# COGNITION IN SWALLOWING: IS ATTENTION INVOLVED?

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This study examined the hypothesis that cognitive resources may be involved in swallowing. The approach involved a dual-task, reaction time (RT) paradigm with 10 healthy, non-impaired (NI) control participants and 10 participants in early to middle stages of Parkinson's disease (PD). First, baseline measures were obtained for durations of anticipatory phase and oropharyngeal phase during swallowing and RTs to non-word, auditory stimuli. Next, a dual-task was introduced requiring participants to swallow 5 ml of water from a cup while listening for a target non-word presented auditorily during anticipatory or oropharyngeal phases. Target stimuli were randomized across 19 baseline/single-task and 19 dual-task trials. For the single-task data, repeated measures analyses of variance were used to assess differences in (a) durations of the anticipatory phase across trials within and between participant groups; (b) durations of the oropharyngeal phase across trials within and between participant groups; and (c) durations of reaction times across trials within and between groups. For the dual-task data, analyses of variance were used to assess differences in (a) durations of the anticipatory phase between baseline/single-task and dual-task conditions; (b) durations of the oropharyngeal phase between baseline/single-task and dual-task conditions; and (c) durations of reaction times between baseline/single-task and dual-task conditions for each of the two swallowing phases. Results showed slowed swallowing and RTs in participants with PD compared to controls in both anticipatory and oropharyngeal phases of swallowing. This effect was largely carried by participants in more severe, mid-stage disease as compared to early disease. The anticipatory phase was more affected than the oropharyngeal phase, suggesting that cognitive demands may be greater for that phase. Swallowing durations were similar for NIs and participants in early stage PD, underscoring the strength and persistent nature of swallowing.

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# PREFACE

The course of my academic program and the evolution and duration of my dissertation, though frustrating by themselves, have truly been a blessing in disguise. In hindsight, these delays enabled me to meet so many wonderful people throughout these 8 years that it seems hardly proper to thank them in the several paragraphs that follow. Many remain as close friends and colleagues, others have moved on to wonderful lives in other places, but *all* have shaped my thinking and added to my experience as a student, a professional, and a human being. For the time spent with you—all of you—I am truly grateful.

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# I. INTRODUCTION

In humans, swallowing is a complex set of events fundamental to survival and quality of life. Swallowing is classically viewed as reflexive, vegetative, and/or automatic. Probably because of this view, little, if any, attention has been paid to the role of cognition in swallowing. The situation is somewhat paradoxical, because behavioral therapy—which is the primary intervention modality for swallowing problems—ultimately rests on some level of cognitive manipulation. The present study addresses this paradox by exploring the possible role of cognition in swallowing. Specifically, the study addresses cognitive resources that may be involved in swallowing. The findings should be relevant for therapy models in dysphagia, especially for individuals with cognitive deficits and/or motor dysfunction.

The introduction is divided into the following sections: (a) overview of phases of swallowing; (b) discussion of cognition and its possible role in swallowing; (c) how fundamental cognitive processes and resources can be measured in swallowing; and (d) outline of experimental questions and hypotheses.

## A. PHASES OF SWALLOWING

Swallowing generally is considered a complex neuromuscular event. Magendie (1822) noted:

> If we judge of the importance of a function, from the number and variety of the organs which concur to effect it, digestion will occupy the first rank. No other function in the animal economy presents an apparatus so complicated (pp. 177-178).

He continued, "Though apparently simple, deglutition is by far the most complicated of all the muscular actions, which assist in digestion" (p. 201).

In fact, the origins of the now classic phase model of swallowing can be traced to Magendie (1822). For descriptive purposes, Magendie separated deglutition, or swallowing, into three phases. Although he never named them, these phases are now universally recognized as the oral, pharyngeal, and esophageal phases of swallowing. Although labels have been given to each of these parts of the swallow for explanatory and/or diagnostic purposes, they are neither discrete nor isolated from each other. Events in one phase can impact events in another phase, ultimately affecting the physiology of the whole swallow. Videofluorographic and electromyographic (EMG) studies have provided evidence to this effect, by elucidating the overlapping nature of many events in swallowing (Cook et al., 1989; Doty & Bosma, 1956; Ertekin et al., 2001; Kendall, McKenzie, Leonard, Goncalves, & Walker, 2000; Leonard, Kendall, McKenzie, Goncalves, & Walker, 2000; Martin, 1991; Martin, Logemann, Shaker, & Dodds, 1994; Martin-Harris, Michel, & Castell, 2005; McKeown, Torpey, & Gehm, 2002; Perlman, Palmer, McCulloch, & Vandaele, 1999).

Assuming for a moment a simplified, linear model, the oral phase of swallowing classically is considered to involve chewing, mashing, and chemically breaking down food, and preparing a cohesive bolus (ball of food) for propulsion further into the digestive system. Then, still in the oral phase, the food is placed on the tongue blade, awaiting transmission up and back towards the pharynx. The pharyngeal phase of swallowing involves the passage of the bolus from the posterior oral cavity through the pharynx and into the cervical esophagus. Finally, the esophageal phase involves bolus transport from the cervical entrance of the esophagus to the entrance into the stomach.

Leopold and Kagel (1983) suggested that such a simple model fails to sufficiently consider "voluntary aspects of ingestion" (p. 371), especially as these apply clinically. Instead of one oral phase encompassing both the preparation and the transit of the bolus, these authors distinguished between "preparatory" and "lingual" phases, respectively. Empirical research has shown that this distinction is useful clinically. Bolus preparation and bolus transport may affect patients independently or concomitantly (e.g., Lazarus & Logemann, 1987; Willig, Paulus, Saint Guily, Béon & Navarro, 1994). Since the time of Leopold and Kagel's 1983 publication, clinicians have routinely distinguished between these phases, referring to them as "oral preparatory" and "oral" phases of the swallow. Although the phases were identified to address voluntary aspects of swallowing, oddly, there remains a paucity of information in the literature regarding specific cognitive factors associated with either of the phases. Instead, research has focused on physical factors in the oral phase of swallowing, including bolus characteristics (Dantas et al., 1990), the aerodigestive system's response to bolus characteristics (Adnerhill, Ekberg, & Groher, 1989; Bisch, Logemann, Rademaker, Kahrilas, & Lazarus, 1994; Hamlet et al., 1996; Hiiemae & Palmer, 1999; Logemann et al., 1995; Miller & Watkin, 1996; Raut, McKee, & Johnston, 2001; Stachler et al., 1994; Wintzen, Badrising, Roos, Vielvoye, & Liauw, 1994), aging and age effects (Hind, Nicosia, Boecker, Carnes, & Robbins, 2001; Hiss, Treole, & Stuart, 2001; Robbins, 1996; Robbins, Hamilton, Lof, and Kempster, 1992; Shaker & Lang, 1994; Shaker et al., 1994; Sonies, Parent, Morrish, & Baum, 1988; Tracy et al., 1989), the coordination of respiration with swallowing (Gross, Atwood, Grayhack, & Shaiman, 2003; Hiss et al., 2001; Martin, 1991; Martin et al. 1994; Martin-Harris et al., 1999; Martin-Harris, Brodsky, Price, Michel, & Walters, 2003; Martin-Harris, Brodsky, et al., 2005; Perlman, Ettema, & Barkmeier, 2000; Preiksaitis & Mills, 1996; Shaker, Dodds, Dantas, Hogan, & Arndorfer, 1990), and timing of events related to swallowing (Cook et al., 1989; Doty & Bosma, 1956; Ertekin et al., 2001; Kendall et al., 2000; Perlman et al., 1999).

Some researchers have suggested there is value to identifying yet another phase of swallowing. That phase involves all activities that are preparatory to the direct introduction of food or liquid into the mouth. Magendie (1822) described this process as "prehension," which he considered quite "simple" (p. 193):

> For this purpose the hands seize the food, and divide it into small portions, capable of being contained in the mouth, and then introduce it into this cavity, perhaps, by the assistance of instruments convenient for this purpose (p. 193).

Despite the apparent simplicity of this phase, Magendie did describe the way the jaws need to open relative to the volume and type of food or drink introduced, and the utensil chosen for the job. He also described the manner in which the hands assist if the muscles of the jaws are not adequate to separate the food (e.g., biting into a stick of taffy).

Until recently, acts preceding swallowing have been largely ignored in the literature. Although they never cited Magendie's (1822) notions of prehension, Leopold and Kagel (1983, 1997a) reintroduced the general concept to the literature and labeled it the "anticipatory phase." Occurring first in the now theorized five phases of swallowing (i.e., anticipatory, oral preparatory, oral, pharyngeal, esophageal), Leopold and Kagel defined the anticipatory phase as the phase involving all preparation of nutritional materials prior to and including their introduction to the mouth, including decisions and physical actions. Specifics include the speed with which food or drink is presented to the mouth and the size of the bolus prepared for intake, both of which impact on meal duration. It would seem clear that this phase involves some level of cognition, yet the role of cognition in it has not been explored, nor has cognition been specifically explored relative to other phases of swallowing.

## B. COGNITION AND ITS POSSIBLE ROLE IN SWALLOWING

Numerous definitions exist in the literature regarding the nature of cognition. Somewhat enigmatically, the famed American psychologist, William James (1890), described cognition as a "thoroughgoing dualism" (p. 218). He further stated:

> It supposes two elements, mind knowing and thing known, and treats them as irreducible. Neither gets out of itself or into the other, neither in any way *is* the other, neither *makes* the other. They just stand face to face in a common world, and one simply knows, or is known unto, its counterpart. This singular relation is not to be expressed in any lower terms, or translated into any more intelligible name. Some sort of *signal* must be given by the thing to the mind's brain, or the knowing will not occur—we find as a matter of fact that the mere, *existence* of a

> thing outside the brain is not a sufficient cause for our knowing it: it must strike the brain in some way, as well as be there, to be known. But the brain being struck, the knowledge is constituted by a new construction that occurs altogether *in* the mind. The thing remains the same whether known or not. And when once there, the knowledge may remain there, whatever becomes of the thing. (pp. 218-219)

Purves (1997), who described cognition as "the process by which we come to know the world" (p. 465), proposed similar notions. In the present investigation, at the broadest level, *cognition* is defined after Schmidt and Lee (1999) as the collection of all unobservable mental processes. More specifically, in the present context, we consider cognition as involving mental processes involved in acquisition, storage, analysis, synthesis, representation, retrieval, response selection, and production of information (expanded from Solso, 1995), and the integration of those processes. Cognitive processes may be conscious or non-conscious, linguistic or non-linguistic. Neurophysiological activity certainly occurs in conjunction with cognition, however such activity is not isomorphic to it. Rather, cognition may be considered an "emergent property" related to neuronal activation (or the reverse), which can only be inferred, not directly observed (e.g., Verdolini, 2006).

Next is a discussion of the possible role of cognition for swallowing. The discussion begins with consideration of the anticipatory phase, which seems the most cognitively demanding in humans.

## 1. Evidence of a role of cognition in the anticipatory phase

From a behavioral standpoint, it is intuitive that cognition should be particularly relevant for the anticipatory phase of swallowing. Clinically, it seems likely that cognitive deficits due to neurogenic disorders such as dementia can disrupt preparatory actions (Leopold & Kagel, 1983, 1997a; Logemann, 1983) for feeding. Also, individuals having cognitive changes such as impulsiveness, altered attention, disinhibition, or poor judgment due to stroke, head injury, or extrapyramidal disease often manifest changes in actions anticipatory to swallowing (Leopold & Kagel, 1997a; McGuire & Rothenberg, 1986; Pimental & Kingsbury, 1989).

