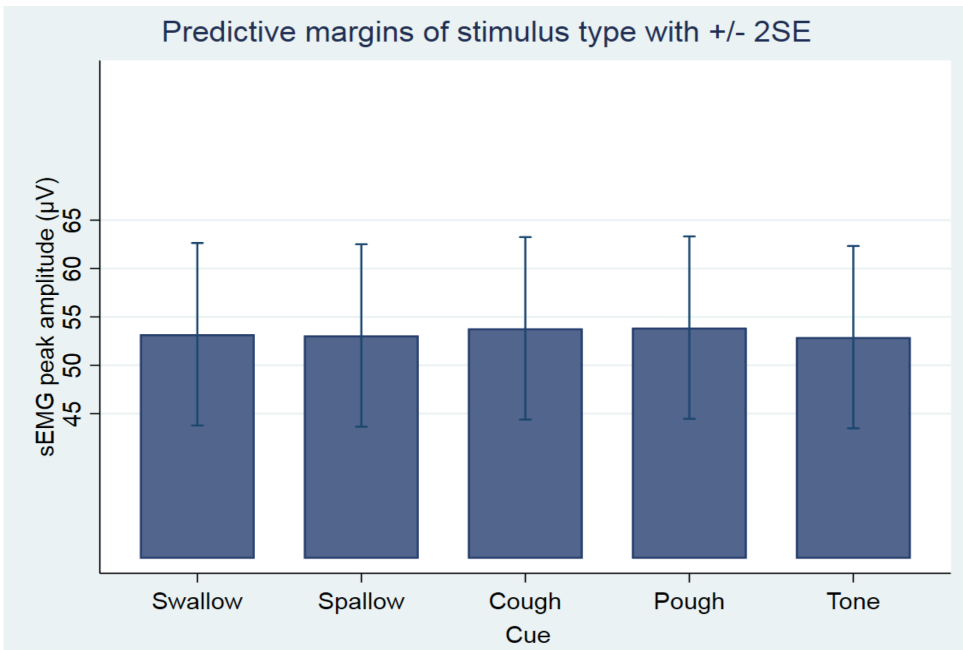

Figure 14. Predictive marginal mean and standard error on sEMG peak amplitude for each cue

8.5 SEMG PEAK LATENCY

8.5.1 sEMG peak latency model building

After multilevel model building, assumptions of normality, linearity, and homoscedasticity were tested for sEMG peak latency. After removing two swallows with residuals below -3 *SD* and 15 swallows above +3 *SD* (n=1785), all assumptions were met. Random intercepts were normally distributed, Shapiro-Wilk W=.955, p=.456. An intra-class correlation (ICC=.517) indicated that about 52% of the variance in sEMG peak latency was due to differences among participants. Adding a random intercept significantly improved the model, $\chi^2(1)$=620.31, p=.06402x10^{-135}. Adding block order also significantly improved model fit over the random intercept model, $\chi^2(1)$=8.22, p=.004. Yet, order within blocks did not improve model fit, $\chi^2(1)$ =.04, p=.838. Thus, only block order was included in subsequent model fitting. There also was no significant improvement on model fit by adding nasal airflow at sEMG onset, $\chi^2(2)$=.87, p=.646. Nasal airflow at cue onset significantly improve model fit, $\chi^2(2)$=7.66, p=.022. Thus, it was added to the model. Stimulus type (cue) had a significant overall effect, $\chi^2(4)$=44.04, p=.06294x10^{-7}. Table 20 summarizes the fit statistics. Table 21 lists the complete tests results for sEMG peak latency. The results relative to the specific aims follow.

Table 20. Summary of the fit statistics for sEMG peak latency

#	*Variable*	χ^2	*df*	*p-value*
1	Random intercept	620.31	1	$.06402 \times 10^{-135}$**
2	Block #	8.22	1	.004*
3	Order in block	.04	1	.838
4	Nasal airflow at sEMG onset	.87	2	.646
5	Nasal airflow at cue onset	7.66	2	.022*
6	Cue	44.04	4	$.06402 \times 10^{-135}$**

Table 21. Results from final model for sEMG peak latency (in ms)

Fixed Effects	*Coefficient*	*Standard Error*	*z*	*p*	*95% confidential Interval*	
sEMG peak latency: *spallow* vs. *swallow* (γ_{01})	46.308	16.809	2.750	.006**	13.363	79.254
sEMG peak latency: *cough* vs. *swallow* (γ_{02})	-10.354	16.861	-0.610	.539	-43.401	22.693
sEMG peak latency: *pough* vs. *swallow* (γ_{03})	52.396	16.768	3.120	.002**	19.532	85.260
sEMG peak latency: tone vs. *swallow* (γ_{04})	109.530	16.582	6.610	$.040 \times 10^{-9}$**	77.030	142.029
Block (γ_{05})	28.066	4.725	5.940	$.029 \times 10^{-7}$**	18.805	37.328
Nasal airflow at cue onset: inspiration vs. zero- flow (γ_{06})	-9.196	14.394	-0.640	.523	-37.408	19.016
Nasal airflow at cue onset: inspiration vs. zero- flow (γ_{07})	17.409	13.550	1.280	.199	-9.149	43.967
Grand mean γ_{00}	1219.660	54.548	22.360	$.010 \times 10^{-109}$**	1112.748	1326.571
Random Effects	*Estimate*	*Standard Error*			*95% confidential Interval*	
intercept (u_{00})	53238.06	17010.07			28461.32	99583.93
residual (ε_{it})	49675.22	1672.18			46503.59	53063.15

Note: *=significant at p<0.5; **=significant at p<.01.

The first and second levels of the model based on the above model fitting procedures are listed below. In the level 1 model, the β_{0i} indicates the intercept that has random component. The

$\beta_{1\text{-}4}$ indicates the fixed effect for cue. The β_5 indicates the fixed effect for block order. The $\beta_{6\text{-}7}$ indicates the fixed effect for nasal airflow at cue onset. The ε_{it} indicates the level 1 residual error. In the level 2 model, the γ_{00} is the grand mean intercept, and the u_{0i} is the random intercept.

Equation 1: Level 1

$$\text{sEMG peak latency}_{it} = \beta_{0i} + \beta_{1\text{-}4}\,(\text{cue})_{it} + \beta_5\,(\text{block})_{it} + \beta_{6\text{-}7}\,(\text{nasal airflow at cue onset})_{it} + \varepsilon_{it}$$

Equation 2: Level 2

$$\beta_{0i} = \gamma_{00} + u_{0i}$$

$$\varepsilon_{ij} \sim N\,(0, \sigma^2)$$

$$u_{0i} \sim N\,(0, \sigma^2)$$

Combined model:

$$\text{sEMG peak latency}_{it} = (\gamma_{00} + u_{0i}) + \beta_{1\text{-}4}\,(\text{cue})_{it} + \beta_5\,(\text{block})_{it} + \beta_{6\text{-}7}\,(\text{nasal airflow at cue onset})_{it} + \varepsilon_{it}$$

8.5.2 sEMG peak latency cue comparisons

After the model was built, the data were added into the same multilevel mixed model to further test the sEMG peak latency differences among the cues. Table 22 lists the complete model results. Table 23 summarizes the model-based means and standard errors, and 95% confidence intervals on sEMG peak latency for each cue. The results relative to specific aims follow.

Table 22. Model results for sEMG peak latency among cue

Cue		*Coefficient*	*Standard Error*	*z*	*P*	*95% confidence Interval*	
1	2					*lower*	*upper*
swallow	*spallow*	46.308	16.809	2.750	.0059**	13.363	79.254
	cough	-10.354	16.861	-.610	.539	-43.401	22.693
	pough	52.396	16.768	3.120	.002**	19.532	85.260
	tone	109.530	16.582	6.610	$.040x10^{-9}$**	77.030	142.029
spallow	*cough*	-56.662	16.851	-3.360	.00077**	-89.689	-23.636
	pough	6.088	16.749	.360	.716	-26.739	38.915
	tone	63.221	16.549	3.820	.00013**	30.785	95.657
cough	*pough*	62.751	16.787	3.740	.00019**	29.848	95.653
	tone	119.884	16.605	7.220	$.0520x10^{-11}$**	87.339	152.428
pough	tone	57.133	16.498	3.460	$.053x10^{-2}$**	24.797	89.469

Note: *=significant at $p<0.5$; **=significant at $p<.01$.

Table 23. Predictive marginal mean, standard error, and 95% confidence intervals on sEMG peak latency for cue

Cue	*Marginal mean(ms)*	*Standard Error*	*95% Confidence interval*	
			lower	*upper*
swallow	1293.594	52.951	1189.813	1397.375
spallow	1339.902	52.944	1236.133	1443.671
cough	1283.240	52.960	1179.441	1387.039
pough	1345.991	52.928	1242.254	1449.727
tone	1403.124	52.868	1299.505	1506.743

8.5.3 sEMG peak latency results

Specific aim 1:

Specific aim 1 was to determine if there was a significant difference on sEMG peak latency for swallows following the word *swallow* and a pure-tone after controlling for swallow-respiratory pattern. The sEMG peak latency for swallows following *swallow* was significantly shorter than for swallows following the pure-tone (*B*=109.53, *SE*=16.582, *z*=6.61, *p*=.040x10^{-9}). Figure 15 indicates the predictive marginal mean and standard error on sEMG peak latency for each cue.

Specific aim 2:

Specific aim 2 was to test if there was a significant difference in sEMG peak latency in swallows following the word *swallow* and the pseudo-word *spallow* after controlling for swallow-respiratory pattern. The sEMG peak latency for swallows following *swallow* was statistically shorter than for swallows following *spallow*, (*B*=46.308, *SE*=16.809, *z*=2.75, *p*=.0059).

Specific aim 3:

Specific aim 3 was to determine if there was a significant difference in sEMG peak latency between swallows following the word *swallow* as compared to the word *cough* after controlling for swallow-respiratory pattern. There was no statistically significant difference on sEMG peak latency between swallows following *swallow* and those following *cough* (*B*=-10.354, *Robust SE*=16.861, *z*=-.61, *p*=.539).

Specific aim 4:

Specific aim 4 was to determine if there was a significant difference in sEMG peak latency for swallows following the word *cough* and the pseudo-word *pough* after controlling for swallow-respiratory pattern. The sEMG peak latency for swallows following *cough* was significantly shorter than for swallows following *pough* (*B*=62.751, *SE*=16.787, *z*=3.74, *p*=.00019).

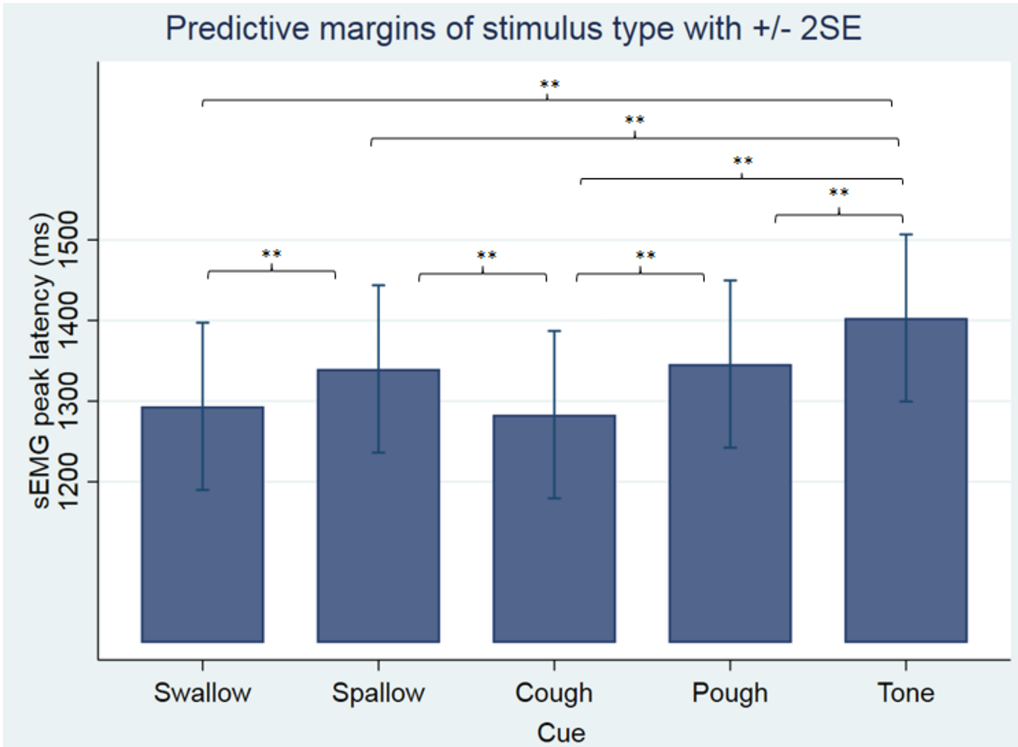

Figure 15. Predictive marginal mean and standard error on sEMG peak latency for each cue

Note: *=significant at p<0.5; **=significant at p<.01.

8.6 SELF-REPORT STIMULI PREFERENCE

All of the participants reported their preference among the stimuli. One participant did not indicate the stimulus least preferred. All the participants responded using sentences, such as "swallow was best to swallow" or "swallow was easiest to drink". Table 24 lists the sentences the participants used to report their preference. The results indicated that 65% of the participants indicated they preferred to swallow after the stimulus *swallow*. 25% of the participants preferred to swallow after the pure-tone. Five percent of the participants preferred to swallow after real words, and 5% had no preference among the stimuli. None of the participants reported that they preferred to swallow after they heard the incongruent word, *cough*, or pseudo-words. Figure 16 indicates the swallow preference self-report results (prefer to swallow).

Table 24. List of the sentences the participants used to report their preference

Preferred stimuli	Non-preferred stimuli
"easy to swallow"	"didn't like…"
"easier to swallow"	"worst"
"best to swallow"	"harder to swallow"
"better to swallow"	"more difficult to swallow"
"faster to swallow"	"threw me out"

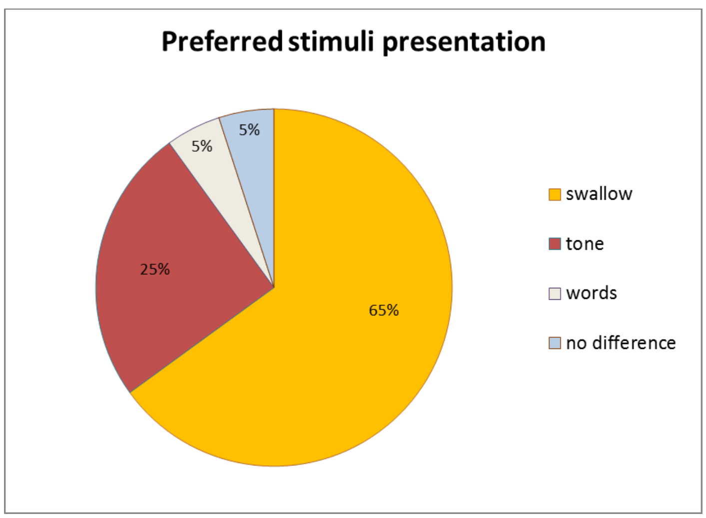

Figure 16. Self-report stimuli preference result (preferred stimuli presentation)

On the other hand, 61% of the participants reported that they did not like to swallow after the incongruent stimulus, *cough*. 17% of the participants indicated swallowing after the non-verbal stimulus was their least preferred condition. 11% of them reported they did not like to swallow after they heard *pough*. None of the participants indicated that they did not prefer to swallow after the stimulus *swallow*. Figure 17 indicates the self-reported results for non-preferred stimuli.

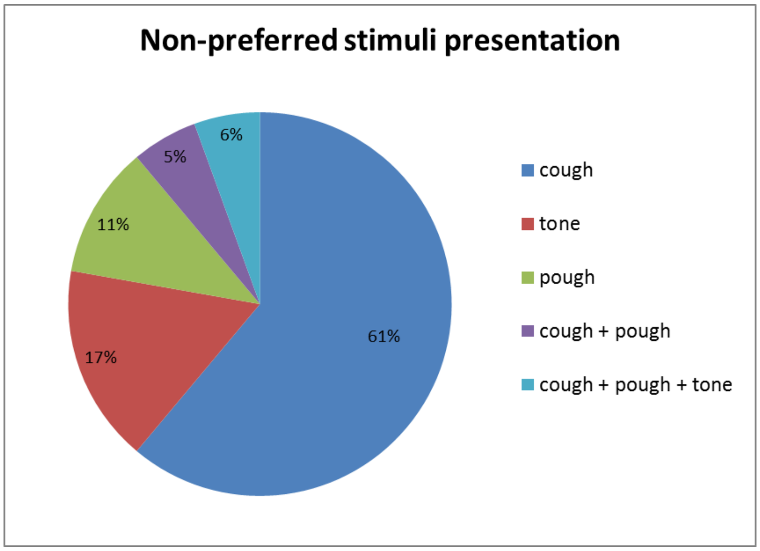

Figure 17. Self-report stimuli preference results (non-preferred stimuli presentation)

8.7 SECONDARY ANALYSIS

8.7.1 Secondary analysis

To further test the potential reasons for the sEMG duration results, the sEMG duration was divided into two parts – rise time and fall time. Additional mixed effects models analyses were conducted on these two durations. The rise time duration was defined as the duration between sEMG onset and sEMG peak amplitude onset (Huckabee & Steele, 2006). The rise time duration is reported to be influenced by the tongue movements (Huckabee & Steele, 2006). The sEMG peak amplitude served as zero for both the rise and fall time measurements. The fall time duration was defined as the duration between the sEMG peak amplitude onset and sEMG offset. The onset of the sEMG peak amplitude is correlated with the hyoid elevation, and the onset of sEMG peak amplitude occurs slightly earlier than the onset of hyoid elevation (Crary, Carnaby, & Groher, 2006). Suprahyoid muscles activation is strongest at the start of the triggering of the pharyngeal swallow (Nakahara, Murayama, Hayashida, & Igasaki, 2006). Given the evidence from these studies, sEMG activation during the fall time is considered mostly reflexive, whereas the rise time is more volitional. Figure 18 displays the rise and fall time of a sample sEMG waveform.