Beyond anecdotal clinical speculation, empirical evidence also exists that strongly suggests a role of cognition in the anticipatory phase of swallowing. Much of that evidence has to do with the well-established fact that people and animals salivate prior to ingestion, when food is presented. Widely described in the literature (e.g. Magendie, 1822; Winsor & Blane, 1929; and Pavlov, as cited in Giduck, Threattem & Kare, 1987), this response has been called the "cephalic phase response" (Giduck et al., 1987; Mattes, 1997). Cognition clearly is implicated in such cases; it must be individuals' *interpretation* of the food's "meaning" (i.e., consumable) that mediates the preparatory salivary response. In fact, salivation occurs not only in response to the visual presentation of food (Christensen & Navazesh, 1984), but also in response to the sound, taste, smell, and most notably for our discussion, the *thought* of food (e.g., Epstein, Paluch, & Coleman, 1996; Guinard, Zoumas-Morse, & Walchak, 1998; Lappalainen, Sjödén, Karhunen, Gladh, & Lesinska, 1994).

Interestingly, recent evidence expands on such notions by demonstrating that not all anticipatory physiological responses in swallowing are mediated by the literal presentation of food. Apparently, the anticipation of actually gaining access to food is a critical cognitive mediator for some of those responses. Yamamoto, Matsuo, Kiyomitsu, and Kitamura (1988) made this point using a rat model. Fifty-nine Wistar male rats were trained to drink water in a test box. Several objects were then positioned, in series, in front of the rats: a black, opaque shutter, a transparent shutter, and a drinking tube. When the opaque shutter was removed, the rat could see the drinking tube behind the transparent shutter, but could not access the tube. When the transparent shutter was removed, the rat could obtain the drinking solution. Single-cell recordings from somatosensory and gustatory neurons identified "anticipation" neurons based on the fact that they were active only when the animals could access the drinking tube. Of the 90 neurons sampled, 4 (4.44%) increased their activity greater than 2.5 standard deviations from baseline rate before the start of licking, when the animal expected access to the drinking tube. In contrast, no increase of electrical discharges occurred when the animals had visual but not physical access to the tube. Therefore, visual presentation of the drinking tube was insufficient to activate these anticipatory neurons. The animal's *expectation* of drinking was a critical factor for the activation of these anticipatory neurons. These studies seem to indicate a clear role of cognition on the anticipatory phase of swallowing, at least in rats.

Perhaps the most compelling evidence for a role of cognition in the anticipatory phase of swallowing comes from studies of classical conditioning. The most noted ones were reported by Pavlov (as cited in Giduk et al., 1987). In his now-famous studies, Pavlov first established that dogs indeed salivated when they were presented with food. For numerous trials, Pavlov then paired an arbitrary "bell-ringing" stimulus with the food. He subsequently removed the food, presenting only the conditioned stimulus (bell-ringing). The surprising observation was that the animals continued to salivate when the bell was rung, even when the food was not presented (conditioned response). Clearly, the experiment had induced the animals to forge a cognitive association between the bell and the likelihood that food would be presented. Evidence of this association was seen in the form of salivation, in what is now referred to as the anticipatory phase of swallowing.

More recently, similar findings have been reported for other animals. Mameli and Tolu (1985), Mameli and Melis (1992), Mameli, Melis, and De Riu (1994) conducted a series of studies in rabbits. Based on their previous research as well as the observation that the sight of food can induce reflexes in the tongue, Mameli and Melis used visual inputs in the form of strobe light pulses (in the absence of food) and electrical stimulation to group II afferent radial (forelimb) nerve fibers to determine the effect of those stimuli on hypoglossal nerve function. EMG recordings were then obtained from 118 hypoglossal neurons as light and electrical stimulation were delivered without food. In a parallel experiment in the same series, a second group of rabbits received the same stimulation techniques; however, additional measures of EMG discharges using bipolar electrodes inserted into the genioglossus and superior longitudinal muscles (extrinsic and intrinsic muscles of the tongue, respectively) were obtained to determine peripheral output of the hypoglossal nerve. The combined results showed that 94 hypoglossal neurons (approximately 80%) responded to both visual and forearm stimulation. The remaining 24 hypoglossal neurons (approximately 20%) were stimulated either by visual input or forearm stimulation. When simultaneous visual stimulation to the retina and electrical stimulation to the forelimbs were sent to the hypoglossal neurons, EMG amplitudes in both the intrinsic and extrinsic muscles of the tongue increased significantly. Interestingly, visual stimulation alone resulted in increased activation of the extrinsic muscles of the tongue, however it diminished the response in the intrinsic muscles. Conversely, electrical stimulation of the forelimbs increased

EMG activity for both intrinsic and extrinsic muscles. Clearly, the animals responded physiologically to the combination of visual and somatosensory input. As an aside, 15% of type III hypoglossal neurons responded only to visual stimulation, and 5% of type IV hypoglossal neurons responded only to forearm stimulation. Therefore, peripheral input influenced both general nerve responses in the tongue and as well as neuron-specific. The point is that visual input appeared to predispose the oral cavity for intake, both in terms of preparedness and postural tone of the tongue. These findings are similar to those described by Pavlov (as cited by Giduck et al., 1987) who noted anticipatory salivation in dogs in response to the presentation of a conditioned stimulus.

The classic canine studies by Pavlov (as cited by Gidduck et al., 1987) and more contemporary studies of classical conditioning in rabbits by Mameli and colleagues (1985, 1992, 1994) were recently translated to a human model. Legenbauer, Vögele, and Rüddel (2004) studied women with eating disorders, specifically bulimia nervosa, and women without eating disorders. Following consent procedure and the completion of several questionnaires during the initial meeting, the researchers gave each participant one list containing sweet and savory food items (number of items was not disclosed). Each food item on the list contained a similar number of calories. Participants indicated between 5 and 10 items on the list that were their favorites and frequently consumed. Participants completed a standardized meal (i.e., slice of bread, cheese, and small green salad) 2 hours prior to the experiment in preparation for a second meeting. Participants then entered the laboratory for testing. The researchers recorded physiologic responses to the presentation of food, including heart rate, blood pressure, respiration rate, skin conductance levels, and salivation. These measurements were taken for between 10 and 20 minutes prior to the introduction of food (i.e., baseline). Following these baseline measures, each participant was exposed for 20 minutes to the same food items she chose on the list containing sweet and savory foods. These foods were placed on a rotating tray near the participant's face. During this time, participants were encouraged to view, smell, and touch the food, though eating the food was not allowed. Participants were promised, however, that they could consume as much of the food as they desired for 5 minutes following their 20-minute exposure to the food. After food exposure, participants were then given 5-minutes rest (follow-up). Saliva samples through the use of dental rolls, and mood ratings of tension, desire to binge, well being, distress, sadness, hunger, insecurity, and strain were collected after baseline physiologic measures were obtained, in 5-minute intervals during the 20 minutes of food exposure, and after follow-up. Two additional mood ratings, guilt and shame, were also collected after follow-up. As they pertain to the present discussion, the results from this study showed that salivation levels increased for both groups of participants from baseline through the period of exposure, then returned to baseline levels after follow-up. Participants with bulimia nervosa had a greater increase in salivation when compared to the participants without eating disorders. This level of salivation was sustained over the 6 periods in which saliva was measured (i.e., baseline, four 5-minute intervals during exposure, and after follow-up). In the women who did not have an eating disorder, there was a steady decline in salivation across these 6 periods. These findings extend the animal findings to humans and lend further support to the notion that cognition related to visual, tactile, and olfactory inputs indeed influences the cephalic phase response and that cognition can play a role in the anticipatory phase of swallowing.

Similar to the findings of Legenbauer et al. (2004), Maeda et al. (2004) found that visual input is a significant contributor to the body's preparatory response to food, and specifically, may facilitate the initiation of swallowing. In their study, Maeda et al. recruited seven young adults and restricted their drinking for at least 3 hours before testing. The researchers blocked the subjects' field of vision completely with the exception that they could view a LCD monitor that presented color photographs encouraging a desire to drink (e.g., a glass of beer) or general, everyday items, unrelated to drinking (e.g., a pair of scissors). After being presented with a randomly selected image in one of the two categories, the subject performed a dry swallow to empty the contents of his or her mouth. Within 4 seconds following the first swallow, the subject was tapped on the knee with an impulse hammer as an instruction to swallow a second time, either as a dry swallow (i.e., no presentation of water), or following the administration of a 3-ml water bolus presented by the researchers. Swallowing activity was recorded by surface EMG signals using bipolar electrodes placed over the suprahyoid muscles. Results showed the latency of the second swallow onset and maximum EMG amplitude of the second swallow for water swallows with drink-related images to be significantly less than with general images unrelated to drinking. There was, however, no difference in latency or amplitude for dry swallows, regardless of the type of image presented. The researchers concluded that cognition, in the form of visual input prior to swallowing, might influence, and more specifically assist, the initiation of swallowing, but that cognition may not directly relate to muscle activity. These findings provide further support for the notion that cognition can play a role in the anticipatory phase of swallowing, though the role it plays may be somewhat limited in scope.

In summary, both anecdotal, clinical speculation and empirical studies suggest that cognition affects the anticipatory phase of swallowing. At minimum, cognitive processes involving interpretation ("food might be presented, or is likely to be presented") and expectation ("food is accessible") produce anticipatory physiological responses such as salivation, cortical activation, and possible neuromuscular activation, in laboratory animals. Human studies have shown that visual, tactile, and olfactory inputs invoke cephalic phase responses, suggesting that cognition is involved with the anticipatory phase of swallowing. What is not known is the effect cognition may have in the anticipatory phase of swallowing in humans.

The next section addresses a possible role of cognition in other phases of swallowing. In that discussion, concepts relating to the putative "reflexive," "vegetative," and "automatic" nature of swallowing will be key in examining the possible role of cognition.

**2. Discussion of the possible role of cognition in oral and pharyngeal phases of swallowing**

Debated in the literature are the definitions of certain core constructs that relate to classic, post-anticipatory phases of swallowing, specifically constructs relating to reflexive, vegetative, and automatic behaviors. Traditionally, people think about such phenomena as lying outside the realm of cognition. As such, post-anticipatory phases of swallowing would not seem to be subject to cognitive influences. Provided first is a history and traditional definitions of reflexive, vegetative, and automatic behaviors in general, and their putative relation to swallowing in particular. Then, the possibility is entertained that cognition may indeed be involved not only in the anticipatory phase but also in other phases of swallowing as well.

**a. Reflexive behaviors** In cognitive neuroscience, a distinction has sometimes been made between cognitively mediated actions, which are called *responses* (Pinel, 2000), and involuntary or automatic actions, which are called *reflexive* (Ghez & Krakauer, 2000; Marieb, 1998; Purves, et al., 1997; Scanlon & Sanders, 1997). Relative to the latter term, *reflex* was first formally defined by Procháska (1784), as cited in Prochazka, Clarac, Loeb, Rothwell, & Wolpaw (2000), as “a behaviour in response to an excitation, mediated by separate motor and sensory nerves” (p. 418). Currently, Prochazka and colleagues suggest there seem to be two camps for defining reflex: (a) a camp that sees reflexes as behaviors that are difficult to suppress, uninterruptible, and poorly amenable to conscious modification; and (b) a camp that sees reflexes as simple reactions regulated by an input-output mechanism or pathway that functions as a tool inherent to the nervous system.