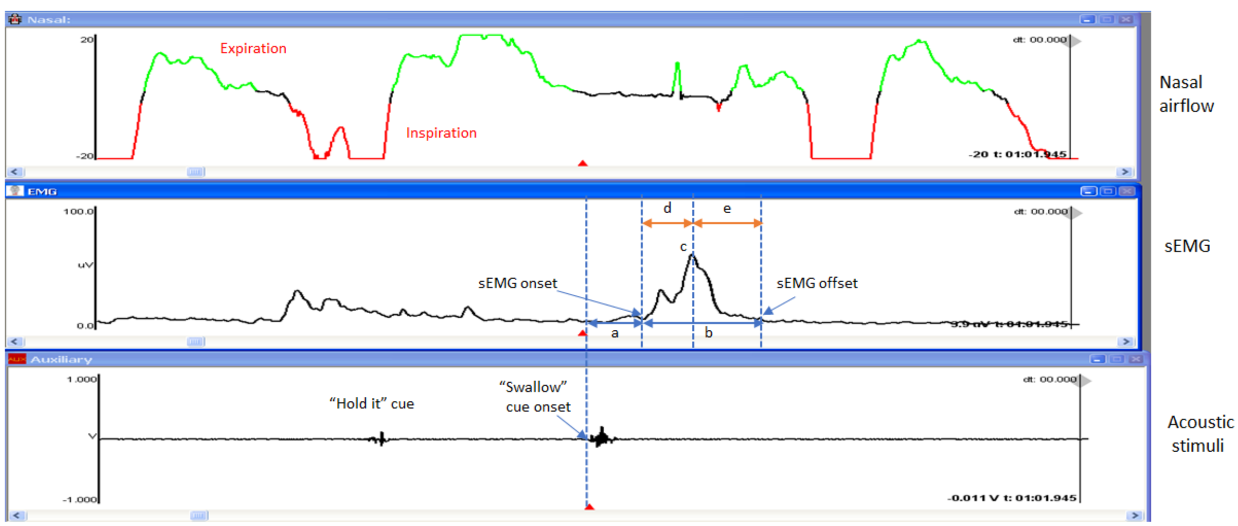

Figure 18. Rise and fall time on a sample sEMG waveform

Note: a=sEMG latency, b=sEMG duration, c=sEMG peak amplitude, d= rise time, e=fall time

8.7.2 Rise time duration

All assumptions were met for the rise time duration. Normality in random effects also was met, Shapiro-Wilk W=.986, p=.986. Based on the results of a likelihood Ratio test using Chi-square test with alpha set to 0.05, random intercept ($\chi^2(1)$=321.26, p=.07699x10^{-70}), block order $\chi^2(2)$=12.45, p=.00013), order within block ($\chi^2(2)$ =14.68, p=.002), nasal airflow at sEMG onset ($\chi^2(2)$=6.19, p=.045) and stimulus type (cue) ($\chi^2(4)$=14.58, p=.006) were added to the model. Nasal airflow at cue onset was not added to the model because it did not significantly improve model fit, $\chi^2(2)$ = 14.58, p=.071. After removing two swallow with residuals below -3 *SD* and 13 swallows above +3 *SD*, all assumptions were met. Normality in the random effects also was met, Shapiro-Wilk W= .986, p= .986. Table 25 summarizes the fit statistics. Table 26 lists the complete tests results for rise time duration.

Table 25. Summary of fit statistics for rise time duration

#	*Variable*	χ^2	*df*	*p-value*
1	Random intercept	321.26	1	.07699x10^{-70}**
2	Order within block	12.45	2	.002**
3	Block	14.68	1	.00013**
4	Nasal airflow at cue onset	5.29	2	.071
5	Nasal airflow at sEMG onset	6.19	2	.045*
6	Cue	14.58	4	.006**

Note: *=significant at p<0.5; **=significant at p<.01.

Table 26. Test results for rise time duration

Fixed Effects	*Coefficient*	*Standard Error*	*z*	*p*	*95% confidential Interval*	
Rise time: *spallow* vs. *swallow* (γ_{01})	-37.401	17.470	-2.140	.032*	-71.642	-3.161
Rise time: *cough* vs. *swallow* (γ_{02})	-19.697	17.571	-1.120	.262	-54.137	14.742
Rise time: *pough* vs. *swallow* (γ_{03})	-52.383	17.423	-3.010	.003**	-86.531	-18.234
Rise time: tone vs. *swallow* (γ_{04})	-40.721	17.182	-2.370	.018*	-74.398	-7.044
Order within block (γ_{05})	3.564	0.771	4.620	$.038 \times 10^{-4}$**	2.054	5.075
Block (γ_{06})	31.574	4.911	6.430	$.0130 \times 10^{-8}$**	21.948	41.200
Nasal airflow at cue onset: inspiration vs. zero- flow (γ_{06})	49.489	16.653	2.970	.003**	16.849	82.129
Nasal airflow at cue onset: inspiration vs. zero- flow (γ_{07})	29.550	14.552	2.030	.042*	1.028	58.072
Grand mean γ_{00}	652.939	40.894	15.970	$2.20+10^{-57}$**	572.789	733.089
Random Effects	*Estimate*	*Standard Error*			*95% confidential Interval*	
intercept (u_{00})	25694.640	8504.417			3431.110	49155.640
residual (ε_{it})	109689.7	3656.302			102752.6	117095.2

After the model was built, the data were added into the same multilevel mixed model to further to test for differences on rise time duration among the levels of stimulus type. Table 27 lists the complete model results. Table 28 summarizes the model-based means and standard errors, and 95% confidence intervals on rise time duration for each stimulus type. Results indicated that rise time duration for swallows following *swallow* was significantly longer than for swallows following other stimuli except *cough* after controlling for swallow-respiratory pattern at the sEMG onset. These results indicated, in relation to the onset of sEMG peak amplitude, that the onset of sEMG activation started significantly earlier for swallows following *swallow* than swallows following other stimuli except *cough* (i.e., *spallow*, *pough*, and pure-tone). This pattern suggests the possibility that the longer sEMG duration for swallows following *swallow* than those following *spallow*, *pough,* and the pure-tone stimulus were due to the earlier sEMG activation in swallows following *swallow*. Figure 19 indicates the predictive marginal mean and standard error on rise time duration for each cue.

Table 27. Model results for rise time duration among cue

cue		*Coefficient*	*Stranded Error*	*z*	*p*	*95% confidence Interval*	
1	2					*lower*	*upper*
swallow	*spallow*	-37.401	17.470	-2.140	.032*	-71.642	-3.161
	cough	-19.697	17.571	-1.120	.262	-54.137	14.742
	pough	-52.383	17.423	-3.010	.003**	-86.531	-18.234
	tone	-40.721	17.182	-2.370	.018*	-74.398	-7.044
spallow	*cough*	17.704	17.528	1.010	.312	-16.650	52.058
	pough	-14.982	17.377	-.860	.389	-49.039	19.076
	tone	-3.320	17.144	-.190	.846	-36.922	30.283
cough	*pough*	-32.685	17.495	-1.870	.062	-66.975	1.604
	tone	-21.024	17.254	-1.220	.223	-54.840	12.793
pough	tone	11.662	17.098	.680	.495	-21.849	45.173

Note: *=significant at $p<0.5$; **=significant at $p<.01$.

Table 28. Predictive marginal mean, standard error, and 95% confidence intervals on rise time duration for cue

Cue	*Marginal mean (ms)*	*Standard Error*	*95% Confidence interval*	
			lower	*upper*
swallow	797.100	37.387	723.823	870.377
spallow	759.698	37.366	686.463	832.934
cough	777.402	37.416	704.067	850.737
pough	744.717	37.342	671.528	817.906
tone	756.379	37.232	683.405	829.353

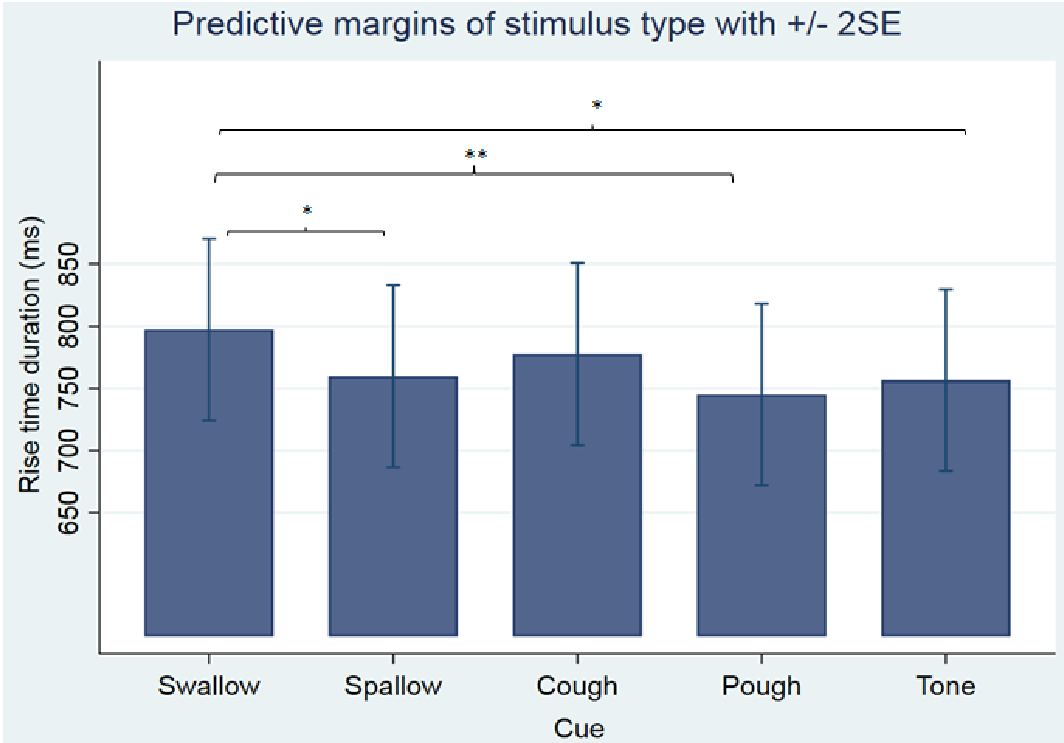

Figure 19. Predictive marginal mean and standard error on rise time duration for each cue

Note: *=significant at p<0.5; **=significant at p<.01.

8.7.3 Fall time analysis

Random intercept ($\chi^2(1)$=630.57.76, p=.03757x10^{-137}) and block ($\chi^2(1)$ =14.99, p=.0001), and stimulus type (cue) ($\chi^2(4)$ =5.43, p=.246) were added to the model based on the results of a Likelihood Ratio test using Chi-square test with alpha set to .05. Table 29 summarizes the fit statistics for fall time duration. There were no significant effects for stimulus type on fall time duration. There was no statistical significance on any of the comparisons for fall time duration (Figure 20). Table 30 lists the complete tests results for fall time duration. Table 31 indicates predictive marginal mean and standard error on fall time duration for each stimulus type.

Table 29. Summary of the fit statistics for fall time duration

#	*Variable*	χ^2	*df*	*p-value*
1	Random intercept	630.57	1	$.03757 \times 10^{-137}$**
2	Block	14.99	1	.0001**
3	Order within block	0.32	1	.574
4	Nasal airflow at cue onset	0.17	2	.919
5	Nasal airflow at sEMG onset	0.15	2	.926
6	Cue	5.43	4	.246

Table 30. Tests results for fall time duration

Fixed Effects	*Coefficient*	*Standard Error*	*z*	*p*	*95% confidential interval*	
					lower	*upper*
Fulltime: spallow vs. swallow (γ_{01})	-28.803	44.385	-.650	.516	-115.795	58.190
Fall time: cough vs. swallow (γ_{02})	44.531	47.095	.950	.344	-47.775	136.836
Fall time: pough vs. swallow (γ_{03})	-42.378	52.466	-.810	.419	-145.209	60.453
Fall time: tone vs. swallow (γ_{04})	-98.198	53.312	-1.840	.065	-202.688	6.291
Block	-44.474	34.790	-1.280	.201	-112.662	23.714
Grand mean γ_{00}	1247.831	148.054	8.430	$.035 \times 10^{-15}$**	957.651	1538.011
Random Effects	*Estimate*	*Standard Error*			*95% confidential interval*	
intercept (u_{00})	227768.2	63877.33			131454.2	394649.6
residual (ε_{it})	381920.2	71093.62			265169.4	550075.1

Note: *=significant at $p<0.5$; **=significant at $p<.01$.

Table 31. Predictive marginal mean, standard error, and 95% confidence intervals on fall time duration for each cue

Cue	*Marginal mean (mc)*	*Standard Error*	*95% Confidence interval*	
			lower	*upper*
swallow	1136.009	115.044	910.527	1361.492
spallow	1107.207	112.441	886.826	1327.588
cough	1180.540	119.395	946.531	1414.55
pough	1093.631	126.116	846.449	1340.814
tone	1037.811	96.497	848.681	1226.941

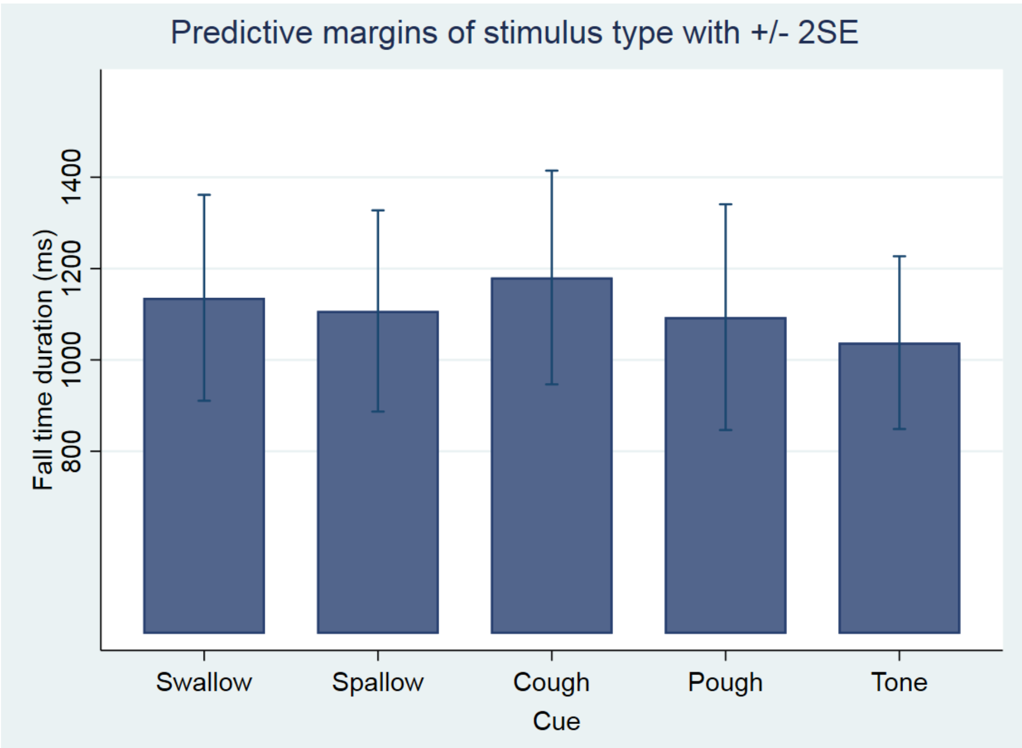

Figure 20. Predictive marginal mean and standard error on fall time duration for each cue

8.8 SAMPLE SIZE JUSTIFICATION

The number of participants needed for multilevel modeling was re-estimated using G*Power (Faul et al., 2009) using the parameters from the current study results. With a significance level of 95%; power of .80, correlation amongst measures of .2232, 20 trials per condition, 5 conditions, and a medium effect (f=.25), a total of 15 participants were needed for sufficient power to find differences among experimental conditions. Given the result, the actual sample size of 20 for the current study met the requirement given the power analysis. Table 32 indicates the required sample size for each measure. Furthermore, a total of 1500 swallows was needed for each stimulus condition. After removing outliers, the number of observations in each stimulus condition still met the requirement for the power analysis.

Table 32. Results of the Sample size re-estimation: Required sample size for each measurement base on the current study results

Parameters	sEMG latency	sEMG duration	sEMG peak amplitude	sEMG peak latency
Significance	.05	.05	.05	.05
Power	.8	.8	.8	.8
Correlation among measures	.2232	.3581	.8026	.3123
Number of trials per condition	20	20	20	20
Number of condition	5	5	5	5
Effect size (medium)	.25	.25	.25	.25
Observed power	.842	.92	1	.89
Sample size	15	15	10	15

9.0 DISCUSSION

During swallowing examinations with videofluoroscopy, patients commonly are told to hold a bolus in their mouth until they are commanded to swallow (Daniels et al., 2007; Nagy et al., 2013; Palmer et al., 2007). This procedure is referred to as the command swallow. Both components of the command swallow, bolus hold and swallowing in response to a command, are rather unnatural (Hiiemae & Palmer, 1999) and could influence the act of swallowing. The focus of the current study was to examine the linguistic influences of the verbal command on the act of swallowing. The bolus hold was included in the procedures but not manipulated. Table 33 summarized the findings of the study.

Table 33. Summary of the findings

	sEMG latency	sEMG duration	sEMG peak amplitude	sEMG peak latency
SA 1: *swallow* vs. *tone*	*swallow* < tone	*swallow* > tone	*NS*	*swallow* < tone
SA 2: *swallow* vs. *spallow*	*swallow* < *spallow*	*swallow* > *spallow*	*NS*	*swallow* < spallow
SA 3: *swallow* vs. *cough*	*NS*	*NS*	*NS*	*NS*
SA 4: *cough* vs. *pough*	*cough* < *pough*	*cough* > *pough*	*NS*	*cough* < *pough*
SA 5: sEMG latency pattern differences	*swallow* < *spallow, pough* < tone; *swallow, spallow, cough* < tone; *swallow, cough* < *spallow, pough*			

Note: NS= not significant.

9.1 LANGUAGE INDUCED MOTOR FACILITATION IN SWALLOW DURATIONS

9.1.1 Linguistic processing effect (Specific aim 1)

The language induced motor activation theory argues for a neural link between foot/leg-, hand/arm-, and articulator-/face-related action words and motor cortical areas involved in the execution of their related actions. The language induced motor facilitation theory suggests that action words presented prior to the initiation of their related movement facilities their control. As such, the lexical properties of the verbal command to swallow likely influence some swallow behaviors, especially those under voluntary control. Also, according to the language induced motor facilitation theory, the word *swallow* should facilitate the swallow in contrast to the other words and the pure-tone used in the current study.

In contrast to the language induced motor facilitation theory, the dual stream model suggests that non-verbal stimuli require less processing because they can bypass the linguistic system. Therefore, non-verbal stimuli, like the pure-tone used in this study should activate a swallowing response more directly and quicker than a stimulus with linguistic content.

The swallow-related sEMG comparisons between *swallow* and the pure-tone stimulus were used to compare the language induced motor facilitation theory and the dual stream model.

The sEMG latency and sEMG peak latencies for swallows following the word *swallow* were significantly shorter than for swallows following the pure-tone. Because the latency and peak latency shifts were not proportional, the word *swallow* also produced a longer sEMG duration than the pure-tone. The effect was larger for sEMG latency than for the sEMG peak latency suggesting greater linguistic facilitation for *swallow* at the initial and more voluntary part of the swallow. It also should be noted that the sEMG latencies for swallows following the other words also were shorter, and the sEMG durations were longer, than for swallows following the pure-tone. Figure 21 shows a schematic that summarizes of the sEMG latencies, sEMG duration, and rise time duration results. In total, these results demonstrated a linguistic influence on swallow-related sEMG and agree with the language induced motor facilitation theory rather than the dual stream model.

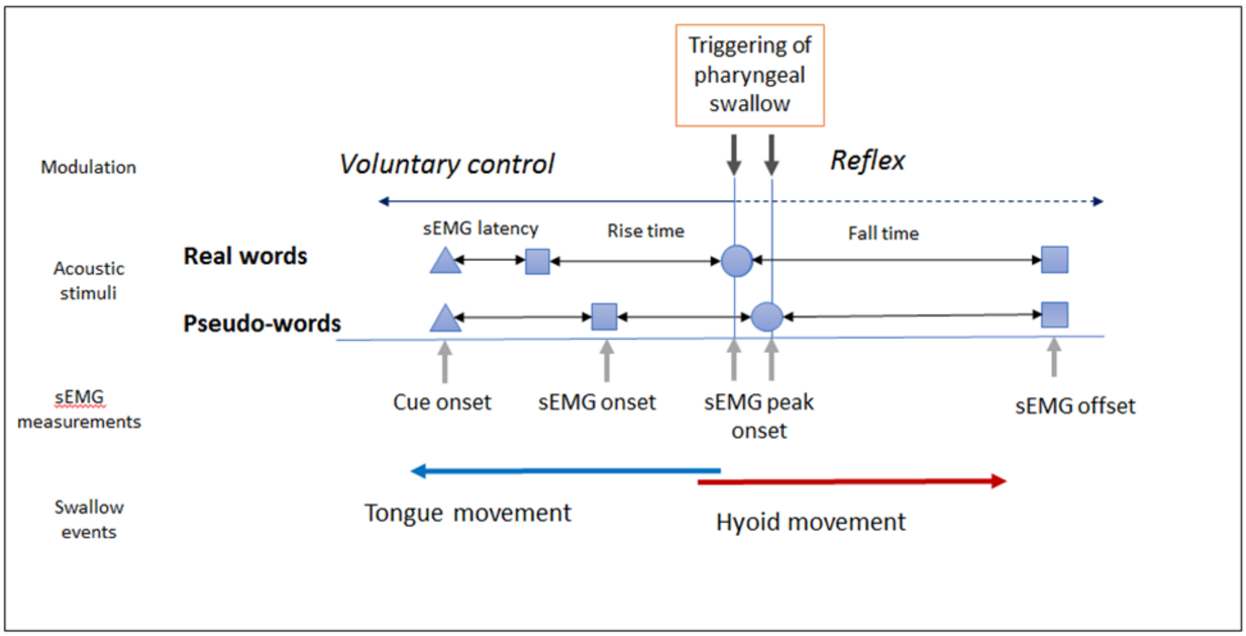

Figure 21. Schematic summary of the findings

The dual stream model suggests the acoustic signal is processed concurrently by two separate streams. More specifically, the acoustic signal is first sent to auditory cortices for spectro-temporal analysis and then projected to the middle-posterior superior temporal sulcus for phonological level processing. After phonological analysis there is a bifurcation into the dorsal and ventral steams. The dorsal steam has an auditory-motor integration function, whereby the acoustic signal is sent to the parietal-temporal junction, and then in the case of the command swallowing, is integrated into a swallowing motor response. In contrast, the ventral steam has an auditory-lexical integration function. The signal is projected to posterior middle temporal gyrus and posterior inferior temporal sulcus for lexical-semantic-grammatical processing. Then, the signal is further projected to the "combination network" in the anterior middle temporal gyrus and anterior inferior temporal sulcus to mix the linguistic information with the motor act of swallowing. Subsequently, the information from both streams is projected to the "swallowing-related network" (Hicock & Poeppel, 2007).

Because phonological, lexical, semantic, and grammatical processing is not necessary for non-verbal stimuli, it was hypothesized that the pure-tone stimuli would be directed to the swallowing-related motor network after the spectro-temporal analysis. It was postulated that by bypassing the linguistic levels of processing, the pure-tone stimuli would produce shorter reaction times than the verbal stimuli. As such, the longer sEMG latencies for swallows following the pure-tone signal than for the action words and pseudo-words did not correspond with the dual stream model. These results suggested that the pure-tone signal may have projected to the middle-posterior superior temporal sulcus for the phonological processing and then possibly projected to the dorsal stream.

It is not clear why the pure-tone signals received phonological analysis. Possibly, dorsal stream involvement was necessary for the integration of the pure-tone signal with the swallow motor function – that the signal projects to the middle-posterior superior temporal sulcus and then was treated as a linguistic signal like the other stimuli. Delays occurred because during phonological and lexical processing there were no linguistic matches and extra processing occurred to rectify the error.

As previously noted, the dorsal stream mediates the mapping of the speech signal to speech motor representations (Hicock & Poeppel, 2007). Evidence exists that the dorsal stream is involved in speech comprehension tasks as well as speech perception tasks (i.e., syllable discrimination tasks), which do not require lexical access (Hickok & Poeppel, 2007). During the verbal and non-verbal discrimination tasks, the dorsal stream also is involved in the non-verbal stimuli (e.g., tones and wideband noise bursts) processing in heathy participants (Joanisse & Gati, 2002; Zaehe, Geiser, Alter, Jancke, & Meyer, 2008). Zaehe and colleagues (2008) hypothesized that the speech perception tasks engage the dorsal stream because it plays an important role in the speech–motor integration. After the phonological processing was carried out in the current study, it is speculated that the non-verbal signal in the experiment also was projected to the dorsal stream to integrate the non-verbal signals to the swallowing motor functions.

The non-verbal signal more likely was not projected to the ventral stream after the phonological processing because further lexical-semantic-grammatical processing was not required. Using a one stream (dorsal stream) instead of two streams also may have caused delays because the motor plan and program for swallowing had to be constructed each time without benefit of linguistic facilitation from the ventral steam.

9.1.2 Pseudo-word interference effect (Specific aim 2)

The inclusion of pseudo-words allowed for further examination of the linguistic effect on swallowing. The pseudo-words were created to interfere with the real words and are believed to activate the lexical networks via their phoneme and syllable features without stored lexical representations (Cibelli, 2012; Hickok & Poeppel, 2007). As a result, they require more processing time than for real words. Pseudo-word interference has been found previously with action words. For example, Gentilucci (2003) reported that presenting adjectives and the pseudo-words did not differentially impact hand-related sequential actions (i.e., reach, grasp a target object with the thumb and index finger, and place the object on a table), but the peak velocity of finger aperture during the reach movement was increased when the congruent action word, rather than the pseudo-words, were presented.

Similarly, a pseudo-word effect was observed in the current study. The sEMG latency and sEMG peak latency for swallows following the congruent action word, *swallow*, were significantly shorter than for swallows following the pseudo-words, *spallow* and *pough.* As noted for the pure-tone, this earlier activation resulted in longer sEMG duration for swallows following *swallow* than for the pseudo-words. These results further support the language induced motor facilitation theory.

9.1.3 Lexical directionality effect (Specific aim 3 and 4)

It was hypothesized that the semantic differences in action directionality between *swallow* and *cough* (i.e., lexical directionality effect) would be reflected in the swallow sEMG – that *cough* would produce greater latencies than *swallow*. However, no statistically significant differences were observed in sEMG latency, sEMG peak latency, and sEMG duration for swallows following the congruent and incongruent action words. The semantic directionality of the two words did not appear to impact swallowing as measured by sEMG.

These results did not correspond with Rabahi et al. (2013) who reported participants jumping higher after hearing the congruent action word *jump* than after the incongruent word *fall*. They also do not agree with the action sentence compatibility effect (ACE), where some investigators have observed an interaction between semantic directionality of a sentence and movement facilitation and interference (Borreggine & Kaschak, 2006; Glenberg & Kaschak, 2002). Of note, however, were the results of the preliminary studies (Appendix C-F), which attempted to replicate the work of Kaschak and colleagues but did not show significant directionality effects.

Although directionality did not appear to affect the sEMG associated with swallowing, the impact of other stimulus factors should be considered. There are lexical and sublexical differences between *swallow* and *cough* that were not controlled. As described in the methods section, it was difficult to select an incongruent word that had the same syllable number and word-frequency of *swallow* given the limited numbers of action words that describe an action incongruent with swallowing. The word-frequency of *cough* is slightly lower (7.703) than *swallow* (8.066) and syllable number (1 vs. 2) obviously differed. However, the impact of higher word-frequency would have been faciliatory and associated with shorter latencies, which did not occur. So too, the limited number of syllables and phonemes in *cough* provides less information and should be less intelligible than *swallow*. However, each acoustic cue was manipulated to have the same duration and average RMS intensity, which may had reduced any potential impact of syllable or phoneme number (also not controlled). Other characteristics, such as lexical neighborhood density and phototactic complexity, were similar across the two words and likely had little or no influence (Storkel & Hoover, 2010).

The word *vomit* would have been a better match for *swallow* than *cough* but it carries highly negative connotations that likely would have impacted the results. A possible alternative would be to conduct the study in another language and/or culture. For example, Japanese has several words that carry the meaning of *vomit*. One polite form of *vomit* (i.e., *Haite-kudasai*/ "please vomit" in English) has the same syllable number as a *swallow* in polite form (i.e., *Nonde-kudasai/* "please swallow" in English). Conducting the study using the polite Japanese forms could allow for greater sublexical control.

9.1.4 Pattern differences on sEMG latency (Specific aim 5)

As indicated above, it was not possible to control the syllable numbers between the congruent and incongruent action words. In order to determine whether the results of the study were influenced by these sublexical characteristics, pattern differences on sEMG latency among the four different word cues (*swallow*, *spallow*, *cough*, and *pough*) were examined.

None of the predicted possible outcomes was observed. Pattern 1 indicated a lexical directionality effect without the syllable number effect on swallows following the action words (*swallow* and *cough*) along with the syllable number effect on swallows following the pseudo-words (*spallow* and *pough*). The sEMG latencies for swallows following *swallow* were predicted to be shorter than swallows following the other words, and sEMG latency for swallows following *cough* was predicted to be longer than swallows following *pough*. However, the study results did not match pattern 1. The results for *swallow* and *cough* were similar with no lexical directionality effects. There also was no syllable number effect in the pseudo-words conditions, and no statistically significant difference between swallows following *spallow* and *pough.*

Outcome pattern 2 predicted no sEMG latency differences between swallows following *swallow* and those following *cough* due to a cancellation of influences by a lexical directionality effect and syllable number along with a syllable number effect on the pseudo-words. However, due to the lack of a syllable number effect in the pseudo-words conditions, this outcome was not observed.

Pattern 3 predicated that sEMG latencies following *swallow* and *spallow* would be longer than swallows following *cough* and *pough* due to the syllable number effect without a lexical directionality effect. The possible outcome 4 predicated there would be no difference in any conditions. Both possible outcome 3 and 4 were not observed due to the presence of pseudo-words interference on sEMG latency between swallows following *swallow* and the pseudo-words. Among the word stimuli conditions, the language induced motor facilitation in swallowing was partially supported.

Although the pure-tone cue was not included in the above patterns, the sEMG latency for swallows following the pure-tone were consistent with a link between language and motor systems, and supported the language induced motor facilitation model to some extent. It was further supported by the interference observed by the pseudo-words but not by the lack of lexical directionality.

9.2 LANGUAGE INDUCED MOTOR FACILITATION IN PEAK AMPLITUDE

It was hypothesized that sEMG peak amplitude would be greater for swallows following *swallow* than the other cues. However, there was no significant difference on sEMG peak amplitude among any stimulus type, which suggested that the influence of language was limited to timing and not amplitude or power of the swallowing in the current study.

These results did not correspond with those from the Nakamura and Imaizumi (2013) who used sEMG to investigate the impact of liquid names on swallowing. They reported that sEMG peak amplitude was higher for swallows with the name of drinks compared to swallows without the names. They postulated that the anticipation of swallowing induced by the name of the drinks caused an enhancement of the suprahyoid muscle activity. Although the difference across studies may be due to the liquids used (water vs. apple juice and bitter grass juice), sEMG peak amplitude was a reliable measure with limited variability within and across sessions in a study conducted by Huckabee, Low, and McAuliffe (2012) using a thin liquid. On the other hand, sEMG peak amplitude also is known to be altered by bolus taste (Ding et al., 2003; Leow, Huckabee, Sharma, & Tooley, 2007). There could have an interaction between the naming of the drinks and the taste of the drinks in the Nakamura and Imaizumi (2013) study. Further, the differences in experimental conditions could explain the discrepancy between their results and those of the current study.

9.3 RISE AND FALL TIME DURAITON

As a secondary analysis, the rise time (i.e., duration between sEMG onset and sEMG peak amplitude onset) and fall time (i.e., the duration between the sEMG peak amplitude onset and sEMG offset) duration were examined to better understand the sEMG duration results. There were stimulus-type effects on the rise time duration, whereas none were observed for fall time duration. The rise time, which can be influenced by tongue movements, is under voluntary control, but the fall time typically occurs after the onset of hyoid elevation, and is mostly reflexive (Shaw & Martino, 2013). Once the pharyngeal swallow is triggered, reflexive components of swallowing can no longer be altered by top-down processing (Ertekin, 2003). The rise time and fall time duration results corresponded to the swallow physiology in that swallowing is not a purely reflexive act, but it contains some voluntary components (Humbert et al., 2009; Malandraki & Robbins, 2013; Martin et al., 2007; Shaw & Martino, 2013), and some of the voluntary components of swallowing can be modulated by top-down input from the cortex (Humbert et al., 2012).

The rise time and fall time durations for the current study confirmed that some of the voluntary components, but not the reflexive components, of swallowing can be modulated by the verbal commands.

9.4 SWALLOW PREFERENCE SELF-REPORT

Although subjective and offline, the self-reported swallow preferences corresponded with the language induced motor facilitation theory to some extent. Sixty-five percent of the participants preferred to swallow after they heard the congruent action word *swallow* and none of them reported not liking to swallow after they heard *swallow*. Also, none of the participants reported a specific preference for the other words. These results may reflect an advantage of using a congruent stimulus even though not entirely supported by the sEMG results. Of note is that 25% of the participants indicated a preference for swallowing after the pure-tone. This preference did not correspond with the language induced motor facilitation theory and was not reflected in the sEMG results.

10.0 SIGNIFICANCE

10.1 THEORETICAL SIGNIFICANCE

No previous studies have tested the language induced motor facilitation theory using action words referring to ingestion, such as *eat, chew* and *swallow*. Although the current study showed that the word *swallow* facilitated swallows, as reflected in the timing of sEMG activity, so did the word *cough*. These findings could mean that real words facilitate swallowing, or that real words more generally facilitate motor activity. Another possibility is that *swallow* and *cough* are sufficiently related to the aerodigestive tract, such that they show similar levels of facilitated swallowing.