Whatever the definition, swallowing is widely described in the literature and by clinicians as reflexive, particularly with respect to the triggering of events in the pharyngeal phase (e.g., Dodds, 1989). The history of swallowing’s characterization as reflexive is as follows. Hall (1836) appears to have been the first author to describe swallowing as involving a *reflex*. Oddly, his use of the term was synonymous with *motor* or *efferent*. In fact, he was referring only to the motor aspects of what he called the “True Spinal or Excito-motory System”—today, the central nervous system, or CNS. Through their observations, Miller and Sherrington (1916) perpetuated the notion that swallowing is reflexive. They suggested an “all or nothing” response in swallowing and consequently referred to swallowing as *reflex deglutition*.

Miller (1982) further promoted the characterization of swallowing as reflexive. Specifically, he proposed the *reflex chain hypothesis* of swallowing. Stated simply, the proposal is that from the time a bolus enters the oral cavity, sensations in the oral and pharyngeal cavities set into motion, or trigger (Dodds, 1989; Miller, 1982), the events of swallowing, one right after another. Current literature in swallowing often uses the term *swallow reflex* synonymously with the notions put forth in Miller’s *reflex chain hypothesis*. In brief, the swallow reflex is seen as a cascade of behaviors that, once initiated, is involuntary and cannot be interrupted. The concatenation of events includes tongue base retraction toward the pharyngeal wall, soft palate elevation, laryngeal elevation, progressive upward and forward movement of the hyoid bone leading to closure by intrinsic and extrinsic laryngeal valving, inversion of the epiglottis, pharyngeal contraction, cricopharyngeal muscle relaxation, and upper esophageal sphincter opening (Atkinson, Kramer, Wyman, & Ingelfinger, 1957; Cook et al., 1989; Jacob, Kahrilas, Logemann, Shah, & Ha, 1989; Kahrilis, Dodds, Dent, Logemann, & Shaker, 1988; Logemann et al., 1992; Martin-Harris & Robbins, 1995; McConnel, Cerenko, & Mendelsohn, 1988; Ramsey, Watson, Gramiak, & Weinberg, 1955; Sokol, Heitmann, Wolf, & Cohen, 1966). If the *reflex chain* described in this way actually does involve a neurologic reflex, it might seem rather difficult to imagine that cognition could be involved in the oral and pharyngeal phases of swallowing.

As it turns out, three flaws can be noted in that thinking. First, if swallowing does involve a physiological reflex, cognition cannot be excluded as relevant. Numerous studies have illustrated this principle with respect to reflexes in general. Data indicate that people have the ability to set reflex thresholds purposefully, that is using cognitive mechanisms (e.g., Earles, Vardaxis, & Koceja, 2001; Lipp, Blumenthal, & Adam, 2001; Svensson, McMillan, Graven-Nielsen, Wang, & Arendt-Nielsen, 1999). Therefore, oral and pharyngeal phases of swallowing could involve cognition, even if they are reflexive as widely understood

Second, although people have used the term reflex loosely and haphazardly in the swallowing literature for almost 200 years, recent arguments suggest that swallowing is not reflexive at all. To reiterate, strictly defined, a reflex involvles a motor response triggered by sensory input to specific, low-level pathways. Researchers have failed to identify the circuitry necessary to consider the swallow "reflex" a true physiological reflex defined in this way. Miller (1972) explained:

> Certain properties, possibly inherent in such organization which would separate swallowing from such classically studied reflexes as the flexion of the hind limb, include particular patterns of sensory input over specific nerves triggering a group of interneurons with a common threshold, a threshold level below which the interneurons as a group or center are inadequately excited, and the consistent stereotyped activation of motor nuclei anatomically situated over an extensive rostro-caudal axis by these interneurons when threshold is attained. (p. 156)

Further contributing to the challenge of viewing swallowing as reflexive, Dodds (1989) argued that swallowing is probably dependent upon a mix of a reflex chain and a central pattern generator, which influences a network of programmed, medullary neurons acting independently of sensory feedback to complete the sequence of events for swallowing. Swallowing may be pre-programmed, but feedback to sensory stimuli may alter the mechanics of the swallow. Moreover, Robbins' (1996) review of current literature on the temporospatial characteristics and neural events of swallowing strongly suggests that swallowing is not reflexive in any clear way at all. She suggested that the term "reflexive" be substituted altogether with "patterned response."

Despite these arguments, which have found consensus in many quarters, numerous authors have continued to describe swallowing as reflexive in the literature (e.g., Cole & Cowie, 1987; Ertekin et al., 2001; Kern, Jaradeh, Arndorfer, & Shaker, 2001; Nishino, 2000; Okada, Ouchi, & Teramoto, 2000; Pinto et al., 1994; Sessle & Henry, 1989; Shingai, Miyaoka, Ikarashi, & Shimada, 1989; Sonies et al., 1988; Stevenson & Allaire, 1991; Teramoto et al., 1999). Contemporary consensus suggests such usage is misguided, making room for the consideration that cognition—and not only low-level neuromuscular circuitry—could be involved in oral and pharyngeal phases of swallowing.

A third challenge to the view of oropharyngeal phases of swallowing as impervious to cognition comes from neurophysiological data. A number of studies completed in animals and humans just a few decades ago suggested that cortical structures play a considerable role in swallowing, especially swallows that were voluntarily produced. Some studies using electrical stimulation in the primary motor cortex of monkeys were not able to elicit oral, pharyngeal, or esophageal swallowing (Murray & Sessle, 1992a, 1992b), whereas other studies have been successful in stimulating the cortex in monkeys (Martin et al., 1999; Miller & Bowman, 1977), rabbits (Sumi, 1969), and cats (Hamdy, Xue, Valdex, & Diamant, 2001; Miller, 1972) to evoke both swallowing and chewing-like movements and in projections from the cortex to medullary swallowing regions in sheep (Jean, Car, & Roman, 1975). With translation into human studies using magnetic stimulation, Hamdy et al. (1996) suggested that parts of the precentral and frontal gyri were able to induce oral, pharyngeal, and esophageal phases of swallowing (For a review of animal and human studies, see Miller, 1999). Further, Larson, Byrd, Garthwaite, and Luschei (1980) created experimental cortical lesions in monkeys that resulted in difficulty transitioning from chewing to swallowing. Similarly, numerous neuroimaging studies have demonstrated cortical and subcortical activations during oral and pharyngeal phases of swallowing (e.g., Daniels & Foundas, 1997; Gautier et al., 1999; Hamdy, Mikulis, et al., 1999; Hamdy, Rothwell, et al., 1999; Hamdy, Rothwell, Aziz, & Thompson, 2000; Kern, et al., 2001; Martin, Goodyear, Gati, & Menon, 2001; Watanabe, Abe, Ishikawa, Yamada, & Yamane, 2004; Zald & Pardo, 1999, 2000). Although the specific link to cognition remains unclear in those studies, it would seem that such activations might signal some level of cognitive involvement. Along similar lines, if swallowing were only reflexively controlled at the lowest levels of the neuromuscular system, it would be extremely difficult to explain the large number of studies showing swallowing disorders in patients with cortical, cerebellar, or subcortical strokes; head injuries; motor disorders; or other neurological conditions affecting cognitive circuitry (e.g, Groher, 1992; Langmore, 1996; Lazarus & Logemann, 1987; Logemann, 1998; Teasell, Bach, & McRae, 1994).

To summarize, if oral and pharyngeal phases of swallowing were *purely* reflexive, arguments that cognition must be excluded are erroneous. Cognition is known to affect reflexive actions. Second, there is serious concern about the relevance of reflexes in swallowing at all. Third, both empirical and clinical neurophysiological evidence suggests cognitive changes can produce deleterious effects on swallowing. The combined observations suggest there is reason to explore the role of cognition in swallowing, despite its (possibly erroneous) characterization as "reflexive."

**b. Vegetative behaviors** Frequently, oral and pharyngeal phases of swallowing have been characterized as *vegetative,* often apparently synonymously with *reflexive.* Arguments that consider the pharyngeal phase of swallowing as reflexive generally are extended to swallowing *en bloc* in descriptions of swallowing as a *vegetative* behavior (e.g., Cole & Cowie, 1987; Stevenson & Allaire, 1991). According to Webster, vegetative functions are those that persist in states of "severe mental impairment in which only involuntary bodily functions" occur (Webster's New Complete Medical Dictionary, 1996, p. 739), that is, in a *persistent vegetative state* (PVS). According to Owen et al. (2002):

> There must be no evidence of sustained, reproducible, purposeful or voluntary behavioral response to visual, auditory, tactile or noxious stimuli. There must also be no evidence of language comprehension or expression, although there is generally sufficiently preserved hypothalamic and brainstem autonomic functions to permit survival with medical care….[PVS] is characterized by an irregular but cyclic state of circadian sleeping and waking. In contrast, patients in coma present with eyes closed and lack any consistent wake-sleep cycles. (p. 394)

There is debate about the specific somatic functions that can be considered vegetative, including chewing and swallowing. Extrapolating from definitions by the American Medical Association (AMA) and the American Academy of Neurology (AAN) (Spudis, 1991), vegetative functions are those associated with the brainstem, and exclude those regulated by the cortex. The consideration of chewing and swallowing becomes a pivotal issue. The AMA regards "chewing" or "clamping" of a patient's teeth, in the context of loss of consciousness, as an acceptable indicator of a PVS, thereby implying these actions can be considered vegetative—occurring without usual voluntary cortical control. In contrast, the AAN asserts that a PVS "is the result of a functioning brainstem and the total loss of cerebral cortical functioning….The capacity to chew and swallow in a normal manner is lost because these functions are voluntary" (p. 129). It follows that the AAN does *not* regard chewing and swallowing as indicators of a PVS. These abilities are not vegetative because such functions are voluntary, that is, "cortically driven." Therefore, there is lack of consensus within the medical community about whether swallowing is vegetative. Moreover, there is lack of consensus about the role of cortical control, and accordingly typical cognitive circuitry for chewing and swallowing.

Another approach to characterizing vegetative functions in general is to consider them somatic responses that can be initiated by stimulation of the brainstem and/or hypothalamus (Bransfield, 1997-1998; Owen et al., 2002). Such responses are assumed to be hard-wired; organisms are born with them, although they may be modified over the life span due to physical and experiential factors. In this definition, vegetative functions (e.g., digestion, heart rate, respiration) can be accomplished without cortical control of obvious cognition, even during sleep. The fact that swallowing *can* occur without conscious control during sleep does not mean that it routinely *does* occur in this way in the awake state. However, sleeping and waking swallows demonstrate some biomechanical and behavioral differences, for example in the frequency of swallowing. These differences suggest the possibility of variable control mechanisms for swallowing, in humans (Bremner et al., 1993; Lichter & Muir, 1975; Nishino & Hiraga, 1991; Orr, Johnson, & Robinson, 1984; Pinto et al., 1994), in cats (Anderson, Dick, & Orem, 1995), and in dogs (Issa, 1994).

If one buys into the notion that cortical activation may imply cognitive activity, some evidence does indicate cortical control, and therefore possibly cognition, in swallowing. Early work on deglutition in humans demonstrated that swallowing could be induced using transcranial magnetic stimulation (TMS) with 65-Hz trains of electrical stimulation (Penfield & Boldery, 1937), though it should be noted that this evoked swallow likely did not possess the necessary characteristics of a functional swallow that was safe and efficient for nutrition and that cortical lesions can cause abnormal reflexes. Unfortunately, due to risks of seizures, TMS studies in humans now are modified to provide single bursts of electrical energy several seconds apart. With this method, swallows are no longer evoked (Hamdy et al., 2000). Due to these limitations, animal studies are more widely used and continue to replicate cortically induced swallowing

(Anderson et al., 1995; Bieger & Hockman, 1976; Hamdy, Xue, Valdez, & Diamant, 2001; Jean & Car, 1979; Martin et al., 1999; Sumi, 1969).