Another contribution is that none of the previous studies tested the language induced motor facilitation theory by comparing verbal and simple acoustic stimuli. It is unknown whether other actions and body parts, especially those under more voluntary control will show similar effects.

10.2 CLINICAL SIGNIFICANCE

There has been continued debate about whether the command swallow condition should be used during videofluoroscopic evaluation of swallowing disorders. There was limited information about the impact of using a verbal command to elicit the swallow and the impact has not been isolated from the effects of the bolus hold. The current study indicated that verbal information can impact swallow physiology. It also provided evidence that will contribute to a better understanding of the voluntary control of swallowing, as well as the relationships between language and motor systems. The clinical utility of the information obtained in the study may depend on the purposes for using the command swallow and the type of patient being assessed. However, clinicians should be aware that both components of the command swallow condition may alter swallow behaviors and not represent a patient's swallowing skills under the conditions in which he/she routinely swallows.

The study results do suggest potential clinical benefits of the command swallow condition. The sEMG onset is likely due to the tongue movement and occurred significantly earlier for swallows preceded by the word *swallow*. These results suggest that patients who show difficulty initiating oropharyngeal swallows, such as patients with Parkinson's disease, may benefit from linguistic stimuli prior to the swallow initiation. It would be reasonable to investigate the command swallow condition as a swallow compensatory technique for patients with dysphagia.

11.0 LIMITATIONS

There are limitations to the study. First, surface electromyography (sEMG) was employed for the study. The study used sEMG rather than videofluoroscopy because of the need for multiple trials per condition and the risks associated with the radiation exposure. Using sEMG also helped account for the variability associated with reaction time measures. However, it was not possible to obtain detailed kinematic information of the oral preparatory phase and oral phase of swallowing from the sEMG signals. The sEMG is more of an indirect measure of the swallow.

As discussed previously, the stimulus selected for the incongruent word stimulus (c*ough*) may not have functioned as a true incongruent stimulus. There also were sublexical characteristics that were not controlled. Furthermore, the participants' weight was not controlled. Although the variance associated with individual differences was statistically controlled, participants' weight may have impacted the sEMG peak amplitude results.

Lastly, data were obtained from young healthy participants, so results of the current study may not represent swallows by elderly participants and/or patients with dysphagia who need to undergo VFSS assessments. The data also may have limited relevance to treatment approaches for dysphagia.

12.0 FUTURE DIRECTIONS

As a next step, it will be reasonable to investigate the command swallow condition as a swallow compensatory technique for patients with difficulty initiating oropharyngeal swallows, such as patients with Parkinson's disease and age-matched elderly healthy participants.

For this investigation, swallows without the verbal command to swallow (i.e., self-initiated swallow behaviors) and swallows with the various verbal commands (i.e., externally triggered swallow behaviors) should be compared to further examine the role of language. This investigation would be based on the theoretical lines of evidence in language induced motor facilitation including the current study results. It also would be based on the neural and behavioral differences between the self-initiated and externally triggered stimuli, such as visual, tactile, and acoustic stimuli. For example, previous research has shown that external stimuli presented prior to the hand-related actions improves response times (Ballanger et al., 2006; Cunnington et al., 2002; Jahanshahi et al., 1995; Jenkins et al., 2000; Obhi & Haggard, 2004; Yazawa et al., 1997). This type of study would have more ecological validity than the current study.

13.0 CONCLUSIONS

The current study investigated whether language induced motor facilitation was evident in the motor act of swallowing under the voluntary control in young healthy participants. Swallow latencies following the congruent action word were shorter than swallows following the non-verbal stimulus indicating that suprahyoid muscle activity occurred earlier for swallows following the word *swallow* than for the pure-tone. Longer latencies for the pseudo-words than for real words also supported the language induced motor facilitation theory. However, it was not clear whether the observed differences were due to reduced facilitation or longer processing time associated with interference. Stronger support for the language induced motor facilitation theory by capturing effects of the lexical directionality effect created by the incongruent action word was not evidenced. Nevertheless, the facilitation effects of swallow-related action words may not have equally strong sensitivity among effectors, and the incongruent word in the study may not have represented a true incongruent action against the act of swallowing. There also was no facilitation effect on peak suprahyoid muscle activity amplitude.

The evidence from this study advances our understanding of the links between language and movement for behaviors that are not entirely under voluntary control. Linguistic inducement of swallowing as could be useful as a swallow compensatory technique for patients with difficulty initiating oropharyngeal swallows such as patients with Parkinson's disease.

This study became the first step for investigating the clinical benefits of the command swallow condition for patients with dysphagia.

APPENDIX A

IRB APPROVAL LETTER

University of Pittsburgh
Institutional Review Board

3500 Fifth Avenue
Pittsburgh, PA 15213
(412) 383-1480
(412) 383-1508 (fax)
http://www.irb.pitt.edu

Memorandum

To: Atsuko Kurosu
From: IRB Office
Date: 2/1/2017
IRB#: PRO16100375
Subject: Investigation of embodied language processing on command-swallow performance

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The University of Pittsburgh Institutional Review Board reviewed and approved the above referenced study by the expedited review procedure authorized under 45 CFR 46.110 and 21 CFR 56.110. Your research study was approved under:

45 CFR 46.110.(4)
45 CFR 46.110.(7)

The risk level designation is Minimal Risk.

Approval Date: 2/1/2017
Expiration Date: 1/31/2018

For studies being conducted in UPMC facilities, no clinical activities can be undertaken by investigators until they have received approval from the UPMC Fiscal Review Office.

Please note that it is the investigator's responsibility to report to the IRB any unanticipated problems involving risks to subjects or others [see 45 CFR 46.103(b)(5) and 21 CFR 56.108(b)]. Refer to the IRB Policy and Procedure Manual regarding the reporting requirements for unanticipated problems which include, but are not limited to, adverse events. If you have any questions about this process, please contact the Adverse Events Coordinator at 412-383-1480.

The protocol and consent forms, along with a brief progress report must be resubmitted at least one month prior to the renewal date noted above as required by FWA00006790 (University of Pittsburgh), FWA00006735 (University of Pittsburgh Medical Center), FWA00000600 (Children's Hospital of Pittsburgh), FWA00003567 (Magee-Womens Health Corporation), FWA00003338 (University of Pittsburgh Medical Center Cancer Institute).

APPENDIX B

SCREENING QUESTIONARIE FORM

What is your age today?
_____ years (If not between 18 and 35: ineligible)

What is your gender?
Male
Female

How tall are you?
_____ cm

Do you have hair covering the skin under your chin?
Yes (ineligible)
No

Are you willing to shave your hair covering the skin under your chin before an experiment? (This question is only for male participants)
Yes
No (ineligible)

Do you have any difficulty swallowing food or liquids?
Yes (ineligible)
No

Do you have any difficulty hearing?
Yes (ineligible)
No

Do you have any nasal congestion?
Yes (ineligible)
No

Have you ever had a stroke, brain injury, or any diagnosis of neurological conditions such as Multiple sclerosis, Parkinson's disease, myasthenia gravis, or ALS (Lou Gehrig's disease)?

Yes (ineligible)
No

Are you allergic to or have any skin sensitivity to adhesive tape, rubbing alcohol, or any product?

Yes (ineligible)
No

Is English your only language?

Yes
No (ineligible)

Date________________ Time___________ Screened By (initials)__________
Participant Initials_____________ Participant Number____________

APPENDIX C

ACOUSTIC STIMULI VALIDATION TASK

C.1 OUTLINE

Action sentence compatibility effect (ACE) refers to the interaction between a sentence directional content and movement direction, such as moving toward vs. away or up vs. down (Borreggine & Kaschak, 2006; Glenberg & Kaschak, 2002). When making sensibility judgments about action sentences, interference has been observed when hand movements are incongruent with directions conveyed in the sentences (Borreggine & Kaschak, 2006; Glenberg & Kaschak, 2002). Yet, it is unknown whether there is any directionality between swallow-related action words and motor performance. If there is no directional relationship (e.g., toward vs. away, or congruent vs. incongruent) between swallow-related words and motor performance, the interference effect may not be observed in the sEMG main study. Furthermore, if the ACE is observed in sensibility judgment tasks with swallow-related words but not in swallow performance, the facilitation and inference effects may be limited to specific types of tasks or motor systems.

To validate the directionality of the real words used for the main experiment, sensibility judgment tasks were administered prior to implementing the main sEMG experiment. The purpose of the validation procedures was to test the directional relationship between swallow-related action words and a hand movement. There were two sensibility judgment tasks: (1) a task with sentences with non-swallow-related action words, and (2) a task with swallow-related action words. The intention of the first task was to replicate previous findings in the ACE literature, whereas the second task was to determine if directionality was inherent to words used in the main experiment.

Two experiments were conducted: one with a five-key response keypad (Experiment 1) and another with a keyboard (Experiment 2). The experiment 2 was administered because the experiment 1 failed to replicate the ACE. The purpose of the experiment 2 was to determine if the lack of an ACE in the experiment 1 was a result of the mode of responding. The experiment 2 used the same response instrumentation as the original study by Borreggine and Kaschak (2006) and tested the directional relationship between swallow-related action words and a hand movement.

C.2 EXPERIMENT 1

C.2.1 Methods

C.2.1.1 Participants

A power analysis was conducted using G*power (Faul, Erdfelder, Lang, & Buchener, 2011) to estimate the number of participants needed for a repeated measures within subject analysis of variance (ANOVA) with a power of .80 and alpha of .05. A medium effect size, Cohen's f =.25 or η^2 =.059 and the correlation among the repeated measures ρ =.5 were assumed to obtain the recommended statistical power of .80 level (Cohen, 1992). Based on the power analysis, 24 participants were recruited for the experiment 1. They were aged 18 years or older with no screening or grouping for race or sex, were native speakers of American English, and had no hearing or vision losses. Table 1 summarizes the demographic information of the participants. Their hearing was screened prior to the experiment based on the ASHA guidelines for audiologic screening, which have been described previously. Their vison was screened with a standard Snellen chart and has been described previously.

Table1. Demographic information of the participants.

Variable		Experiment 1
Age (years)	*Mean* ± *SD*	27.42 ± 6.4
	Range	19-41
Sex	Male	6
	Female	18
Race/ethnicity	Asian	1
	African-American	2
	Caucasian	20
	Hispanic	1

C.2.1.2 Materials

Sentences from the Borreggine and Kaschak (2006) study were used for the replication portion of the experiment. There was a total of 80 sentences: (1) 20 non-swallow-related sentences that indicate a toward direction, such as "Andy delivered the pizza to you", (2) 20 non-swallow-related sentences that indicate an away direction, such as "You delivered the pizza to Andy", and (3) 40 filler sentences, such as "Al poured the horse to you" (Borreggine & Kaschak, 2006; Glenberg & Kaschak, 2002). Also, 18 sentences (9 filler sentences) from the same study were used as practice sentences. Five of the filler sentences contained the swallow-related action words (See Appendix D).

For the sentence judgment task with swallow-related sentences, a total of 80 sentences were used. There were: (1) 20 sentences with congruent swallow-related action words that indicated a toward direction, such as "You <u>swallowed</u> a glass of water", (2) 20 sentences with incongruent swallow-related action words that indicated an away direction, such as "You <u>coughed</u> from a cold", and (3) 40 filler sentences from the original study (See Appendix D). The 40 swallow-related sentences were developed for the task. The database from the Washington University English

Lexicon project (Balota et al., 2007) was used to generate the swallow-related action words. Ten congruent and 10 incongruent swallow-related action words were selected from the database, and two sentences were generated for each action word.

All sentence stimuli were produced by a young adult female native speaker of American English. The sentences were recorded with a Shure 33-3043 microphone (Shure, Niles, IL) in a sound-treated booth and edited with a digital audio editing program (Adobe Audition CS5.5) and saved in a wav audio file format. The amplitude of each sentence was matched to the original stimuli (i.e., average RMS for signal amplitude=-25dB). The duration of sentences with the syllable number less than eight was set within one standard deviation (*SD*) of the average duration of American English speakers in ms (Eberwein et al., 2007; Robb & Gillon, 2009). The duration of sentences with the syllable number more than 9 was set within 2 *SD* of the average duration (See Appendix E). A silent period of 20 ms was added before and after each sentence to avoid producing a click stimuli presentation.

To verify the naturalness of the recorded sentences, four naïve adult native speakers of English with normal hearing rated the recorded stimuli. During the naturalness rating task, each sentence was presented in the sound field at 65 dB SPL as measured at the level of the pinna of each listener. The listeners were asked to rate each sentence for naturalness on a scale 1 to 5 (i.e., score 1= poor, score 3= good, and score 5=very good). Any sentences rated lower than the score 3 were re-edited or replaced, and then re-presented to the volunteers until all sentences were scored above the score 3.

C.2.1.3 Instrumentations

All sentences were presented and controlled via SuperLab 5.0 experiment software (Cedrus, Phoenix, AZ) residing on a notebook computer (MacBook Air, 1.6 GHz processor, Intel Core i5). The sentences were presented at 65 dB SPL in the sound field as measured at the pinna. A pair of loudspeakers (Multi-media SL-80) was placed on a desk in front of each participant. A computer monitor (Dell E2211HC: 21.5-inch display; 1920 x 1080 resolution: Dell Inc, Round Rock, TX) was connected to the notebook computer to present the visual stimuli, and it was placed between the loud-speakers.

A five-key response keypad (RB-540; Cedrus, Phoenix, AZ) was also connected to the notebook computer, and placed on the desk in front of participants. Three of the five keys (i.e., yellow, red, and white keys) on the response keypad were used for the experiment. The yellow key was situated away from the participant's body, and the red key was situated near the participant's body. The participants pressed either the yellow or red key to make a "yes" response. The white key was situated in the middle of the keypad, and it was used as a home key. Figure 1 displays the five-key response keypad. Figure 2 displays the experimental configuration.

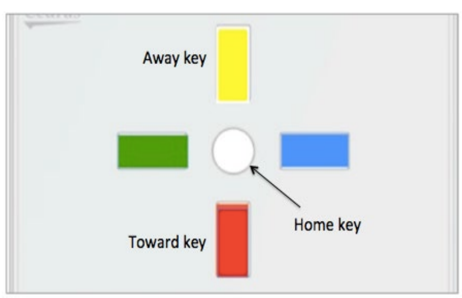


Figure 1. A five-key response keypad

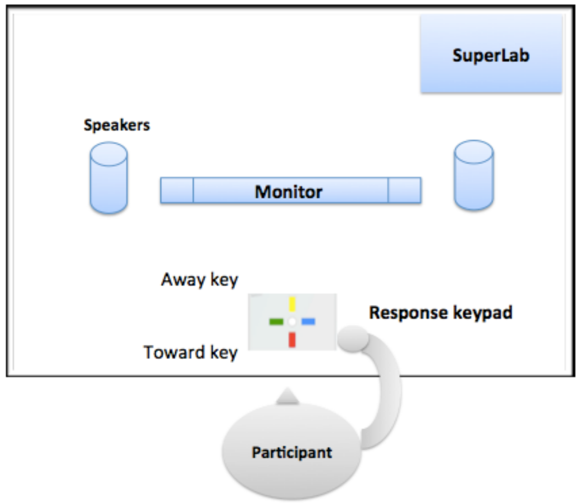


Figure 2. Experiment 1 configuration

C.2.1.4 Experimental procedure

C.2.1.4.1 Key-press reaction time measurement

Prior to the experiment, key-press reaction time (RT) was measured. Key-press RT was defined as the onset of a visual stimulus (i.e., a red or yellow square) on the computer monitor and the onset of key press. For this task, participants sat in front of the desk with the computer monitor and the response keypad. At the beginning of each key press RT trial, a "+" followed by a white circle appeared on the computer monitor. Participants were told to press and hold the white key after they saw the while circle. After pressing the white key, a red or yellow square appeared on the monitor. Participants were told to press a red key on the keypad as quickly and accurately as possible if they saw a red square. Likewise, they were told to press the yellow key if they saw the yellow square. There were twenty trials (ten red key presses and ten yellow key presses), and the order of the visual stimuli was randomized.

C.2.1.4.2 Main experiment

During the experiment, participants sat comfortably in front of the desk with the computer monitor and the response keypad. They were told that they would hear a series of sentences and their task was to decide if each sentence made sense. To initiate the presentation of each sentence, the participants pressed the white key and held it down until they were ready to make a "yes" response. Prior to each sentence onset, either a yellow or red square appeared in the center of the computer screen. Participants were told that when the yellow square appeared they needed to press the yellow key with the index finger of their dominant hand if they thought the sentence was sensible. Likewise, they should press the red key if a red square appeared on the screen. If a sentence was not sensible, participants kept pressing the white key. At the end of each trial, a "+" re-appeared on the computer screen to signal to the participants that they could remove their finger from the white key if they were pressing it. The instructions were given at the beginning of the main experiment in black 30-point, Times New Roman font on a white background, shown on the computer monitor.

There were four sentence-response conditions: (1) away sentence direction with away response direction condition (A-A condition), (2) away sentence direction with toward response direction condition (A-T condition), (3) toward sentence direction with away response direction condition (T-A condition), and (4) toward sentence direction with toward response direction condition (T-T condition) (Borreggine & Kaschak, 2006). There were twenty sentences in each condition. A total of 240 sentences (i.e., 40 non-swallow sentences, 40 swallow sentences, and 40 filler sentences; each sentence was presented twice during the experiment) were randomly presented in four blocks of 60 trials with a five-minutes break between the blocks. The order of the task, condition, and sentences in each condition was randomized.

Prior to the experiment, participants responded to practice sentences to become familiar with the procedures and make sure they were responding correctly. Feedback was given only during the practice when errors occurred. Figure 3 displays the flow chart of the procedure for each swallow trial.

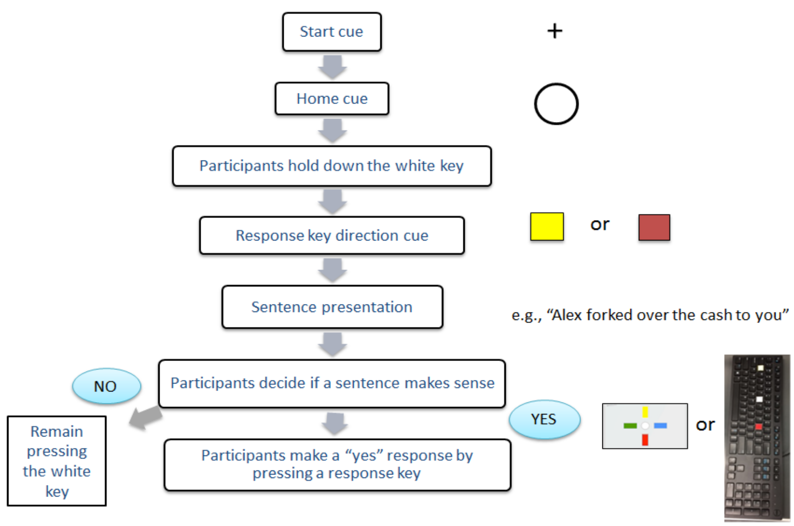


Figure 3. Flow chart of the procedure for each trial

C.2.1.4.3 Statistical analysis

A 2 (sentence direction: toward vs. away) by 2 (response direction: toward vs. away) by 2 (sentence type: non-swallow vs. swallow) within subject ANOVA was performed on the reaction time (RT) as a function of sentence direction and response direction. The RT was defined as the duration between the sentence onset and the onset of keypad press in ms. To adjust for the sentence length difference and the 20 ms silent period, both durations were subtracted from RT for each sentence.

Because the primary focus of the experiment was the interaction effect (sentence direction x response direction), interaction results were the primary statistics of interest reported in the next section. A paired sample t-test was performed for the key-press RT task.

Prior to statistical analysis, any key press responses for non-sensible sentences, incorrect responses, and any RTs more than +/- 2 *SD* from the overall RT mean were eliminated. In addition, one participant's responses were eliminated because she stabilized the participant hand on the keypad that reduced hand movement.

C.2.2 Results

C.2.2.1 Key-press RT task

Two participants did not complete the key press RT task. Key-press RT was faster for pressing the red (toward) key (*Mean*=671.633, *SE*=17.07) than for pressing the yellow (away) key (*Mean*=707.45, *SE*=83.57) although the distance from the white home key to the red key was equal to that to the yellow key, t (19) =3.133, p=.005. Figure 4 shows the means and standard errors of the key-press RT task.

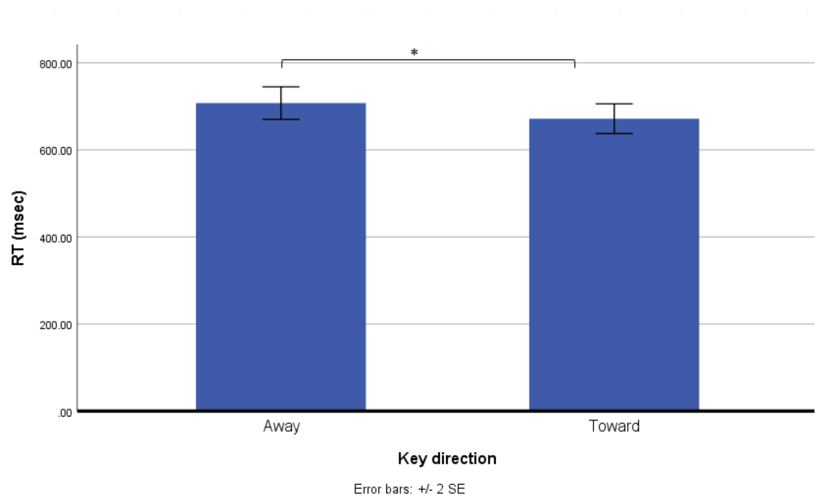


Figure 4. Means and standard errors of the key-press RT task with a keypad.

C. 2.2.2 Main experiment

The means, standard errors, 95% confidence interval for all the sensibility judgment tasks were summarizes in Table 2. Table 3 summarized the statistical analysis results.

Table 2. Means, standard error, 95% confidence interval for all the tests

Experiment (Instrument)	Key RT control	Sentence type	Sentence direction	Response direction	Mean (ms)	Std. Error	95% Confidence Interval	
							Lower Bound	Upper Bound
1 Keypad	No key-press RT controlled	Non-swallow	toward	toward	490.58	31.59	425.07	556.08
				away	500.07	32.30	433.07	567.06
			away	toward	499.83	33.05	431.28	568.37
				away	494.42	33.49	424.97	563.86
		Swallow	toward	toward	429.17	26.91	373.37	484.98
				away	438.95	28.35	380.16	497.75
			away	toward	489.21	30.04	426.91	551.52
				away	495.69	28.85	435.87	555.51
	Key-press RT controlled	Non-swallow	toward	toward	490.58	31.59	425.07	556.08
				away	464.23	32.30	397.24	531.23
			away	toward	499.83	33.05	431.28	568.37
				away	458.58	33.49	389.14	528.03
		Swallow	toward	toward	429.17	26.91	373.37	484.98
				away	403.12	28.35	344.33	461.92
			away	toward	489.21	30.04	426.91	551.52
				away	459.86	28.85	400.04	519.68
2 Keyboard	No key-press RT controlled	Non-swallow	toward	toward	636.65	38.54	556.93	716.38
				away	633.10	32.32	566.24	699.95
			away	toward	612.83	35.16	540.10	685.56
				away	660.70	34.65	589.02	732.37
		Swallow	toward	toward	611.86	32.91	543.79	679.93
				away	633.29	34.75	561.41	705.17
			away	toward	624.77	35.31	551.72	697.82
				away	683.42	35.35	610.29	756.55
	Key-press RT controlled	Non-swallow	toward	toward	636.65	38.54	556.93	716.38
				away	618.44	32.32	551.58	685.29
			away	toward	612.83	35.16	540.10	685.56
				away	646.04	34.65	574.36	717.71
		Swallow	toward	toward	611.86	32.91	543.79	679.93
				away	618.63	34.75	546.75	690.51
			away	toward	624.77	35.31	551.72	697.82
				away	668.76	35.35	595.63	741.89

Table 3. Summary of the statistical analysis results

Experiment	*df*	*F*	*p*	η^2
1	1	.353	.529	.016
2	1	2.48	.129	.097

C. 2.2.2.1 Non-key-press RT controlled results

There was no significant pattern difference on RT between sentence direction and response direction in the non-swallow-related sentence condition, F (1, 22) =.353; p=.529; η^2=.016 (Figure 5). The ACE was not observed in the non-swallow-related sentence condition. Experiment 1 failed to replicate the Borreggine & Kaschak (2006) study.

In the swallow-related sentence condition, there also was no significant pattern difference on RT between sentence direction and response direction (Figure 6). The ACE also was not observed in the swallow-related sentence condition.

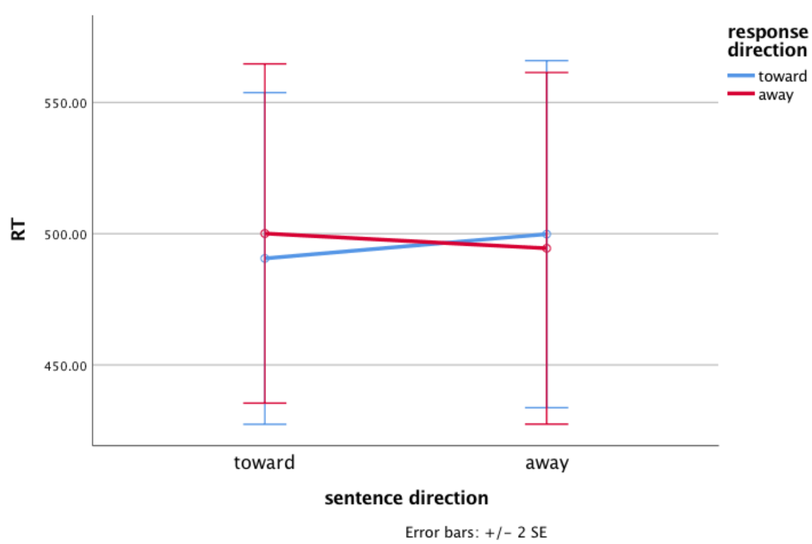


Figure 5. Means and standard errors for the sensibility judgment task in non-swallow-related sentences.

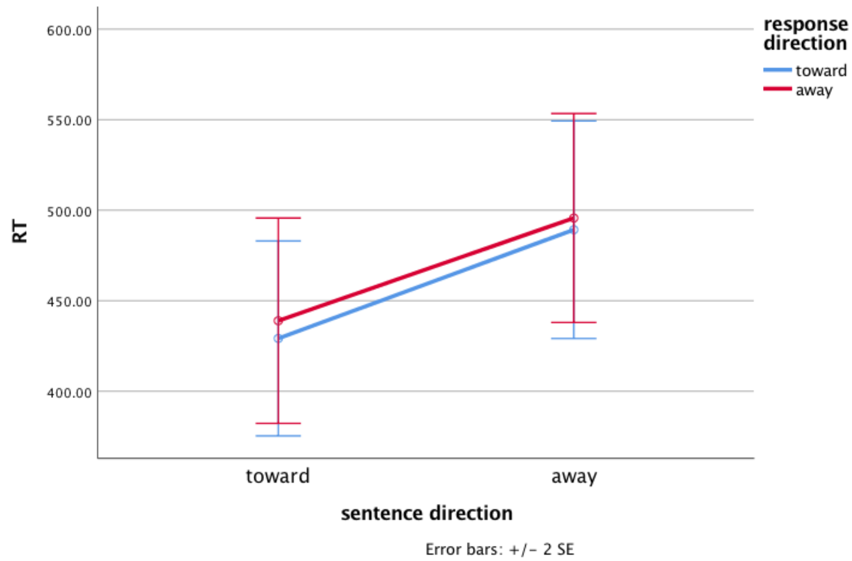


Figure 6. Means and standard errors for the sensibility judgment task in swallow-related sentence condition.

C. 2.2.2.2 Key-press RT controlled results

Because there was a significant difference on key-press RT between the toward and away keys, the key-press RT was controlled in additional analyses. To control for the key-press RT difference, the difference between the two keys were subtracted from the away response conditions.

There was no significant pattern difference on RT between sentence direction and response direction in the non-swallow-related sentence condition after controlling for the key-press RT, F (1, 22) =.353; p=.529; η^2=.016 (Figure 7). There also was no significant pattern difference on RT between sentence direction and response direction in the swallow-related sentence condition (Figure 8).

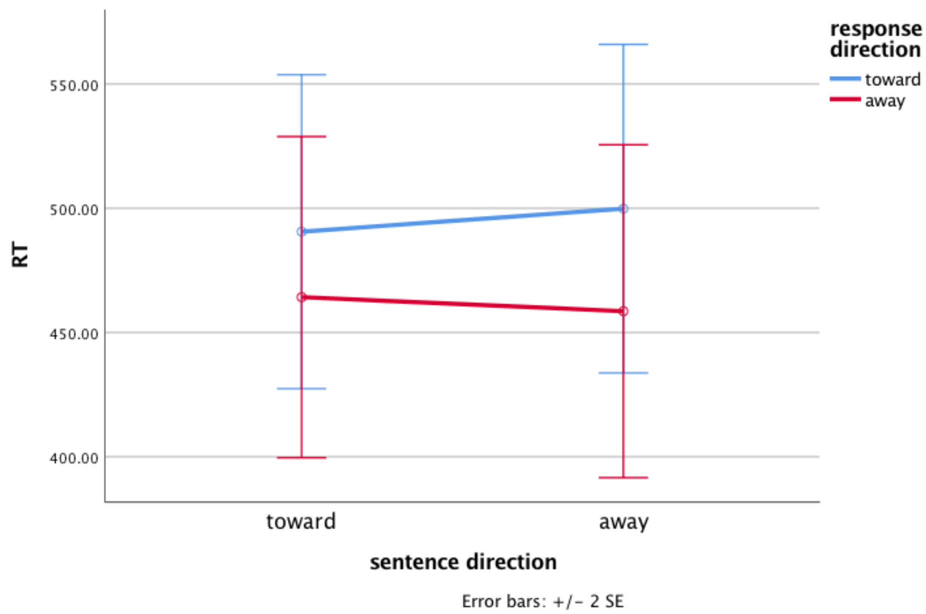


Figure 7. Means and standard errors for the sensibility judgment task in non-swallow-related sentences after controlling for key-press RT

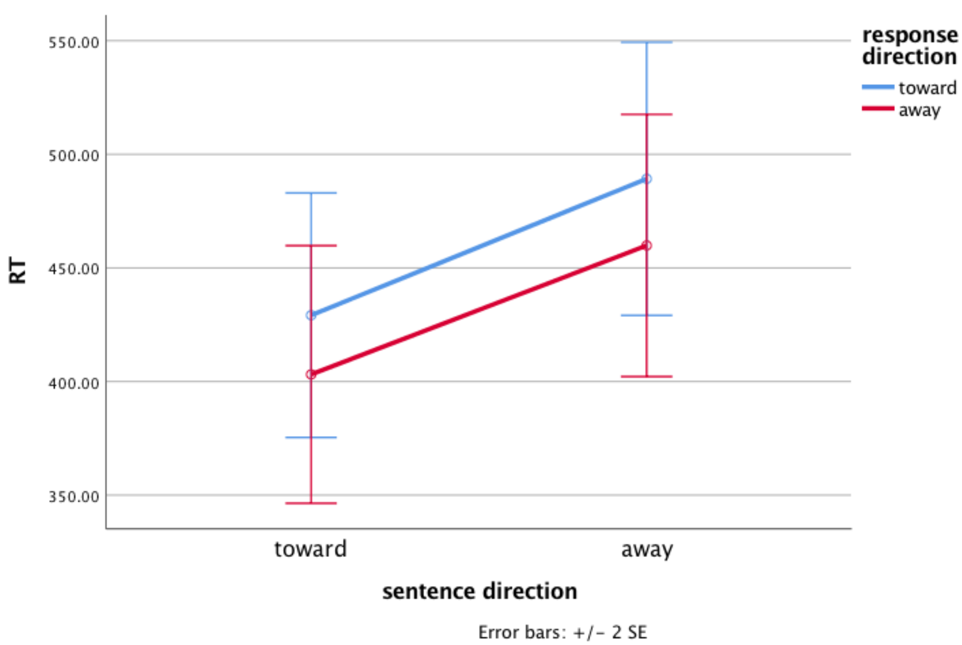


Figure 8. Means and standard errors for the sensibility judgment task in non-swallow-related sentences after controlling for key-press RT.

C.3 EXPERIMENT 2

C.3.1 Methods

C.3.1.1 Participants

A different group of 24 participants were recruited for the experiment 2. They were young adult native speakers of English with normal vision and hearing. Table 4 summarizes the demographic information of the participants in the experiment 2. Screening procedures were the same as that for the experiment 1.

Table 4. Demographic information of the participants in Experiment 2.

Variable		Experiment 2
Age (years)	Mean ± *SD*	30.21 ± 9.6
	Range	21-51
Sex	Male	4
	Female	20
Race/ethnicity	Asian	1
	African-American	0
	Caucasian	24
	Hispanic	0

C.3.1.2 Materials

The same materials used in the experiment 1 were used in the experiment 2.

C.3.1.3 Instrumentation

Instead of a response keypad, a keyboard (Dell keyboard KB212-B) was used for the experiment 2. The keyboard was placed on the desk in front of participants at a 90-degree angle from the normal orientation (Borreggine & Kaschak, 2006). Three keyboard buttons were used (i.e., Q, P, and Y keys). The Q key was used as a yellow (away) key, and a yellow cover was placed on the top of the key. Similarly, the P key with a red cover was uses as a red (toward) key, and the Y key with a white cover was used as a white home key. The spatial location of the keys was identical to that in Experiment 1. Figure 9 displays the experimental configuration.

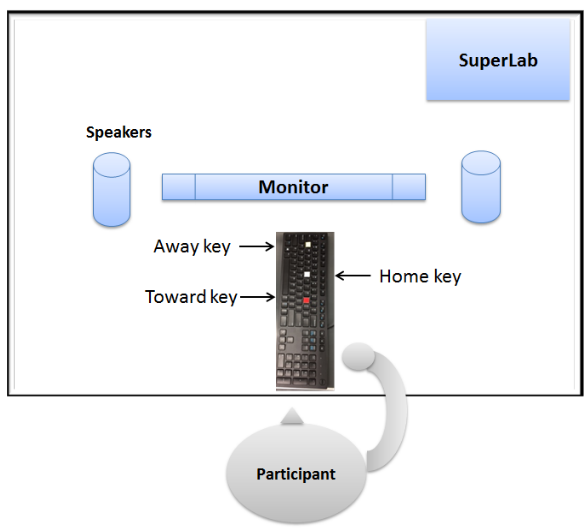


Figure 9. Experiment 2 experimental configuration.