In summary, some medical definitions of vegetative functions exclude actions that are cortically controlled. In those definitions, there is debate over whether swallowing should be considered vegetative, due to evidence that cortical control can be involved in swallowing. Other definitions of vegetative functions focus on those related to hypothalamic and brainstem functioning. In those approaches, swallowing is considered vegetative. However, again, neither cortical nor cognitive control is excluded. Overwhelmingly, the combined evidence suggests that swallowing does involve cortical control. Because much of cognition generally is assumed to live in the cortex (e.g., Kolb & Whishaw, 1990; Marieb, 1998; Purves et al., 1997; Tompkins, 1995), it is not a far stretch to hypothesize that oral and pharyngeal phases of swallowing may be cognitively modulated in the awake state, even if they are considered vegetative. Even if cognition is limited in some aspects of the swallow, it does not follow that cognition is limited in *all* aspects of oral and pharyngeal swallowing.

**c. Automatic behaviors** As the terms reflexive and vegetative sometimes are used synonymously, also the term *automatic* sometimes is used synonymously with reflexive and vegetative. All of these interchanges are erroneous. According to Pashler (1994), most psychologists agree that automaticity is defined as a mental operation that occurs outside of voluntary control, and further, involves minimal (if any) capacity or processing resources. Posner and Snyder (1975; see also Posner, 1986) describe automatic processes as (a) rapid, (b) occurring without intention, (c) hidden from consciousness or awareness, and (d) using little (if any) cognitive resources. A consensus is that with sufficient practice, most tasks can become automatic (Schneider & Shiffrin, 1977). A further corollary is that many psychologists consider automatic behaviors as belonging to a class of responses characterized by predictable, stereotypic outcomes (e.g., Epstein, 1994).

The characterization of automatic behaviors as stereotypic places swallowing well within the scope of automaticity. Magnitude characteristics of swallowing characteristics may change from trial to trial, depending on environmental factors such as bolus volume proportions (e.g., Bisch et al., 1994; Cook et al., 1989; Leonard et al., 2000; Miller & Watkin, 1996; Perlman et al., 1999; Speirs, Staniforth, & Sittampalam, 1988). However, the order of events in swallowing is remarkably consistent. Once a bolus has passed the faucial arches, the events of swallowing occur with little change in serial order across trials (Cook et al., 1989; Doty & Bosma, 1956; Ertekin et al., 2001; Kendall et al., 2000; Martin-Harris et al., 1999; Martin-Harris et al., 2003; Martin-Harris, Brodsky, et al., 2005; Perlman et al., 1999). Another example of swallowing's stereotypicity is that the small intestine has been shown to secrete immunoglobulin A[1] during sham feeding (i.e., chewing and ejecting food without swallowing) in humans (Fändriks et al., 1995). Thus, the body automatically prepares itself for digestion subsequent to the introduction of food to the mouth.

Arguments might be made that because swallowing generally can be considered automatic, cognition is irrelevant to it. These arguments are flawed for two reasons. First, as already noted, automatic processes are one important class of cognitive operations (e.g. Posner & Snyder, 1975).

[1] A protein antibody produced by plasma cells and used to fight bacteria from entering the body. It can be found in saliva, sweat, intestinal secretions, and milk (Marieb, 1998).

Second, automatic processes in general, and in swallowing, in particular, do not exclude the possibility that "effortful" cognitive processes not inherent to automatic actions (e.g. Kahneman, 1973; Titchener, 1908) may be superimposed in some situations. Consider, for example, any of the swallowing maneuvers used to treat swallowing disorders. In the Mendelsohn maneuver, individuals volitionally control and maintain the height and anterior displacement of the hyolaryngeal complex to increase the opening time of the upper esophageal sphincter. Consequently, additional time is available for the bolus to enter the esophagus (Ding, Larson, Logemann, & Rademaker, 2002; Kahrilas, Logemann, Krugler, & Flanagan, 1991; Neumann, Bartolome, Buchholz, & Prosiegel, 1995). Other examples include the use of the supraglottic swallow and the effortful swallow, which are willful attempts to improve glottic closure and tongue base retraction (Bülow, Olsson, & Ekberg, 1999; Hind et al., 2001; Logemann, 1998; Neumann et al., 1995). Therefore, there is room to think that effortful cognitive processes can influence swallowing.

**d. Summary** The focus of the foregoing section was the possible role of cognition in oral and pharyngeal phases of swallowing. It is not immediately apparent that cognition might be involved in these phases because they are usually thought of as reflexive, vegetative, and/or automatic. Within those views, it would seem that there would be little room for a role of cognition in swallowing. The preceding pages have challenged these assumptions. In summary, the key points are as follows: (a) The use of the term "reflexive" to describe oral and pharyngeal phase events in swallowing is actually a misnomer. Strictly understood, a reflex involves a minimal number of sensory and motor nerves that typically do not extend to higher levels of the central nervous system. Understood in that way, a reflex has not been identified for swallowing.

Moreover, the temporospatial characteristics of the oral and pharyngeal phases of swallowing are inconsistent with reflexive action. Therefore, a role of cognition for swallowing cannot be excluded based on the argument that swallowing is reflexive, because it is not. Additionally, cognition can influence reflexes, even if swallowing *were* reflexive. (b) Vegetative functions may be defined based on the presence or absence of cortical—or cognitive—involvement. Considerable evidence exists demonstrating such involvement in swallowing, at least in the awake state. Therefore, swallowing is not necessarily vegetative, by this definition, nor is cognition excluded. (c) There is little doubt that many aspects of the oral and pharyngeal phases do meet the criteria for automatic behaviors. They are stereotypic and under usual circumstances appear to be carried out with little, if any, mental resources. However, this argument fails to effectively argue against a role of cognition in oral and pharyngeal phases of swallowing. Indeed, many automatic processes are cognitively regulated, and are one class of the larger domain of cognition in general. For this reason, arguments that oral and pharyngeal phases of swallowing are automatic in no way exclude a role of cognition. Following this line of reasoning one step further, clinical observations suggest that another class of cognitive operation—effortful processes—also can influence swallowing in some cases. Examples include the clinical use of the Mendelsohn maneuver and the supraglottic swallow to alter the biomechanics and the outcome of swallowing. Furthermore, the fact that much of oral and pharyngeal swallowing appears automatic does not exclude a role of effortful processes in some parts of those phases, some of the time. Cognitive effort may be particularly notable for swallowing in some clinical populations, especially in individuals with motor disorders.

## C. MEASUREMENT OF COGNITIVE PROCESSES

Over the past century and more, a large number of approaches have been taken to study mental processes that occur between stimulus input and response output—that is, in the temporal correlate of what behaviorists once considered the "black box" of mental processes and unsuitable as the target of scientific inquiry. One prevalent approach to the measurement of such processes has involved "reaction time" paradigms. *Reaction time* (RT) is defined as the time between an experimenter-controlled stimulus onset and the onset of a subject's response. A large number of researchers have used this paradigm to make inferences about stages of cognitive processing and processing resources, or attention, used in various tasks. A classic example is seen in a study by Sternberg and colleagues (Sternberg, Monsell, Knoll, & Wright, 1978). In that study, subjects were asked to produce one or more words in response to a stimulus cue (e.g. "Monday," versus "Monday-Tuesday-Wednesday"). Results indicated that RT increased linearly with the linear increase in the number of words to be produced, even though subjects knew ahead of time which sequence would be required. The interpretation was that a cognitive stage must exist corresponding to some sort of motor program "unpacking" in such tasks. In this case, the time required to unpack words had an average latency slope of 8.8 ms/word; digits required 12.6 ms/word.

Another example of how RT paradigms have been used to study stages of cognitive processing was reported in classic experiments by Sternberg (1966, 1969). In those experiments, subjects were presented a set of visual stimuli in parallel (e.g., 3, 8, 9, 2, 6). After the stimuli were removed, subjects were asked to respond (yes/no) whether a specific stimulus was present (e.g. the number "9"). Results showed that RTs, again, linearly increased as a function of the number of stimuli in the presented set. RT results were similar for "yes" and "no" responses. The findings suggested that memory searches were conducted serially rather than in parallel. In addition, these findings suggested that memory searches had been conducted of the entire memory set before a decision was made about the presence or absence of the target stimulus in the stimulus set (exhaustive search). In that study, search time for each item appeared to be on the order of 38 ms.

A third way that RT paradigms have been used has involved the study of mental resources, effort, or capacity, often referred to as "attention" (McNeil, Odell, & Tseng, 1991). Historically, attention has been viewed as both a filter (e.g. Broadbent, 1958; Deutsch & Deutsch, 1963; Norman, 1969; Treisman, 1960, 1964, 1969) and a limited-capacity mental resource (e.g. Kahneman, 1973; Posner, 1986; Posner & Boies, 1971; Posner & Snyder, 1975). RT paradigms have been widely used to study resource issues in particular. An example is seen in a foundational study by Posner and Boies (1971). In that experiment, subjects were presented with a warning stimulus, followed by a letter, and ultimately a second letter. The task was to determine (yes/no) whether the letters matched. Across trials, a tone was sounded at various time-points during the stimulus presentations. Subjects were asked to respond to the tone by pressing a key with their left hand while they continued to perform the letter-matching tasks with two keys using their right hand. The results showed that RTs to the tone increased sharply for tones presented during the presentation of the second letter, as compared to RTs for tones occurring during the first letter. The interpretation was that encoding, comparing, and deciding about a potential letter match requires more mental capacity (second letter presentation), as compared to encoding only (first letter presentation). Therefore, the researchers concluded that subjects had less attention available for the tone response during the more complex task, and consequently responded more slowly to it.

On the heels of this framework, RT and other paradigms have been used widely to make inferences about the amount of effortful, or capacity-dependent mental processing required by a variety of tasks. However, significant objections recently have been raised with regard to interpretation of the results. One of the more virulent ones has come from studies that have addressed the general issue of capacity dependence within and capacity sharing across a variety of tasks (Kahneman, 1973; Navon & Gopher, 1979; Navon & Miller, 2002; Tombu & Jolicœur, 2002; Wickens, 1980). The argument is that increased RT to a secondary task does not necessarily imply increased attention to a primary task. Instead, critical operations required for both tasks, specifically central processing including memory retrieval and response selection, may be accomplished only serially. The suggestion is that a central processing bottleneck exists such that some operations can be carried out only one at a time, even if the contents of these operations are qualitatively different (Pashler, 1984, 1994). In that case, a complex set of operations would occupy the bottleneck until the operations are completed, and then the bottleneck is freed up for the processing of a next set of operations. For example, in a dual-task paradigm, an increase in RT could be caused by the dependence of two tasks on the same mental operations. Processing for the tasks occurs in parallel (i.e., simultaneously) until the tasks require the same mechanism for processing. At that point, parallel processing gives way to serial processing (i.e., one process is completed, then the next process is completed). Because only one task can occupy this "bottleneck," a slowing of RT for the second task will occur. The bottom line is that neither capacity dependence nor capacity sharing may explain differential RTs to various simultaneous stimuli and processing may be temporally limited by the complexity of the tasks at hand.