C.3.1.4 Experimental procedure

C.3.1.4.1 Key-press RT measurement

The same procedure used in the experiment 1 was used.

C.3.1.4.2 Main experiment

The same procedure for the experiment 1 was used in the experiment 2 except that a keyboard and counterbalanced sentence lists were used to replicate the Borreggine and Kaschak (2006) study as much as possible.

Four counterbalanced sentence lists were created based on the criteria in the original Borreggine and Kaschak (2006) study: each list contained the four sentence-response conditions (A-A, A-T, T-T and T-A conditions). A different set of ten sentences was randomly assigned into each condition. There were 60 sentences in each list (i.e., 20 non-swallow sentences, 20 swallow sentences, and 20 filler sentences) (See Appendix D). A participant was given only one counterbalanced list. The order of the sentences in each list was randomized.

C.3.1.4.3 Statistical analysis

The same statistical analyses used in Experiment 1 were used in experiment 2.

C.3.2 Results

C.3.2.1 Key-press RT task

Similar to the experiment 1 result, the key-press RT with a keyboard was faster for the red (toward) key (*Mean*=669.68, *SE*=21.41) than for pressing the yellow (away) key (*Mean*=684.34,

SE=20.17), t (23) =2.224, p=.036. Figure 10 indicates the means and standard errors of the key-press RT task result.

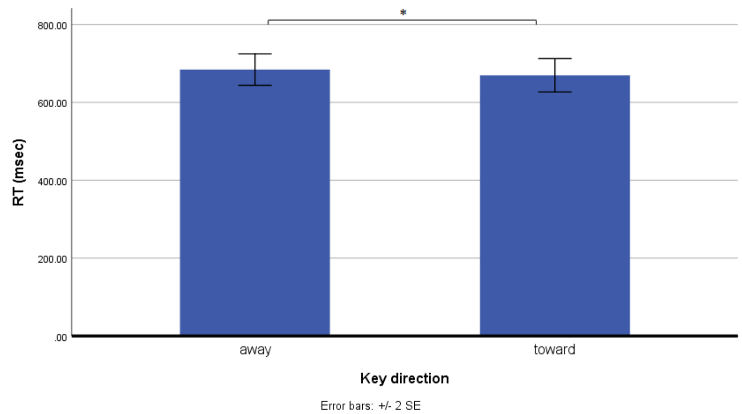


Figure 10. Means and standard errors of the key-press RT task with a keyboard.

C.3.2.2 Main experiment

C. 3.2.2.1 Non-key-press RT controlled results

There was no significant pattern difference on RT between sentence direction and response direction in the non-swallow-related sentence condition, F (1, 23)=2.48; p=.129; η^2=.097. The ACE was not observed in the non-swallow-related sentence condition (Figure 11). The experiment 2 also failed to replicate the Borreggine & Kaschak (2006) study.

There was no significant pattern difference on RT between sentence direction and response direction in the swallow-related sentence condition (Figure 12). The ACE also was not observed in the swallow-related sentence condition.

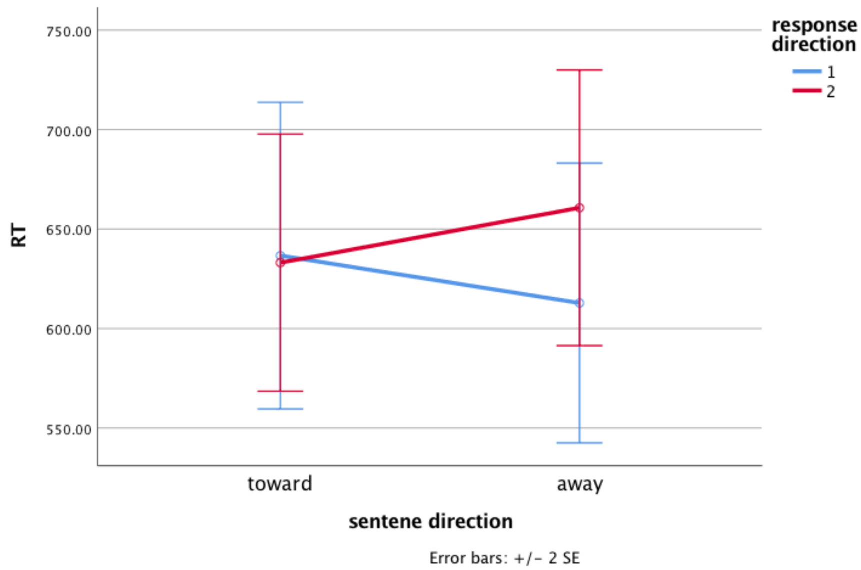


Figure 11. Means and standard errors for the sensibility judgment task in non-swallow-related sentences

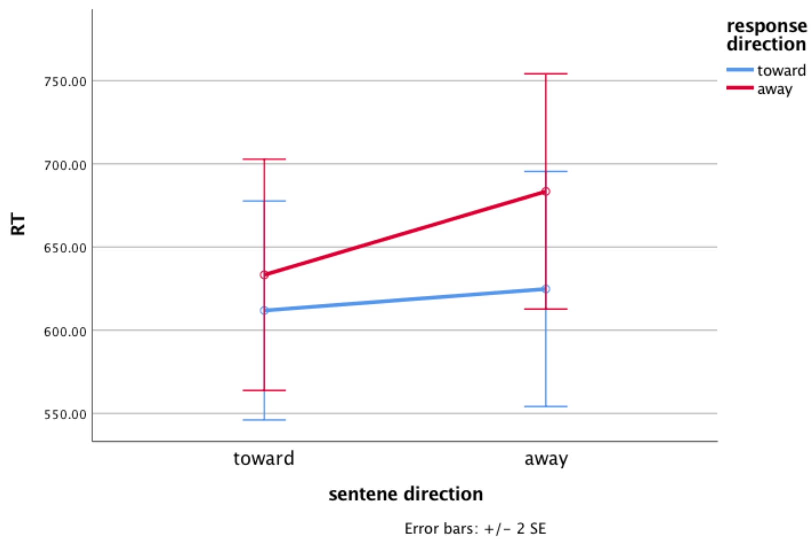


Figure 12. Means and standard errors for the sensibility judgment task in swallow-related sentences.

C. 3.2.2.2 Key-press RT controlled results

The key-press RT was controlled for in this analysis to further test whether the ACE was observed after controlling for the key-press RT.

In the non-swallow-related sentence condition, there was no significant pattern difference on RT between sentence direction and response direction, $F\ (1, 23) = 2.48$; $p = .129$; $\eta^2 = .097$ (Figure 13). These results reject the ACE in the non-swallow-related sentence condition. There also was no significant pattern difference on RT between sentence direction and response direction in the swallow sentence condition, after controlling for the key-press RT (Figure 14).

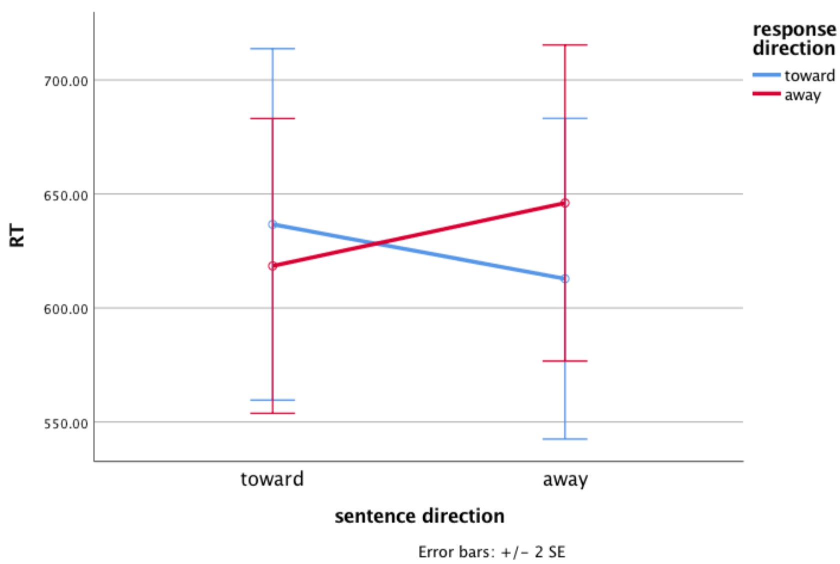


Figure13. Means and standard errors for the sensibility judgment task in non-swallow-related sentences after controlling for key-press RT.

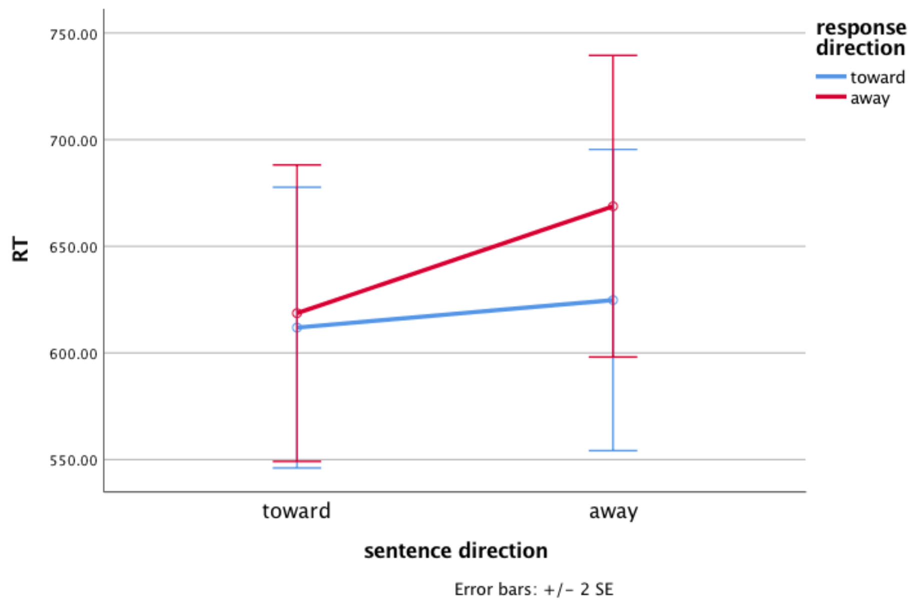


Figure 14. Means and standard errors for the sensibility judgment task in swallow-related sentence condition after controlling for the key-press RT.

C.4 DISCUSSION

By employing the ACE paradigm, the acoustic stimuli validation task attempted to test whether there was a directional relationship between swallow-related action words and direction of hand movement. Two sets of experiments were administered for the task. The experiment 1 employed a five-key response keypad and the experiment 2 used a keyboard and stimuli counterbalanced lists.

The ACE was not observed in the non-swallow-related sentence conditions in the experiment 1 with and without controlling for the key-press reaction time. The experiment 1 failed to replicate the Borreggine and Kaschak (2006) study.

There were some experimental condition differences between the original study and the experiment 1. A response keypad was used in the experiment 1, whereas a keyboard was used in the Borreggine and Kaschak (2006) study. The distance between the white home key and the yellow/red key was shorter on the response keypad (approximately 1.5 cm) than on the keyboard (approximately 8.3 cm). Pressing keys on the response keypad requires less hand/arm movement. Kaschak suggested that "the distance required for key-press response may influence the ACE study results" (Kaschak, personal communication, July 19, 2017). Papesh also indicated that a small arm movement task may interfere with the ACE because it requires less cognitive demand on motor planning compared to a large arm movement task (Papesh, 2015).

Another experimental condition difference was the sentence stimuli presentation method. The stimuli were fully randomized and presented in the experiment 1. In the Borreggine and Kaschak (2006) study, a participant was assigned to one counterbalanced list that contained ¼ of the total number of the sentence stimuli. It was possible that the stimuli overtime produced learning/exposure effect, which may have masked the ACE effect in the experiment 1.

Nevertheless, the experiment 2 with the keyboard and counterbalanced lists also failed to replicate the Borreggine and Kaschak (2006) study. The ACE was not observed in any conditions. The sample size in the experiment 2 was smaller (n=24) than that of the original study (n=42). However, according to the sample size re-calculation by G*power (Faul, Erdfelder, Lang, & Buchener, 2011) with the effect size from the experiment 2 (i.e., $\eta^2 = 0.059$; f=0.328) along with a power of .80, alpha of .05, and the correlation among the repeated measures $\rho = .5$ (required sample size was 10 for a repeated measures within subject ANOVA), there were enough participants in Experiment 2.

The Borreggine and Kaschak (2006) study was a replication and extension of the Glenberg and Kaschak (2002) study in which the ACE was first reported. A number of studies have been able to replicate and extend the Glenberg and Kaschak (2002) study except a recent study by Papesh (2015) (De Scalzi, Rusted, & Oakhill, 2014; Kaschak & Borreggine, 2008; Papesh, 2015; Zwaan, van der Stoep, Guadalupe, & Bouwmeester, 2012). The current results corresponded with data from Papesh (2015).

Papesh (2015) conducted eight experiments with a larger sample size that were replications and extensions of the Glenberg and Kaschak (2002) study but failed to replicate the ACE. Regardless of the instruments (i.e., a keyboard or a mouse) or stimuli (i.e., same sentences from the Glenberg and Kaschak study or new sentences), the interaction between a sentence and movement direction was not observed in any of the eight experiments. Papesh indicated the ACE was weak and elusive. The researcher also speculated that publication bias impacted the current ACE literature. Studies that failed to replicate the ACE likely remained unpublished, and the published ACE studies may represent a limited perspective. The current study added additional evidence to the negative ACE studies.

C.5 CONCLUSION

The study was designed to validate the directionality of the real words used in the main sEMG experiment. By employing the ACE paradigm, the directional relationship between non-swallow-related action words as well as swallow-related action words and hand movement was tested.

However, the ACE was not observed in the non-swallow-related action or the swallow-related action word conditions. Without replicating the ACE in the non-swallow-related action word condition, the directionality of swallow-related action words in the sEMG experiment remains unclear. Further studies are needed to test the directional relationship between swallow-related action words and motor performance.

APPENDIX D

ACOUSTIC STIMULI VALIDATIOAN TASK STIMULI

Non-swallow-related sentences (Borreggine & Kaschak, 2006)			
Direction			
#	Toward	#	Away
1	Alex forked over the cash to you.	1	You forked over the cash to Alex.
2	Andy delivered the pizza to you.	2	You delivered the pizza to Andy.
3	Helen awarded a medal to you.	3	You awarded a medal to Helen.
4	Jack kicked the football to you.	4	You kicked the football to Jack.
5	Vincent donated money to you.	5	You donated money to Vincent.
6	Amber drove the car to you.	6	You drove the car to Amber.
7	Mark dealt the cards to you.	7	You dealt the cards to Mark.
8	Kelly dispensed the rations to you.	8	You dispensed the rations to Kelly.
9	Jeff entrusted the key to you.	9	You entrusted the key to Jeff.
10	Katie handed the puppy to you.	10	You handed the puppy to Katie.
11	Christine bought you ice cream.	11	You bought Christine ice cream.
12	Diane threw you the pen.	12	You threw Diane the pen.
13	Joe kicked you the soccer ball.	13	You kicked Joe the soccer ball.
14	Sally slid you the cafeteria tray.	14	You slid Sally the cafeteria tray.
15	Courtney handed you the notebook.	15	You handed Courtney the notebook.
16	Shawn shot you the rubber band.	16	You shot Shawn the rubber band.
17	Mike rolled you the marble.	17	You rolled Mike the marble.
18	Your dad poured you some water.	18	You poured your dad some water.
19	Heather slipped you a note.	19	You slipped Heather a note.
20	Paul hit you the baseball.	20	You hit Paul the baseball.

Filler sentences (Borreggine & Kaschak, 2006)			
#	Toward	#	Away
1	Al poured the horse to you.	1	You bestowed the message Mike.
2	Amber dealt you the tree.	2	You blew a lesson to Liz.
3	Andrea heard you the chicken.	3	You confessed the tray to John.
4	Brett saw you the bridge.	4	You devoted the song Jenni.
5	Courtney snuggled you the water.	5	You dispensed ice-cream Sandra.
6	Gabe grabbed you to the vase.	6	You drank the house to Joe.
7	Hector played the cake to you.	7	You dreamt your dad a soccer ball.
8	Jack thought you the ice cream.	8	You drove the land to China.
9	Jeff swallowed the cash to you.	9	You forged the chair to George.
10	Jim pretended the stew to you.	10	You gave the earing Susan.
11	Joe sang the cared to you.	11	You lavished the responsibility Dan
12	Katie ate the pizza to you.	12	You pitched the story Andy.
13	Kelly hindered the rubber band to you.	13	You reduced the land to Tiana.
14	Mark treated you the car.	14	You saw the cow the baseball.
15	Paul followed you the puppy.	15	You sneezed baseball to Shawan.
16	Sally ate you the teacup.	16	You sugared Alex the floor.
17	Sally thought the marble to you.	17	You taught her time to Anna.
18	Sam received cookies to you.	18	You told the kiss to Ian.
19	Theresa smoked you the idea.	19	You transferred the change Steve.
20	Tom slept the marble to you.	20	You wrote Dave to the pencil.
Swallow-related sentences			
#	Toward	#	Away
1	You swallowed a glass of water.	1	You spit out a glass of water.
2	You swallowed a piece of pasta.	2	You spit out a piece of pasta.
3	You ate a slice of pizza.	3	You spewed up a cup of coffee.
4	You ate a chunk of meat.	4	You spewed up a glass of juice.
5	You ingested a medicine pill.	5	You gagged on a medicine pill.
6	You ingested a small bone.	6	You gagged on a small bone.
7	You inhaled the cigarette smoke.	7	You exhaled the cigarette smoke.
8	You inhaled the stale air.	8	You exhaled the stale air.
9	You slurped a bowl of soup.	9	You vomited up a bowl of soup.
10	You slurped a bowl of noodles.	10	You vomited up a bowl of noodles.
11	You drank a cup of coffee.	11	You coughed from a cold.
12	You drank a glass of juice.	12	You coughed up the mucus.