The debate about the correct interpretation of RT results in a dual-task paradigm is an ongoing one, which has seen numerous data sets arguing for a capacity versus central bottleneck interpretation of the data (e.g. Levy & Pashler, 2001; Navon & Miller, 2002; Ruthruff, Pashler, & Klaassen, 2001; Schumacher et al., 2001). However, an important note for the present context is that "bottleneck" theory rests on experimental setups involving "choice" dual-task RTs. Alternate "go/no go" paradigms are irrelevant to it. The present investigation will use the simpler "go/no go" setup to explore the possible relevance of cognitive resources in swallowing, thus side-stepping the capacity versus bottleneck debates altogether. Issues of bottleneck versus capacity models of data interpretation can be left to future studies. For the present investigation, capacity models will probably be the most appropriate ones for interpretation of the findings.

A further issue in the measurement of cognition, relevant to the present investigation, has to do with the concept of "double dissociation." If RTs for a secondary, cognitive-dependent task relative to swallowing (e.g. a verbal memory task, tone-response task) were shown to be greater for the dual-task situation when compared with RTs for the secondary task in isolation—keeping swallowing consistent between baseline/single-task and dual-task conditions—an argument could be made that the tasks share attention, and thus, swallowing has an attentional component. However, that conclusion would be strengthened by evidence of a double dissociation in which the RTs, or timing characteristics, of swallowing were also altered as a result of the presence of a secondary task, especially when instructions are varied across trials regarding which task to favor. Stated differently, the strongest argument for shared processes across swallowing and another task would be made by evidence that performances for either swallowing or the second task, or both, were affected by attempts to carry them out simultaneously. These considerations will be partially folded into the experimental design for the present investigation, although shifts in instructions regarding the primacy of the tasks will not be made in the present study.

Another interesting question relative to the attempt to garner initial evidence regarding a possible role of cognitive resources in swallowing has to do with the possibility of null results. That is, it is possible that neither changes in RTs to a secondary stimulus during swallowing nor changes in swallowing would be seen using a dual-task paradigm. At one level, the implication would be that attention is not involved in swallowing. However, one can rarely impute significance to null results. An alternative explanation would be that the experimental setup was simply insensitive to the question. In that light, to optimize the investigation's sensitivity, the best approach would probably be to assess swallowing not only in a group of healthy individuals, but also in a group of participants who may have cognitive (broadly), attentional (specifically), and/or sensorimotor constraints, especially those that may affect swallowing. Especially in the latter case, cognitive requirements of swallowing might be increased and there would be greater likelihood of seeing increased response latencies to secondary stimuli in the affected group. Ideally, findings also would be clinically relevant. In light of these considerations, the present investigation will evaluate a possible role of attention in swallowing in healthy individuals and in individuals with Parkinson's disease. Further rationale for this choice and information about characteristics of cognition and swallowing in Parkinson's disease are provided in the next section.

## D. PARKINSON'S DISEASE

One of the most devastating progressive diseases in existence today is Parkinson's disease (PD). According to Jahanshahi & Marsden (2000), the prevalence of PD is approximately 1 person in every 1000 in the population, with the incidence rising dramatically with increasing age. Although the average age at onset is 55 years (Hoehn & Yahr, 1967), 1 in 7 people with PD develop symptoms before the age of 40 years. Additionally, there is a subset of individuals with young-onset disease, consisting of approximately 20% of the total number diagnosed, who develop symptoms between the ages of 21 and 40 years.

### 1. General description of the disease

James Parkinson, a British surgeon for whom the disease is named, cited a number of cases and described the progression of this disease in his classic writing, *An Essay on the Shaking Palsy* (1817). He described the disease as involving:

> Involuntary tremulous motion, with lessened muscular power, in parts not in action and even when supported; with a propensity to bend the trunk forwards, and to pass from a walking to a running pace: the senses and intellects being uninjured. (p. 1).

Still today, the essence of this description of PD holds true. Stage information is as follows. With the onset of PD, 90% of patients have tremors and muscular rigidity (Hoehn & Yahr, 1967). In the first 3 of 5 stages outlined by Hoehn and Yahr, patients are considered only minimally disabled. Distinctions among these three stages are associated with unilateral involvement in Stage 1, progressing to bilateral involvement in Stage 2, and continued bilateral involvement leading to unsteadiness in balance and restriction in activities, but continued ability to lead a fairly independent life in Stage 3. Stage 4 is characterized by a more fully developed and severely debilitating clinical picture, minimally sparing ambulation. Stage 5, the final stage, leaves the patient entirely confined to a bed or wheelchair unless helped into a different position or location. Specific to behaviors related to swallowing, according to Parkinson (1817), tremors extend to affect feeding. Throughout the stages, individuals have progressive difficulty bringing the utensils to the mouth because of tremulous limb motion. Swallowing physiology also has additional associated problems, as discussed shortly.

In summary, sensorimotor deficits are not only characteristic of PD, they are its hallmark. However, contrary to Parkinson's (1817) original impressions, cognitive declines are also noted in a large number of individuals, as discussed next.

### 2. Cognitive deficits

Although the majority of patients with PD do not develop dementia, there seems to be a range of between 11% and 25% (Brown & Marsden, 1984; Jahanshahi & Marsden, 2000; Mayeux et al., 1988) and a maximum of 63% (Bine, Frank, & McDade, 1995; Korczyn et al., 1987) who do develop a progressive loss of intellectual and cognitive abilities. Such losses affect attention/concentration, memory, associative learning, and picture naming. Unfortunately, whereas these deficits are treatable, they are not reversible because the disease process is not reversible.

Further light is shed on the issue of cognition in PD by observations that some cognitive changes are seen throughout the progression of the disease, regardless of whether frank dementia is observable (Goldman, Baty, Buckles, Sahrmann, & Morris, 1998). Sharpe (1992), for example, studied the effects of auditory attention with a dichotic listening task comparing patients with early PD (Hoehn & Yahr, 1967; Stages 1 and 2) and age-matched, normal controls. Relative to normal controls, patients with PD were found to have greater difficulty ignoring irrelevant information during the time their tremor medication was effective. Sharpe hypothesized that the reason for the deficits in attention was related to degenerative changes in ascending monoamine pathways (i.e., the pathways responsible for the transmission of dopamine to various areas of the cortex and subcortex through the midbrain). Stated differently, although the presence of this neurotransmitter (i.e., dopamine) maintains the patient's ability to remain attentive, the pathways related to attention in the cortex may not be fully accessible by medication (Rodríguez-Puertas, Herrera-Marschitz, Koistinaho, & Hökfelt, 1999). Similar findings have been reported in other studies (Hsieh, Hwang, Tsai, & Tsai, 1996; Serrano & García-Borreguero, 2004; Sharpe, 1990; Watts & Dagenais, 2001).

Likewise, Goldman et al. (1998) compared healthy, elderly controls with two groups of patients with PD—those with suspected dementia and those without dementia, in Hoehn and Yahr's (1967) Stages 1 through 4, the predominance (96%) of whom were in Stages 1 through 3. The three groups were compared on various measures of cognition including logical memory, digit span, associate learning, general information, block design, digit symbol, trail making, cancellation, picture naming, and word fluency. Compared with the healthy elderly controls, subjects with PD in the absence of dementia performed significantly worse on all tests except digit span and word fluency. Subjects with PD and suspected dementia performed significantly worse on the logical memory, block design, digit symbol, and trial making tests—three of which require both speed and accuracy (i.e., motor and cognition). The study's results suggest that even without much compromise in motor function or the presence of dementia, widespread impairments of cognitive skills exist in PD.

Added to these observations regarding cognitive deficits in PD, another difficulty experienced by many patients with PD has to do with another dimension of psychological functioning that has implications for cognition—mood disorders. Among the most common mood disorders in patients with Parkinson's disease is depression, which affects approximately one-third of patients at any given time (Jahanshahi & Marsden, 2000). In turn, depression may have dramatic impact on overall cognitive functioning (Kuzis, Sabe, Tiberti, Leiguarda, & Starkstein, 1997). Among the criteria for major depressive episode according to the American Psychiatric Association's *Diagnostic and Statistical Manual of Mental Disorders* (4th edition, 1994), is a "diminished ability to think or concentrate…" (p. 327). As such, it would stand to reason that patients with PD and concomitant depression not only have a predisposition for compromised cognitive abilities, they may also have diminished attention or motor slowing due to depression.

A final question relative to cognitive functioning in PD regards the potential increase in cognitive demands due to motor deficits. Whereas the demands for any given task remain the same from person to person, and recurrences of the same task, patients with PD may have reduced cognitive resources available with which to execute the tasks. Arguably, motor deficits, which are an essential feature of PD, increase cognitive demands relative to motor functioning. Stated more simply, when people have motoric problems, motor actions require more cognitive resources than the same acts require under healthy conditions, even those assumed to be simple, common, and highly repetitive (Beauchet et al., 2005; Brauer, Wollacott, & Shumway-Cook, 2001; Camicioli, Howieson, Lehman, & Kaye, 1997; Dault, Yardley, & Frank, 2003; Hausdorff, Yogev, Springer, Simon, & Giladi, 2005; O'Shea, Morris, & Iansek, 2002; Verghese et al., 2002; Woollacott & Shumway-Cook, 2002; Yardley et al., 2001; Yogev et al., 2005). One example of this potential scenario has to do with swallowing, as discussed next.

### 3. Swallowing disorders

Over the past 20 years, increased attention has been paid to swallowing disorders in patients with progressive diseases in general, and more specifically in patients with PD. In PD, swallowing disorders may not present clinically for some time (Bird, Woodward, Gibson, Phyland, & Fonda, 1994). One study, more than 25 years ago, reported the incidence of a swallowing disorder to be 50% in patients with PD (Lieberman et al., 1980). Since then, many other studies have reported incidences of swallowing problems in 75%-100% of patients with PD, across all stages of the disease (Bird et al., 1994; Bushman, Dobmeyer, Leeker, & Perlmutter, 1989; Ertekin et al., 2002; Leopold & Kagel, 1997b; Nagaya, Kachi, Yamada, & Igata, 1998; Robbins, Logemann, & Kirshner, 1986; Stroudley & Walsh, 1991; for a review, see Johnston, Li, Castell, & Castell, 1995). It is likely that discrepancies between early and later reports partially are the result of increased awareness of swallowing problems, in general, since the earlier reports. Findings indicate the most common clinical observations of swallowing problems in patients with PD are difficulty with initiation of the swallow, problems with bolus formation, impaired motility (oral and pharyngeal), pooling in the valleculae and pyriform sinuses, and aspiration. Aspiration is of particular importance because it can lead to pneumonia and even death (Langmore et al., 1998;

Marik & Kaplan, 2003; Martin et al., 1994). It is estimated that bronchopneumonia occurs as frequently as 46% in individuals with PD (Bird et al., 1994). Moreover, it should be noted that bronchopneumonia is the leading cause of death in PD, controlling for causes of death in the general, age-matched population (Hoehn & Yahr, 1967). This finding is undoubtedly due to the severe reduction in general mobilization and progressive decline in swallowing skills in individuals with PD. In addition to oral and pharyngeal difficulties in PD, swallowing problems continue further in the digestive system to involve esophageal (Bassotti et al., 1998; Johnston et al., 2001; Leopold & Kagel, 1997b) and other gastrointestinal functions such as gastroesophageal reflux (Bassotti et al., 1998; Edwards, Pfeiffer, Quigley, Hofman, & Balluff, 1991; Leopold & Kagel, 1997b).

Among the difficulties patients with PD have with swallowing is what Wintzen et al. (1994) refer to as "aborted swallowing movements" or "hesitations." In Wintzen's study measuring the movement of the hyoid bone during the swallowing of various liquid bolus volumes, 57 hesitations were noticed in patients with PD, as compared to 11 hesitations seen in age-matched, unimpaired controls. Although some researchers have described such hesitation as "multiple gestures of the hyoid" (Sonies et al., 1988), others have described "lingual rocking" and "repetitive tongue pumping" (Nagaya et al., 1998; Robbins et al., 1986). Wintzen and colleagues speculate such behaviors are an expression of the inability to switch from the volitional aspects of swallowing to the automatic phase of swallowing. The tremors in later stages of the disease may also be an expression of an uncoordinated motor system.

In the later months and years of mid-stage PD, patients may become weary over the amount of effort and physical exertion to feed themselves. Often, patients rely on significant others, family members, or other caregivers for support in feeding. Parkinson (1817) described the patient's words as "scarcely intelligible…." in the last stage of this insidious disease. He continued:

> He is not only no longer able to feed himself, but when the food is conveyed to the mouth, so much are the actions of the muscles of the tongue, pharynx, &c. impeded by impaired action and perpetual agitation, that the food is with difficulty retained in the mouth until masticated; and then as difficulty swallowed. Now, also, from the same cause, another very unpleasant circumstance occurs: the saliva fails of being directed to the back part of the fauces, and hence is continually draining from the mouth, mixed with the particles of food, which he is no longer able to clear from the inside of the mouth. (p. 8)

In addition to speech and swallowing impairments, the patient is unable to ambulate. He or she is overcome with tremors that often prevent sleep, and is incontinent of both bladder and bowel. In sum, the patient is trapped. "At the last," as Parkinson poignantly wrote, comes "constant sleepiness, with slight delirium, and other marks of extreme exhaustion; [patients] announce the wished-for release" (p. 9).

## 4. Summary

Parkinson's disease is a devastating, progressive, neurological impairment of the sensorimotor system. It is classically characterized by motor deficits with "the senses and intellects being uninjured" (p. 1, Parkinson, 1817). However, in recent years it has been determined that patients with PD also have cognitive declines, which challenge the sensorimotor system even if such declines do not surface as frank dementia or swallowing problems. Theoretically, for these reasons, PD is a sensitive population to study with respect to the hypothesis that cognition, specifically attention, may be involved in swallowing. If the swallowing system were taxed by cognitive deficits, sensorimotor deficits, or both, it would seem that adding experimental demands on attention might reveal additional cognitive or motor deficits, if swallowing involves attention.

## E. GAPS IN THE LITERATURE AND SIGNIFICANCE

The most fundamental gap is a dearth of information in the literature regarding the involvement of cognition in swallowing. Implicit arguments against such involvement are derived from general notions that swallowing involves some combination of reflexive, vegetative, and automatic processes. Accordingly, swallowing should not involve much, if any, contribution from cognition, and more specifically, attention. However, these conclusions are flawed at several levels. First, even if swallowing were "reflexive" (which it is not), cognition is known to influence reflexes. Thus, there could be a role for cognition in swallowing. Second, it is not clear that swallowing can be considered "reflexive" anyway. Third, there is neither agreement about the definition of "vegetative" functions nor about the relevance of cognition for those functions in general. Thus, a role of cognition is not categorically excluded even if swallowing is vegetative. Fourth, the reasonable argument that swallowing is automatic, and thus stereotypic, does little to suggest that swallowing would not involve cognition. Indeed, automatic processes are robustly identified in the literature as one, huge and perhaps predominant, class of cognitive operations that contrast with "controlled" or "effortful" processes. Finally, controlled, effortful processes can be routinely superimposed on automatic ones—as for example occurs with the introduction of a series of purposeful maneuvers in the behavioral treatment of swallowing disorders. Thus, the consideration of swallowing under the rubric of automatic behaviors in no way excludes an involvement of cognition.

Thus, there is ample reason to consider that cognition may be involved in swallowing. The present investigation will address the gap in the literature by exploring, at a rudimentary level, the potential involvement of attention in swallowing. Such exploration has relevance not only theoretically, but ultimately also for common behavioral treatments of dysphagia. In particular, it would seem that information about attention influences in swallowing ultimately would be important considerations in the further development, application, and assessment of treatment techniques.

In fact, clinicians, more than researchers, seem to grasp the potential relevance of cognition for swallowing. Clinicians often go to great lengths during therapy to control the eating environment, despite the absence of empirical data from studies addressing swallowing relative to cognitive operations. Common examples of such maneuvers include clinicians turning off radios and televisions, reducing distractions and interruptions by closing the doors to patients' rooms, eliminating conversations during mealtimes, and even removing personal artifacts from the dining table during treatment sessions. Not surprisingly, once patients return home or go to a restaurant, few (if any) of the recommendations made by clinicians are followed. Sociologically, pragmatically, and understandably, patients share their mealtimes with the company of their significant other, family members, and friends, in situations radically different from the often times limiting, confining, and isolating environment of the hospital or therapy room.

The external environment in which a person consumes a meal changes from meal to meal and from day to day. Even if the environment were held constant, too many other factors exist to control swallowing changes from bite to bite and from sip to sip across a meal. In all phases, swallowing has to be a constantly changing system. Differences in food textures, temperatures, tastes, smells, sizes of the pieces of food or sips of drink, and speed with which the food arrives at the mouth are among the influences that affect the consistency of the system's behavior from bite to bite, let alone meal to meal (Adnerhill et al., 1989; Bisch et al., 1994; Hamlet et al., 1996; Hiiemae & Palmer, 1999; Logemann et al., 1995; Miller & Watkin, 1996; Raut et al., 2001; Stachler et al., 1994; Wintzen et al., 1994). Even just considering these influences, cognition could be presumed to be involved in making physiological adjustments during swallowing. Even in aging when changes in speed and accuracy of swallowing (defined in terms of presence or absence of penetration or aspiration) are seen (Hind et al., 2001; Robbins, 1996; Robbins et al., 1992; Shaker & Lang, 1994; Shaker et al., 1994; Sonies et al., 1988; Tracy et al., 1989), swallowing is largely predictable. It is only when disease, injury, or anatomical abnormalities are present (for reviews, see Groher, 1996; Langmore, 1996; Lazarus & Logemann, 1987; Logemann, 1998; Perlman, 1996) that swallowing can become unpredictable. Although the goals of swallowing remain constant (i.e., passing the food safely from the mouth, through the pharynx and esophagus, and into the stomach; management of saliva, expectorated material, and nasal mucous), anatomical changes due to development, disease, injury, or surgery alter the swallowing system as well. Still unknown, however, is whether this normally stable and largely unchanged system becomes (more) dependent on cognition (or attention) in the face of disease.

Although recent neuroimaging studies have pointed to specific cortical and subcortical involvement during swallowing (Daniels & Foundas, 1997; Gautier et al., 1999; Hamdy, Mikulis, et al., 1999; Hamdy et al., 2000; Hamdy, Rothwell, et al., 1999; Kern et al., 2001; Martin et al., 2001; Zald & Pardo, 1999, 2000), the question remains as to whether cognitive processing, in general, and attentional mechanics during swallowing, in particular, will be manifested in behaviorally measurable ways. Whereas Leopold and Kagel (1983, 1997a) hint at this idea in a theoretical manner, to date no other researchers have attempted to study empirically the involvement of cognitive resources during feeding and/or swallowing. Moreover, if such resources are involved in swallowing, it is not clear in which phase(s) resources are used. The need to elucidate attention's role in swallowing may have direct relevance on treatment models for dysphagia for patients with cognitive and/or motoric impairment.

## F. EXPERIMENTAL QUESTIONS

The purpose of the present experiment is to address the noted gaps by posing the following general experimental questions:

1. Is there evidence attention is involved in swallowing?
2. If attention is involved in swallowing, do differences exist in attentional demands across different phases of swallowing?
3. Does the presence of a sensorimotor impairment increase the involvement of attention required during swallowing and if so, in which phases?

## G. HYPOTHESES

This investigation uses a go/no-go dual-task paradigm to address the foregoing questions in healthy, non-impaired, control participants and in age-matched participants with early-to-mid stage Parkinson's disease (PD). The following hypotheses were generated:

1. Reaction times (RTs) to secondary auditory stimuli presented during both anticipatory and oropharyngeal phases of swallowing will be significantly longer than baseline/single-task RTs for both healthy, non-impaired, control participants and participants with PD.
2. RTs to secondary auditory stimuli presented during swallowing will be significantly longer during anticipatory as compared to oropharyngeal phases of swallowing for both healthy, non-impaired, control participants and participants with PD.
3. RTs to secondary auditory stimuli presented during both anticipatory and oropharyngeal phases of swallowing will be significantly longer for participants with PD than healthy, non-impaired, controls.

# II. METHODS

## A. PARTICIPANTS

### 1. Demographics

Two groups of 10 individuals participated in the experimental study. One group contained healthy, non-impaired (NI) individuals and the other group contained individuals with Parkinson's disease (PD). The NIs were age-matched by group distribution to the participants with PD. Any NI participant reporting the use of illicit drugs or prescribed medications having known effects on swallowing (see Table 1) was excluded from this investigation. NIs with histories of and/or self-reported swallowing difficulties or impairments were excluded as well. Reported gross visual impairment (e.g., cataracts, blindness) preventing participants to view the computer monitor and the cup placed in front of them were excluded from this investigation.

PD participants had a confirmed and documented diagnosis of Parkinson's disease by a neurologist, according to the criteria set forth by the United Kingdom Parkinson's Disease Society brain bank diagnostic criteria for Parkinson's disease (Hughes, Daniel, Kilford, & Lees, 1992). Dosing and scheduling of medications was not altered for the experiment. Participants with PD verbally confirmed stability on their current medication regimen prior to administration

Table 1

*Drugs implicated in altering swallowing function and their associated effects*

| Agent(s) | Proposed Mechanism(s) |
|---|---|
| Alendronate | Local chemical irritation of the esophagus |
| Antipsychotics | Inhibition of esophageal or pharyngeal/laryngeal motility |
| | Pharyngeal-laryngeal dystonia |
| Benzodiazepines | Inhibition of pharyngeal/laryngeal motility |
| Botulinium toxin | Impaired laryngeal movement |
| Chloroquine | Unknown |
| Cytarabine/methotrexate | Unknown |
| Digoxin | Unknown |
| Doxycycline | Local chemical irritation of the esophagus |
| Emepronium | Local chemical irritation of the esophagus |
| | Physical obstruction of esophagus from tablet |
| L-dopa | Unknown |
| Potassium chloride | Local chemical irritation of the esophagus |
| Tetrabenazine | Physical obstruction of esophagus from tablet |
| Quinidine | Local chemical irritation of the esophagus |
| | Physical obstruction of esophagus from tablet |
| Vinca alkaloids | Unknown |

*Note.* Source: O'Sullivan & Fagan (1998).

of the experimental protocol. In addition, participants with PD had symptoms commensurate with minimal disability in the early-to-middle stages (Hoehn and Yahr Stages 1, 2, and 3; Hoehn & Yahr, 1967) of the disease.