13	You chugged a bottle of beer.	13	You blew out the candles on the cake.
14	You chugged a glass of water.	14	You blew the dust off.
15	You gulped a glass of milk.	15	You whistled for your dog.
16	You gulped a bottle of soda.	16	You whistled an old song.
17	You sipped a cup of green tea.	17	You sneezed from the pollen.
18	You sipped a glass of champagne.	18	You sneezed in the library.
19	You gobbled down a hotdog.	19	You threw up a hotdog.
20	You gobbled down a sandwich.	20	You threw up a sandwich.
Practice sentences (Borreggine & Kaschak, 2006)			
#	Sensible	#	Non-sensible
1	City highways are often busy.	1	Bread baked the oven.
2	Flowers bloom in the springtime.	2	Cows pastured in the graze
3	He graduated from college.	3	The basket gathered in the fruit.
4	People usually sleep at night.	4	The food bought the people.
5	The boy raced the dog.	5	The holiday fell off the door.
6	The clerk rang up the items.	6	The home followed me cats.
7	The English have tea time.	7	The shelves dusted the maid.
8	The store opens at nine.	8	The wall hung on the picture.
9	The weather is sunny today.	9	Walls adorned her posters.

APPENDIX E

ACOUSTIC STIMULI VALIDATIOAN TASK STIMULI DURATION

#	Sentence type	Average RMS	File duration (sec)	Sentence duration (sec)	Syllable #	Estimated average sentence duration by native American English speakers (sec)					
						1SD-	1SD+	1.5SD-	1.5SD+	2SD-	2SD+
Non-swallow-related sentences											
1	Alex forked over the cash to you.	-25.00	1.802	1.76	8	1.75	2.46	1.67	2.26	1.60	2.40
2	Amber drove the car to you.	-25.00	1.350	1.31	6	1.31	1.85	1.25	1.69	1.20	1.80
3	Andy delivered the pizza to you.	-25.00	1.840	1.80	9	1.97	2.77	1.88	2.54	1.80	2.70
4	Christine bought you ice cream.	-25.00	1.557	1.52	6	1.31	1.85	1.25	1.69	1.20	1.80
5	Courtney handed you the notebook.	-25.00	1.795	1.76	8	1.75	2.46	1.67	2.26	1.60	2.40
6	Diane threw you the pen.	-25.00	1.354	1.31	6	1.31	1.85	1.25	1.69	1.20	1.80
7	Heather slipped you a note.	-25.00	1.494	1.45	6	1.31	1.85	1.25	1.69	1.20	1.80
8	Helen awarded a medal to you.	-25.00	2.036	2.00	10	2.18	3.08	2.09	2.82	2.00	3.00
9	Jeff entrusted the key to you.	-25.00	1.628	1.59	7	1.53	2.15	1.46	1.98	1.40	2.10

10	Joe kicked you the soccer ball.	-25.00	1.570	1.53	7	1.53	2.15	1.46	1.98	1.40	2.10
11	Katie handed the puppy to you.	-25.00	1.573	1.53	6	1.31	1.85	1.25	1.69	1.20	1.80
12	Kelly dispensed the rations to you.	-25.00	1.961	1.92	8	1.75	2.46	1.67	2.26	1.60	2.40
13	Mark dealt the cards to you.	-25.00	1.569	1.53	5	1.09	1.54	1.04	1.41	1.00	1.50
14	Mike rolled you the marble.	-25.00	1.369	1.33	6	1.31	1.85	1.25	1.69	1.20	1.80
15	Paul hit you the baseball.	-25.00	2.498	1.46	6	1.31	1.85	1.25	1.69	1.20	1.80
16	Shawn shot you the rubber band.	-25.00	1.740	1.70	7	1.53	2.15	1.46	1.98	1.40	2.10
17	Vincent donated money to you.	-25.00	1.772	1.75	8	1.75	2.46	1.67	2.26	1.60	2.40
18	You awarded a medal to Helen.	-25.00	1.856	1.82	9	2.18	2.67	2.09	2.82	1.80	2.70
19	You bought Christine ice cream.	-25.00	1.640	1.60	6	1.31	1.60	1.25	1.69	1.20	1.80
20	You dealt the cards to Mark.	-25.00	1.529	1.49	6	1.31	1.60	1.25	1.69	1.20	1.80
21	You delivered the pizza to Andy.	-25.00	2.040	2.00	10	2.18	2.67	2.09	2.82	2.00	3.00
22	You dispensed the rations to Kelly.	-25.00	2.007	1.97	9	1.97	2.40	1.88	2.54	1.80	2.70
23	You donated money to Vincent.	-25.00	1.915	1.88	9	1.97	2.40	1.88	2.54	1.80	2.70
24	You drove the car to Amber.	-25.00	1.597	1.56	7	1.53	1.87	1.46	1.98	1.40	2.10
25	You entrusted the key to Jeff.	-25.00	1.960	1.92	8	1.75	2.13	1.67	2.26	1.60	2.40
26	You forked over the cash to Alex.	-25.00	2.140	2.10	9	1.97	2.40	1.88	2.54	1.80	2.70
27	You handed Courtney the notebook.	-25.00	1.785	1.75	8	1.75	2.13	1.67	2.26	1.60	2.40
28	You handed the puppy to Katie.	-25.00	1.895	1.85	9	1.97	2.40	1.88	2.54	1.80	2.70
29	You hit Paul the baseball.	-25.00	1.624	1.58	6	1.31	1.60	1.25	1.69	1.20	1.80
30	You kicked Joe the soccer ball.	-25.00	1.620	1.58	7	1.53	1.87	1.46	1.98	1.40	2.10
31	You kicked the football to Jack.	-25.00	1.696	1.66	7	1.53	1.87	1.46	1.98	1.40	2.10
32	You poured your dad some water.	-25.00	1.855	1.82	7	1.53	1.87	1.46	1.98	1.40	2.10
33	You rolled Mike the marble.	-25.00	1.490	1.45	6	1.31	1.60	1.25	1.69	1.20	1.80
34	You shot Shawn the rubber band.	-25.00	1.740	1.70	7	1.53	1.87	1.46	1.98	1.40	2.10
35	You slid Sally the cafeteria tray.	-25.00	2.294	2.25	11	2.40	2.93	2.30	3.11	2.20	3.30
36	You slipped Heather a note.	-25.00	1.556	1.52	6	1.31	1.60	1.25	1.69	1.20	1.80

37	You threw Diane the pen.	-24.95	1.440	1.40	6	1.31	1.60	1.25	1.69	1.20	1.80
38	Your dad poured you some water.	-25.00	1.590	1.55	7	1.53	2.15	1.46	1.98	1.40	2.10
39	Sally slid you the cafeteria tray.	-25.00	2.442	2.40	11	2.40	3.38	2.30	3.11	2.20	3.30
40	Jack kicked the football to you.	-25.00	1.571	1.53	7	1.53	2.15	1.46	1.98	1.40	2.10
Filler sentences											
1	Al poured the horse to you.	-25.00	1.574	1.53	6	1.31	1.60	1.25	1.69	1.20	1.80
2	Amber dealt you the tree.	-25.00	1.380	1.34	6	1.31	1.60	1.25	1.69	1.20	1.80
3	Andrea heard you the chicken.	-25.00	1.785	1.75	8	1.75	2.13	1.67	2.26	1.60	2.40
4	Brett saw you the bridge.	-25.00	1.371	1.33	5	1.09	1.33	1.04	1.41	1.00	1.50
5	Courtney snuggled you the water.	-25.00	1.854	1.81	8	1.75	2.13	1.67	2.26	1.60	2.40
6	Gabe grabbed you to the vase.	-25.00	1.560	1.52	6	1.31	1.60	1.25	1.69	1.20	1.80
7	Hector played the cake to you.	-25.00	1.669	1.63	7	1.53	1.87	1.46	1.98	1.40	2.10
8	Jack thought you the ice cream.	-25.00	1.635	1.60	6	1.31	1.60	1.25	1.69	1.20	1.80
9	Jeff swallowed the cash to you.	-25.00	1.674	1.63	7	1.53	1.87	1.46	1.98	1.40	2.10
10	Jim pretended the stew to you.	-25.00	1.884	1.84	8	1.75	2.13	1.67	2.26	1.60	2.40
11	Joe sang the cared to you.	-25.00	1.608	1.57	6	1.31	1.60	1.25	1.69	1.20	1.80
12	Katie ate the pizza to you.	-25.00	1.792	1.75	8	1.75	2.13	1.67	2.26	1.60	2.40
13	Kelly hindered the rubber band to you.	-25.00	2.175	2.14	10	2.18	2.67	2.09	2.82	2.00	3.00
14	Mark treated you the car.	-25.00	1.375	1.34	6	1.31	1.60	1.25	1.69	1.20	1.80
15	Paul followed you the puppy.	-25.00	1.785	1.75	8	1.75	2.13	1.67	2.26	1.60	2.40
16	Sally ate you the teacup.	-25.00	1.902	1.86	7	1.53	1.87	1.46	1.98	1.40	2.10
17	Sally thought the marble to you.	-25.00	1.794	1.75	8	1.75	2.13	1.67	2.26	1.60	2.40
18	Sam received cookies to you.	-25.00	1.796	1.76	7	1.53	1.87	1.46	1.98	1.40	2.10
19	Theresa smoked you the idea.	-25.00	1.920	1.88	9	1.97	2.40	1.88	2.54	1.80	2.70
20	Tom slept the marble to you.	-25.00	1.670	1.63	7	1.53	1.87	1.46	1.98	1.40	2.10
1	You bestowed the message Mike.	-25.00	1.824	1.78	7	1.53	1.87	1.46	1.98	1.40	2.10
2	You blew a lesson to Liz.	-25.00	1.673	1.63	7	1.53	1.87	1.46	1.98	1.40	2.10
3	You confessed the tray to John.	-25.00	1.867	1.83	7	1.53	1.87	1.46	1.98	1.40	2.10

4	You devoted the song Jenni.	-25.00	1.792	1.75	8	1.75	2.13	1.67	2.26	1.60	2.40
5	You dispensed ice-cream Sandra.	-25.00	1.886	1.85	7	1.53	1.87	1.46	1.98	1.40	2.10
6	You drank the house to Joe.	-25.00	1.640	1.60	6	1.31	1.60	1.25	1.69	1.20	1.80
7	You dreamt your dad a soccer ball.	-25.00	1.702	1.66	7	1.53	1.87	1.46	1.98	1.40	2.10
8	You drove the land to China.	-25.00	1.673	1.63	7	1.53	1.87	1.46	1.98	1.40	2.10
9	You forged the chair to George.	-25.00	1.726	1.69	6	1.31	1.60	1.25	1.69	1.20	1.80
10	You gave the earing Susan.	-25.00	1.666	1.63	7	1.53	1.87	1.46	1.98	1.40	2.10
11	You lavished the responsibility Dan.	-25.00	2.236	2.20	11	2.40	2.93	2.30	3.11	2.20	3.30
12	You pitched the story Andy.	-25.00	1.568	1.53	7	1.53	1.87	1.46	1.98	1.40	2.10
13	You reduced the land to Tiana.	-25.00	1.984	1.94	8	1.75	2.13	1.67	2.26	1.60	2.40
14	You saw the cow the baseball.	-25.00	1.871	1.83	7	1.53	1.87	1.46	1.98	1.40	2.10
15	You sneezed baseball to Shawan.	-25.00	1.921	1.87	7	1.53	1.87	1.46	1.98	1.40	2.10
16	You sugared Alex the floor.	-25.00	1.607	1.57	7	1.53	1.87	1.46	1.98	1.40	2.10
17	You taught her time to Anna.	-25.00	1.640	1.60	7	1.53	1.87	1.46	1.98	1.40	2.10
18	You told the kiss to Ian.	-25.00	1.570	1.53	7	1.53	1.87	1.46	1.98	1.40	2.10
19	You transferred the change Steve.	-25.00	1.640	1.60	6	1.31	1.60	1.25	1.69	1.20	1.80
20	You wrote Dave to the pencil.	-25.00	1.566	1.53	7	1.53	1.87	1.46	1.98	1.40	2.10
Swallow related sentences											
1	You ate a chunk of meat.	-25.00	1.354	1.31	6	1.31	1.60	1.25	1.69	1.20	1.80
2	You ate a slice of pizza.	-25.00	1.567	1.53	7	1.53	1.87	1.46	1.98	1.40	2.10
3	You blew off the dust.	-25.00	1.327	1.29	5	1.09	1.33	1.04	1.41	1.00	1.50
4	You blow out the candles on the cake.	-25.00	1.980	1.94	9	1.97	2.40	1.88	2.54	1.80	2.70
5	You chugged a bottle of soda.	-25.00	1.791	1.75	8	1.75	2.13	1.67	2.26	1.60	2.40
6	You chugged a glass of water.	-25.00	1.592	1.55	7	1.53	1.87	1.46	1.98	1.40	2.10
7	You coughed from a cold.	-25.00	1.336	1.33	5	1.09	1.33	1.04	1.41	1.00	1.50
8	You coughed up the mucus.	-25.00	1.494	1.45	6	1.31	1.60	1.25	1.69	1.20	1.80
9	You drank a cup of coffee.	-25.00	1.567	1.53	7	1.53	1.87	1.46	1.98	1.40	2.10
10	You drank a glass of juice.	-25.00	1.540	1.50	6	1.31	1.60	1.25	1.69	1.20	1.80

11	You exhaled the cigarette smoke.	-25.00	1.801	1.76	8	1.75	2.13	1.67	2.26	1.60	2.40
12	You exhaled the stale air.	-25.00	1.641	1.60	6	1.31	1.60	1.25	1.69	1.20	1.80
13	You gagged on a medicine pill.	-25.00	1.786	1.75	8	1.75	2.13	1.67	2.26	1.60	2.40
14	You gagged on a small bone.	-25.00	1.548	1.51	6	1.31	1.60	1.25	1.69	1.20	1.80
15	You gobbled down a hotdog.	-25.00	1.578	1.54	7	1.53	1.87	1.46	1.98	1.40	2.10
16	You gobbled down a sandwich.	-25.00	1.647	1.61	7	1.53	1.87	1.46	1.98	1.40	2.10
17	You gulped a bottle of beer.	-25.00	1.569	1.53	7	1.53	1.87	1.46	1.98	1.40	2.10
18	You gulped a glass of milk.	-25.00	1.591	1.55	6	1.31	1.60	1.25	1.69	1.20	1.80
19	You ingested a medicine pill.	-25.00	1.845	1.81	9	1.97	2.40	1.88	2.54	1.80	2.70
20	You ingested a small bone.	-25.00	1.698	1.66	7	1.53	1.87	1.46	1.98	1.40	2.10
21	You inhaled the cigarette smoke.	-25.00	1.796	1.76	8	1.75	2.13	1.67	2.26	1.60	2.40
22	You inhaled the stale air.	-25.00	1.598	1.56	6	1.31	1.60	1.25	1.69	1.20	1.80
23	You sipped a cup of green tea.	-25.00	1.883	1.79	7	1.53	1.87	1.46	1.98	1.40	2.10
24	You sipped a glass of champagne.	-25.00	1.795	1.76	7	1.53	1.87	1.46	1.98	1.40	2.10
25	You slurped a bowl of noodles.	-25.00	1.740	1.70	7	1.53	1.87	1.46	1.98	1.40	2.10
26	You slurped a bowl of soup.	-25.00	1.637	1.60	6	1.31	1.60	1.25	1.69	1.20	1.80
27	You sneezed from the pollen.	-25.00	1.532	1.49	6	1.31	1.60	1.25	1.69	1.20	1.80
28	You sneezed in the library.	-25.00	1.585	1.55	7	1.53	1.87	1.46	1.98	1.40	2.10
29	You spewed out a cup of coffee.	-25.00	1.789	1.75	8	1.75	2.13	1.67	2.26	1.60	2.40
30	You spewed out a glass of juice.	-25.00	1.815	1.78	7	1.53	1.87	1.46	1.98	1.40	2.10
31	You spit out a glass of water.	-25.00	1.786	1.75	8	1.75	2.13	1.67	2.26	1.60	2.40
32	You spit out a piece of pasta.	-25.00	1.801	1.76	8	1.75	2.13	1.67	2.26	1.60	2.40
33	You swallowed a glass of water.	-25.00	1.792	1.75	8	1.75	2.13	1.67	2.26	1.60	2.40
34	You swallowed a piece of pasta.	-25.00	1.778	1.75	8	1.75	2.13	1.67	2.26	1.60	2.40
35	You threw up a hotdog.	-25.00	1.398	1.36	6	1.31	1.60	1.25	1.69	1.20	1.80
36	You threw up a sandwich.	-25.00	1.459	1.42	6	1.31	1.60	1.25	1.69	1.20	1.80
37	You vomited up a bowl of noodles.	-25.00	1.840	1.8	9	1.97	2.40	1.88	2.54	1.80	2.70
38	You vomited up a bowl of soup.	-25.00	1.800	1.76	8	1.75	2.13	1.67	2.26	1.60	2.40