**2. Screening and testing**

**a. Hearing** A hearing screening was completed to determine the appropriate level for stimulus presentation. All participants were screened in both ears with pure tone stimuli through headphones at 30 dB HL for 500 Hz, 1 kHz, 2 kHz, and 4 kHz in a distraction-free room that was not sound-treated. Individuals who did not pass the screening in at least one ear required further audiometric assessment to obtain pure tone thresholds for the same frequencies used in the screening. Once thresholds were determined, the pure tone average (PTA) was calculated by taking the average of the thresholds obtained for the 500 Hz, 1 kHz, and 2 kHz pure tones. None of the participants presented with PTAs above 40 dB HL. To insure stimulus audibility above ambient noise levels, the stimuli were presented at 85 dB SPL as measured by a portable sound-level meter with an A-weighted scale at ear-level and a distance of one meter from the speakers. As a worst-case scenario (e.g., PTA = 40 dB HL, or ~50 dB SPL), the stimuli were presented at no less than 35 dB SL. All sound calibration took place with continuous, pre-recorded white noise normalized based on 100% peak level.

**b. Cognition** Participants were screened for cognitive impairment using *COGNISTAT* (The Northern California Neurobehavioral Group, Inc., 1995), formerly called the *Neurobehavioral Cognitive Status Examination* (Kiernan, Mueller, Langston, & Van Dyke, 1987). *COGNISTAT* is a 10 - 20 minute evaluation of a patient's level of consciousness, orientation, attention, comprehension, repetition, naming, constructions, memory, calculations, similarities, and judgment. Validity and reliability measures have been ascertained through comparisons with many instruments (Engelhart, Eisenstein, & Meininger, 1994; Kazmark, 1997; Oehlert et al., 1997; Roper, Bieliauskas, & Peterson, 1996; van Gorp et al., 1999; Wallace, Caroselli, Scheibel, & High, 2000) and show *COGNISTAT* to be 93% - 94% sensitive in identifying cognitive impairment with two or more impaired scales (Schwamm, Van Dyke, Kiernan, Merrin, & Mueller, 1987; van Gorp et al., 1999). The standardized procedure is conducted by administering one complex screening item for each of the cognitive ability areas mentioned above. If the participant does not respond to the screening item accurately, the full metric is presented to quantify level of ability. Scores outside of the normal range on at least 2 of the 10 scales suggest cognitive impairment. NI participants with two or greater impaired ability areas on *COGNISTAT* were excluded from this investigation (Roper et al., 1996). Participants with PD were not excluded from the investigation based on the outcome of this measure.

**c. Mood** Supplementing the results of *COGNISTAT*, one additional measure was used—the *Beck Depression Inventory* (*BDI*) (Beck, Ward, Mendelson, Mock, & Erbaugh, 1961). This widely used, reliable, and valid depression scale (Beck, Steer, & Garbin, 1988; Beck et al., 1961; Kline, 1993; Richter, Werner, Heerlein, Kraus, & Sauer, 1998) determined the presence and degree of depression in all participants. The *BDI* is a 21-question inventory that asks patients to rate their depressive feelings and attitudes on an ordinal scale. The *BDI* was normalized using 226 psychiatric inpatients and outpatients as control subjects and an additional 183 patients for replication purposes. The 409 patients were 61% female (39% male), 65% Caucasian (35%

Black) and between the ages of 15 and 55+ years. Additionally, patients tended to be in lower socioeconomic groups. The 21 questions contained in the *BDI* use a 4-point scale with scores from 0 to 3 (maximum score = 63). As such, scores of 10 or less are attributable to "ups and downs" and are considered to be within normal limits. Any patient scoring 11 - 16 is suggested to have a mild mood disorder, but these patients are not considered depressed. Scores of 17 - 20 translate as borderline clinical depression. Patients with scores over 20 span the diagnosis of depression, including extreme depression beyond a score of 40. Consequently, NI participants were excluded from this investigation with scores greater than 16. However, because depression is very common in Parkinson's disease, participants with PD were not excluded, regardless of their score on the *BDI*.

## B. INSTRUMENTATION

### 1. Hardware

This study employed the use a notebook computer (data computer), which has a 1.6-GHz processor with 256-MB RAM, for the primary experimental control and data logging during the experiments. The data computer was responsible for the execution of the timer, commencement cue, and presentation of the stimuli. With the exception of the submental surface electromyography (sEMG) signal information, the data computer also collected and entered all timing-related data, in real time, to a Microsoft® *Access*® database (see *Instrumentation:*

*Software*). Visual cues were presented on a 17-inch, color, CRT computer monitor connected to this computer.

Hooked wire electromyography has been used for the measurement and timing of different muscle combinations throughout the oral cavity and pharynx (Doty & Bosma, 1956; Palmer, Tanaka, & Siebens, 1989; Perlman et al., 1999). In lieu of this invasive technique, surface electromyography (sEMG) is a non-invasive, viable alternative for observations of submental activity, especially for research in swallowing and swallowing disorders (Cook et al., 1989; Crary & Baldwin, 1997; Ertekin et al., 2001; McKeown et al., 2002; Shaker et al., 1990). There are shortcomings to sEMG, however. As a whole, it is difficult to interpret specific muscle contributions with sEMG (and better to be thought of in terms of a "region" of muscle activity) due to a number of factors. These factors include the distance between and size of the electrodes relative to the size of the muscles of interest and the location of muscles deeper than directly under the skin (Luschei & Finnegan, 1997). Despite these difficulties, a close temporal alignment (60 ms - 150 ms) with sEMG and events of the oropharyngeal swallow (i.e., onsets of tongue tip movement, tongue base movement, and superior hyoid movement) as viewed using videofluoroscopy and esophageal manometry have been found (Cook et al., 1989). Using these techniques, with the addition of transnasal endoscopy, these findings were later replicated by Shaker et al. (1990). The *Kay Digital Swallowing Workstation* (Digital Swallowing Workstation, model 7100, Lincoln Park, NJ: Kay Elemetrics) was used to trace and record the submental sEMG signals. Submental sEMG recordings were obtained using three silver-silver chloride electrodes (2 active, 1 reference) spaced 10 mm apart on a 2.5-inch (6 cm) diameter adhesive patch (Dura Stick EMG Electrodes, Part 42109, Hixon, TN: Chattanooga Group, Inc). The offset of the sEMG signal was used to mark the completion of the oropharyngeal swallow.

In addition to recording submental sEMG tracings, the *Workstation* employed two auxiliary channels, AUX1 and AUX2, in the data acquisition unit. The *Workstation's* data acquisition unit, or *Swallowing Signals Lab* (model 7120), used these two channels to capture the event timing marks (voltage pulses) and cup tilt angle as generated by a custom interface box.

A custom interface box was constructed to provide the connection between the data computer (via the parallel port), the cup tilt circuitry, and the *Workstation's Swallowing Signals Lab* (Figure 1). The interface box consists of a 16F876 microcontroller, which accepts the data stream from the cup tilt circuit via a receiver. The microcontroller also is connected to the data computer to accept the start signal and transmit hand displacement, foot displacement, and cup critical angle reached signals. These signals will be discussed in detail shortly. A hand lift sensor, foot movement sensor, and a foot-activated pedal were also connected to the interface box microcontroller. *Presentation*, software used for stimulus presentation and data acquisition, generated voltage pulses logged through the *Workstation's* AUX1 channel. These pulses acted as event marks for data analysis. An analog voltage proportional to cup tilt was logged through the *Workstation's* AUX2 channel and was linked in time through the interface box microcontroller and *Swallowing Signals Lab* as it is displayed in a separate window (Figure 2).

The cup tilt circuit was placed in the bottom recess of a round, 8 oz. (237 ml), disposable cup (Solo® Hot Drink Cups, No. 378). The cup was 3⅝" in height, 3" in diameter at the rim and 2" in diameter at the base. This circuit contained a 16LF826 microcontroller that accepts the roll and pitch signals from an ADXL accelerometer, calculates the absolute tilt in degrees, and transmits that calculated value to the interface box. The cup tilt calculated from the combination of the accelerometer roll and pitch signals was used to determine the angle at which the cup delivers its liquid contents over the rim operationally defined as the critical angle (Figure 3).

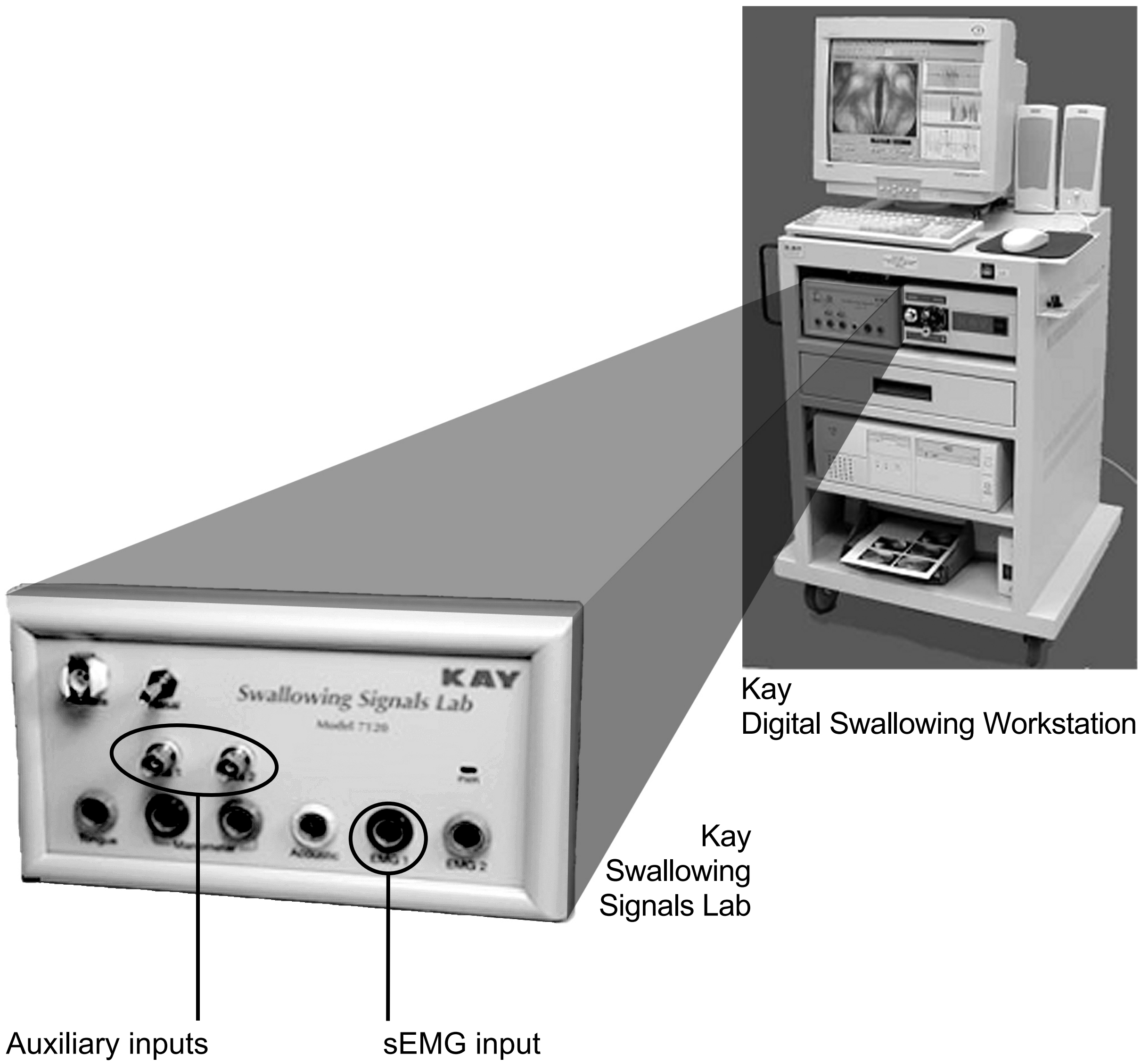


*Figure 1.* *Kay Digital Swallowing Workstation* with *Swallowing Signals Lab* (Model 7120) and associated experimental connections.