39	You whistled an old song.	-25.00	1.367	1.33	6	1.31	1.60	1.25	1.69	1.20	1.80
40	You whistled for your dog.	-25.00	1.440	1.40	6	1.31	1.60	1.25	1.69	1.20	1.80
Practice-sensible											
1	City highways are often busy.	-25.00	1.920	1.88	9	1.97	2.40	1.88	2.54	1.80	2.70
2	Flowers bloom in the springtime.	-25.00	1.776	1.73	7	1.53	1.87	1.46	1.98	1.40	2.10
3	He graduated from college.	-25.00	1.794	1.75	8	1.75	2.13	1.67	2.26	1.60	2.40
4	People usually sleep at night.	-25.00	1.838	1.80	8	1.75	2.13	1.67	2.26	1.60	2.40
5	The boy raced the dog.	-25.00	1.372	1.33	5	1.09	1.33	1.04	1.41	1.00	1.50
6	The clerk rang up the items.	-25.00	1.840	1.80	7	1.53	1.87	1.46	1.98	1.40	2.10
7	The English have tea time.	-25.00	1.501	1.46	6	1.31	1.60	1.25	1.69	1.20	1.80
8	The store opens at nine.	-25.00	1.370	1.33	5	1.09	1.33	1.04	1.41	1.00	1.50
9	The weather is sunny today	-25.00	1.635	1.82	8	1.75	2.13	1.67	2.26	1.60	2.40
Practice-non-sensible											
1	Bread baked the oven.	-25.00	1.271	1.23	5	1.09	1.33	1.04	1.41	1.00	1.50
2	Cows pastured in the graze	-25.00	1.626	1.59	6	1.31	1.60	1.25	1.69	1.20	1.80
3	The basket gathered in the fruit.	-25.00	1.837	1.80	8	1.75	2.13	1.67	2.26	1.60	2.40
4	The food bought the people.	-25.00	1.390	1.35	6	1.31	1.60	1.25	1.69	1.20	1.80
5	The holiday fell off the door.	-25.00	1.923	1.81	9	1.97	2.40	1.88	2.54	1.80	2.70
6	The home followed me cats.	-25.00	1.919	1.60	6	1.31	1.60	1.25	1.69	1.20	1.80
7	The shelves dusted the maid.	-25.00	1.638	1.60	6	1.31	1.60	1.25	1.69	1.20	1.80
8	The wall hung on the picture	-25.00	1.566	1.53	7	1.53	1.87	1.46	1.98	1.40	2.10
9	Walls adorned her posters.	-25.00	1.641	1.60	6	1.31	1.60	1.25	1.69	1.20	1.80

APPENDIX F

ACOUSTIC STIMULI VALIDATIOAN TASK STIMULI COUNTERBALANCE LIST

F.1.1 List 1

#	**Non-swallow-related sentences**	Sentence direction	Response direction
1	Alex forked over the cash to you.	T	T
2	Andy delivered the pizza to you.	T	T
3	Helen awarded a medal to you.	T	T
4	Jack kicked the football to you.	T	T
5	Vincent donated money to you.	T	T
6	Shawn shot you the rubber band.	T	A
7	Mike rolled you the marble.	T	A
8	Your dad poured you some water.	T	A
9	Heather slipped you a note.	T	A
10	Paul hit you the baseball.	T	A
11	You bought Christine ice cream.	A	T
12	You threw Diane the pen.	A	T
13	You kicked Joe the soccer ball.	A	T
14	You slid Sally the cafeteria tray.	A	T
15	You handed Courtney the notebook.	A	T
16	You drove the car to Amber.	A	A
17	You dealt the cards to Mark.	A	A
18	You dispensed the rations to Kelly.	A	A
19	You entrusted the key to Jeff.	A	A
20	You handed the puppy to Katie.	A	A
	Filler sentences	Sentence direction	Response direction
1	Al poured the horse to you.	T	T
2	Amber dealt you the tree.	T	T

3	Andrea heard you the chicken.	T	T
4	Brett saw you the bridge.	T	T
5	Courtney snuggled you the water.	T	T
6	Sally ate you the teacup.	T	A
7	Sally thought the marble to you.	T	A
8	Sam received cookies to you.	T	A
9	Theresa smoked you the idea.	T	A
10	Tom slept the marble to you.	T	A
11	You lavished the responsibility Dan.	A	A
12	You pitched the story Andy.	A	A
13	You reduced the land to Tiana.	A	A
14	You saw the cow the baseball.	A	A
15	You sneezed baseball to Shawan.	A	A
16	You drank the house to Joe.	A	T
17	You dreamt your dad a soccer ball.	A	T
18	You drove the land to China.	A	T
19	You forged the chair to George.	A	T
20	You gave the earing Susan.	A	T
	Swallow related sentences	Sentence direction	Response direction
1	You swallowed a glass of water.	T	T
2	You swallowed a piece of pasta.	T	T
3	You ate a slice of pizza.	T	T
4	You ate a chunk of meat.	T	T
5	You ingested a medicine pill.	T	T
6	You gulped a bottle of beer.	T	A
7	You sip a cup of green tea.	T	A
8	You sipped a glass of champagne.	T	A
9	You gobbled down hotdog.	T	A
10	You gobbled down a sandwich.	T	A
11	You coughed from a cold.	A	T
12	You coughed up the mucus.	A	T
13	You blew candles on the cake.	A	T
14	You blew the dust off.	A	T
15	You whistled for your dog.	A	T
16	You gagged on a small bone.	A	A
17	You exhaled the cigarette smoke.	A	A
18	You exhaled the stale air.	A	A
19	You vomited a bowl of soup.	A	A
20	You vomited a bowl of noodles.	A	A

F.1.2 List 2

#	**Non-swallow-related sentences**	Sentence direction	Response direction
1	Amber drove the car to you.	T	T
2	Mark dealt the cards to you.	T	T
3	Kelly dispensed the rations to you.	T	T
4	Jeff entrusted the key to you.	T	T
5	Katie handed the puppy to you.	T	T
6	Alex forked over the cash to you.	T	A
7	Andy delivered the pizza to you.	T	A
8	Helen awarded a medal to you.	T	A
9	Jack kicked the football to you.	T	A
10	Vincent donated money to you.	T	A
11	You shot Shawn the rubber band.	A	T
12	You rolled Mike the marble.	A	T
13	You poured your dad some water.	A	T
14	You slipped Heather a note.	A	T
15	You hit Paul the baseball.	A	T
16	You bought Christine ice cream.	A	A
17	You threw Diane the pen.	A	A
18	You kicked Joe the soccer ball.	A	A
19	You slid Sally the cafeteria tray.	A	A
20	You handed Courtney the notebook.	A	A
#	**Filler sentences**	Sentence direction	Response direction
1	Gabe grabbed you to the vase.	T	T
2	Hector played the cake to you.	T	T
3	Jack thought you the ice cream.	T	T
4	Jeff swallowed the cash to you.	T	T
5	Jim pretended the stew to you.	T	T
6	Al poured the horse to you.	T	A
7	Amber dealt you the tree.	T	A
8	Andrea heard you the chicken.	T	A
9	Brett saw you the bridge.	T	A
10	Courtney snuggled you the water.	T	A
11	You sugared Alex the floor.	A	A
12	You taught her time to Anna.	A	A
13	You told the kiss to Ian.	A	A
14	You transferred the change Steve.	A	A
15	You wrote Dave to the pencil.	A	A
16	You lavished the responsibility Dan.	A	T

17	You pitched the story Andy.	A	T
18	You reduced the land to Tiana.	A	T
19	You saw the cow the baseball.	A	T
20	You sneezed baseball to Shawan.	A	T
#	**Swallow related sentences**	Sentence direction	Response direction
1	You ingested a small bone.	T	T
2	You inhaled the cigarette smoke.	T	T
3	You inhaled the stale air.	T	T
4	You slurped a bowl of soup.	T	T
5	You slurped a bowl of noodles.	T	T
6	You swallowed a glass of water.	T	A
7	You swallowed a piece of pasta.	T	A
8	You ate a slice of pizza.	T	A
9	You ate a chunk of meat.	T	A
10	You ingested a medicine pill.	T	A
11	You whistled an old song.	A	T
12	You sneezed from the pollen.	A	T
13	You sneezed in the library.	A	T
14	You threw up a hotdog.	A	T
15	You threw up a sandwich.	A	T
16	You coughed from a cold.	A	A
17	You coughed up the mucus.	A	A
18	You blew candles on the cake.	A	A
19	You blew the dust off.	A	A
20	You whistled for your dog.	A	A

F.1.3 List 3

#	**Non-swallow-related sentences**	Sentence direction	Response direction
1	Christine bought you ice cream.	T	T
2	Diane threw you the pen.	T	T
3	Joe kicked you the soccer ball.	T	T
4	Sally slid you the cafeteria tray.	T	T
5	Courtney handed you the notebook.	T	T
6	Amber drove the car to you.	T	A
7	Mark dealt the cards to you.	T	A
8	Kelly dispensed the rations to you.	T	A
9	Jeff entrusted the key to you.	T	A
10	Katie handed the puppy to you.	T	A

11	You forked over the cash to Alex.	A	T
12	You delivered the pizza to Andy.	A	T
13	You awarded a medal to Helen.	A	T
14	You kicked the football to Jack.	A	T
15	You donated money to Vincent.	A	T
16	You shot Shawn the rubber band.	A	A
17	You rolled Mike the marble.	A	A
18	You poured your dad some water.	A	A
19	You slipped Heather a note.	A	A
20	You hit Paul the baseball.	A	A
#	**Filler sentences**	Sentence direction	Response direction
1	Joe sang the cared to you.	T	T
2	Katie ate the pizza to you.	T	T
3	Kelly hindered the rubber band to you.	T	T
4	Mark treated you the car.	T	T
5	Paul followed you the puppy.	T	T
6	Gabe grabbed you to the vase.	T	A
7	Hector played the cake to you.	T	A
8	Jack thought you the ice cream.	T	A
9	Jeff swallowed the cash to you.	T	A
10	Jim pretended the stew to you.	T	A
11	You bestowed the message Mike.	A	A
12	You blew a lesson to Liz.	A	A
13	You confessed the tray to John.	A	A
14	You devoted the song Jenni.	A	A
15	You dispensed ice-cream Sandra.	A	A
16	You sugared Alex the floor.	A	T
17	You taught her time to Anna.	A	T
18	You told the kiss to Ian.	A	T
19	You transferred the change Steve.	A	T
20	You wrote Dave to the pencil.	A	T
#	**Swallow related sentences**	Sentence direction	Response direction
1	You drank a cup of coffee.	T	T
2	You drank a glass of juice.	T	T
3	You chugged a bottle of soda.	T	T
4	You chugged a glass of water.	T	T
5	You gulped a glass of milk.	T	T
6	You ingested a small bone.	T	A
7	You inhaled the cigarette smoke.	T	A
8	You inhaled the stale air.	T	A
9	You slurped a bowl of soup.	T	A

10	You slurped a bowl of noodles.	T	A
11	You spit out a glass of water.	A	T
12	You spit out a piece of pasta.	A	T
13	You spewed a slice of pizza.	A	T
14	You spewed up a chunk of meat.	A	T
15	You gagged on a medicine pill.	A	T
16	You whistled an old song.	A	A
17	You sneezed from the pollen.	A	A
18	You sneezed in the library.	A	A
19	You threw up a hotdog.	A	A
20	You threw up a sandwich.	A	A

F.1.4 List 4

#	**Non-swallow-related sentences**	Sentence direction	Response direction
1	Shawn shot you the rubber band.	T	T
2	Mike rolled you the marble.	T	T
3	Your dad poured you some water.	T	T
4	Heather slipped you a note.	T	T
5	Paul hit you the baseball.	T	T
6	Christine bought you ice cream.	T	A
7	Diane threw you the pen.	T	A
8	Joe kicked you the soccer ball.	T	A
9	Sally slid you the cafeteria tray.	T	A
10	Courtney handed you the notebook.	T	A
11	You drove the car to Amber.	A	T
12	You dealt the cards to Mark.	A	T
13	You dispensed the rations to Kelly.	A	T
14	You entrusted the key to Jeff.	A	T
15	You handed the puppy to Katie.	A	T
16	You forked over the cash to Alex.	A	A
17	You delivered the pizza to Andy.	A	A
18	You awarded a medal to Helen.	A	A
19	You kicked the football to Jack.	A	A
20	You donated money to Vincent.	A	A
#	**Filler sentences**	Sentence direction	Response direction
1	Sally ate you the teacup.	T	T
2	Sally thought the marble to you.	T	T
3	Sam received cookies to you.	T	T

4	Theresa smoked you the idea.	T	T
5	Tom slept the marble to you.	T	T
6	Joe sang the cared to you.	T	A
7	Katie ate the pizza to you.	T	A
8	Kelly hindered the rubber band to you.	T	A
9	Mark treated you the car.	T	A
10	Paul followed you the puppy.	T	A
11	You drank the house to Joe.	A	A
12	You dreamt your dad a soccer ball.	A	A
13	You drove the land to China.	A	A
14	You forged the chair to George.	A	A
15	You gave the earing Susan.	A	A
16	You bestowed the message Mike.	A	T
17	You blew a lesson to Liz.	A	T
18	You confessed to tray to John.	A	T
19	You devoted the song Jenni.	A	T
20	You dispensed ice-cream Sandra.	A	T
#	**Swallow related sentences**	Sentence direction	Response direction
1	You gulped a bottle of beer.	T	T
2	You sipped a cup of green tea.	T	T
3	You sipped a glass of champagne.	T	T
4	You gobbled down a hotdog.	T	T
5	You gobbled down a sandwich.	T	T
6	You drank a cup of coffee.	T	A
7	You drank a glass of juice.	T	A
8	You chugged a bottle of soda.	T	A
9	You chugged a glass of water.	T	A
10	You gulped a glass of milk.	T	A
11	You gagged on a small bone.	A	T
12	You exhaled the cigarette smoke.	A	T
13	You exhaled the stale air.	A	T
14	You vomited a bowl of soup.	A	T
15	You vomited a bowl of noodles.	A	T
16	You spit out a glass of water.	A	A
17	You spit out a piece of pasta.	A	A
18	You spewed a slice of pizza.	A	A
19	You spewed up a chunk of meat.	A	A
20	You gagged on a medicine pill.	A	A

APPENDIX G

SEMG ONSET MEASURE RULES

G.1.1 sEMG wave form

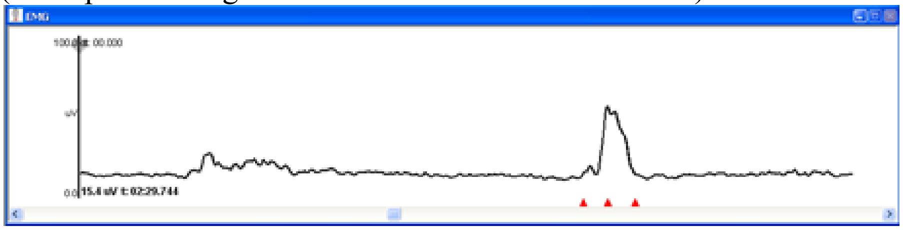
According to Vaiman & Eviatar (2009), sEMG signal for a swallow can be divided into the three sections which are: mild elevation of the line, rapid voltage line elevation, and rapid descent line.

G.1.2 sEMG wave form type

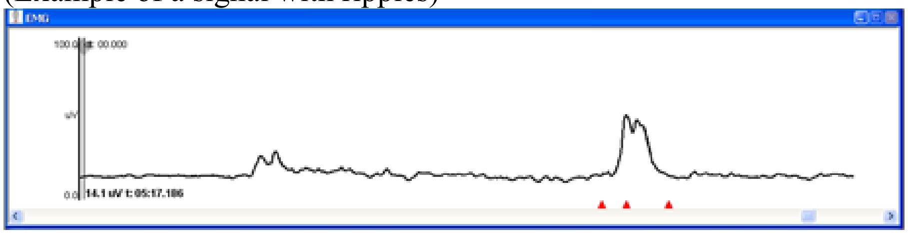
I. signal only without a mild elevation line
II. signal with a mild elevation line
III. signal with ripple(s) before a mild elevation and/or rapid voltage line elevation
IV. signal with a mild descent line after the rapid voltage line elevation

(Example of a signal without a mild elevation of the line)

(Examples of a signal with a mild elevation of the line)



(Example of a signal with ripples)



G.1.3 sEMG onset rules

- Take the point where the sEMG signal goes 2 *SD* above the baseline mean amplitude.
- Take the point where the signal goes above the baseline mean amplitude that leads to the continuous upward excursion on the signal.
- If there is/are ripple(s) before the mild elevation and/or rapid voltage line elevation, do not include the ripples.
- If the ripple(s) is/are above 2 *SD* baseline, include the ripples.
- If there is a mild elevation of the line before a rapid voltage line elevation, take the mild elevation of the line as the onset of the leading events of swallowing (Martin, Logemann, Shaker, & Dodds, 1994).
- Take the 2 *SD* point in the mild elevation event if sEMG goes below 2 *SD* between the mild elevation and the rapid line elevation.

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