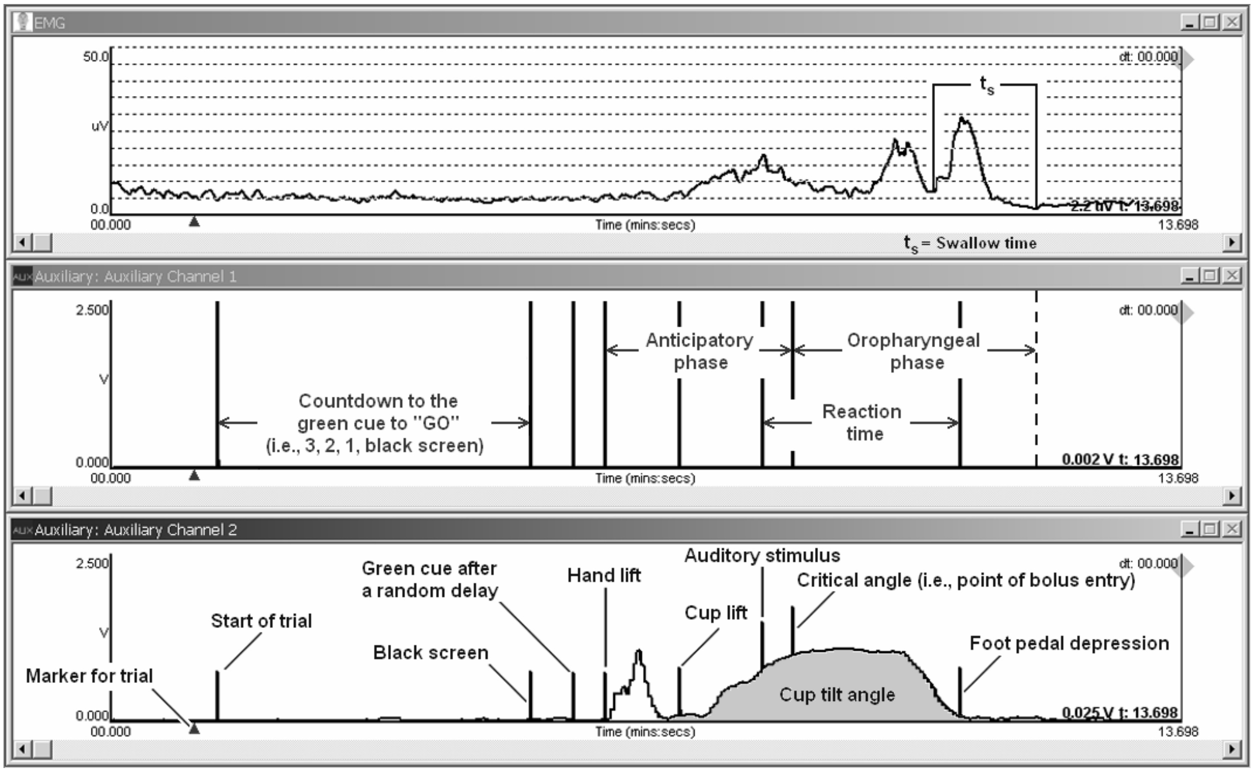


*Figure 2*. Sample screenshot of the *Kay Digital Swallowing Workstation's* time-linked, composite signals screen.

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The sEMG signal, displayed in the top window, is collected without interference from other signals in a dedicated channel through the *Swallowing Signals Lab*. The middle window (Auxiliary Channel 1) captured all input sensors. The bottom window (Auxiliary Channel 2) captured all input sensors in addition to the cup tilt trace. The auditory stimulus, for purposes of this screenshot, was presented in the anticipatory phase of swallowing.

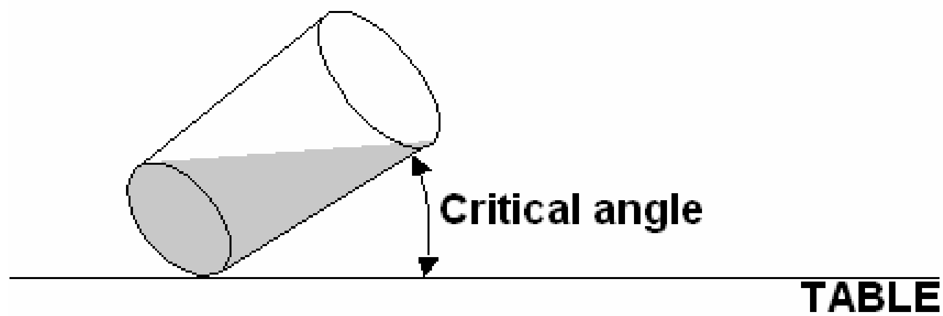


*Figure 3*. Depicted operational definition of the critical angle of the drinking cup.

This critical angle was established empirically in two ways. The first manner was through the use of a protractor to calibrate the angle between the side of the cup facing the table when it was tilted immediately before 5 ml of water flowed over the rim and the table surface. Pre-experiment testing using a protractor showed a consistent critical angle of 80° ± 1° with respect to the side of the cup facing the table and the surface of the table. The second manner used to determine the critical angle was by the voltage output from the cup microcontroller to the interface box. In this manner, the window linked to AUX2 on the *Workstation* was used to measure the change in voltage across time, as the voltage output was directly related to the cup's angle.

Two light-sensitive sensors were used to mark time—one was placed on the table associated with the participant's dominant hand and the other was placed under the drinking cup. The purpose of these two sensors was to mark relative timings (through event pulses) and ultimately determine reaction time (RT) from the "go" signal and other behavioral events. The first sensor, connected directly to the interface box, was used to determine when the participant's hand was displaced from the table (hand sensor). The second sensor, fixed in place under the cup, determined the point at which the cup was removed from the surface of the table (cup lifted contact). Pulses marking these hand and cup movements were relayed through the 16F876 microcontroller to both *Presenation* for data acquisition and transfer to a Microsoft® *Access*® database and the *Swallowing Signals Lab* auxiliary channels for graphical display and backup data acquisition.

Similar to the hand sensor's connection, the foot sensor and the foot pedal were connected to the 16F876 microcontroller and placed on the floor just ahead of the participant's dominant lower extremity. The foot sensor was used in the same manner as the hand sensor—to detect movement. The foot pedal used was borrowed from a typical transcription machine. The purpose of this apparatus was to record responses associated with the non-word, auditory stimuli during the baseline/single-task and dual-task RT testing. Figure 4 contains a functional schematic for the hardware setup of this investigation. A more detailed, electrical schematic is presented as Figure 5.

**2. Software**

The software used for this investigation required the data computer to operate under the Microsoft® *Windows*® *Millennium Edition* (*ME*) operating system[2]. Supported by the National Institute of Neurological Disorders and Stroke, Neurobehavioral Systems, Inc. (2002) designed software capable of stimulus delivery and data acquisition called *Presentation*. This software

[2] *Windows*® *95*, *98*, and *ME* operating systems are recommended for use with *Presentation* because timings are reported to be more accurate and the execution of stimuli occur with less delay using these environments. *ME* was chosen because it was the only one of the three operating systems capable of running on the data computer given the system's hardware configuration.

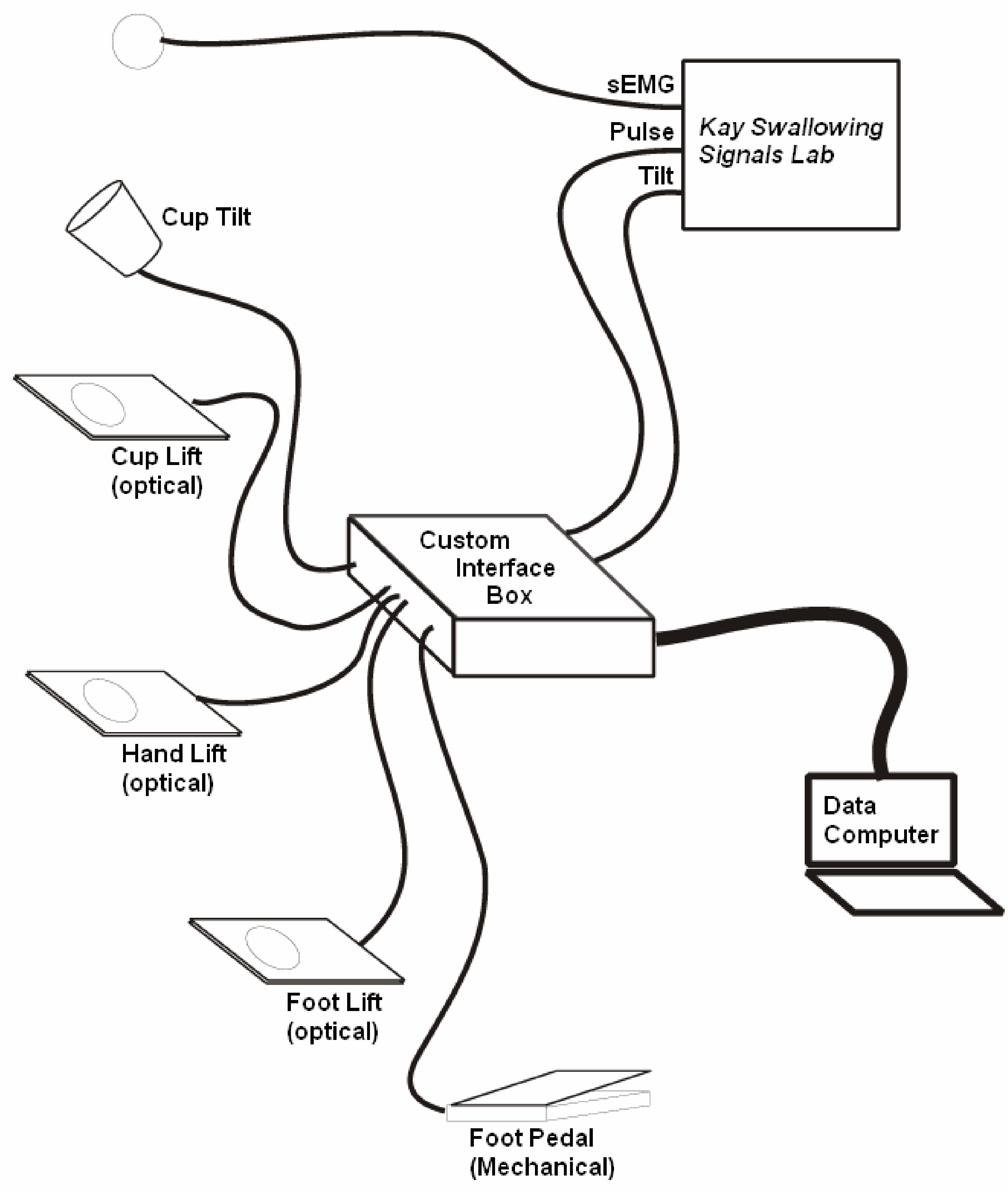


*Figure 4*. Functional schematic for the hardware connections used.

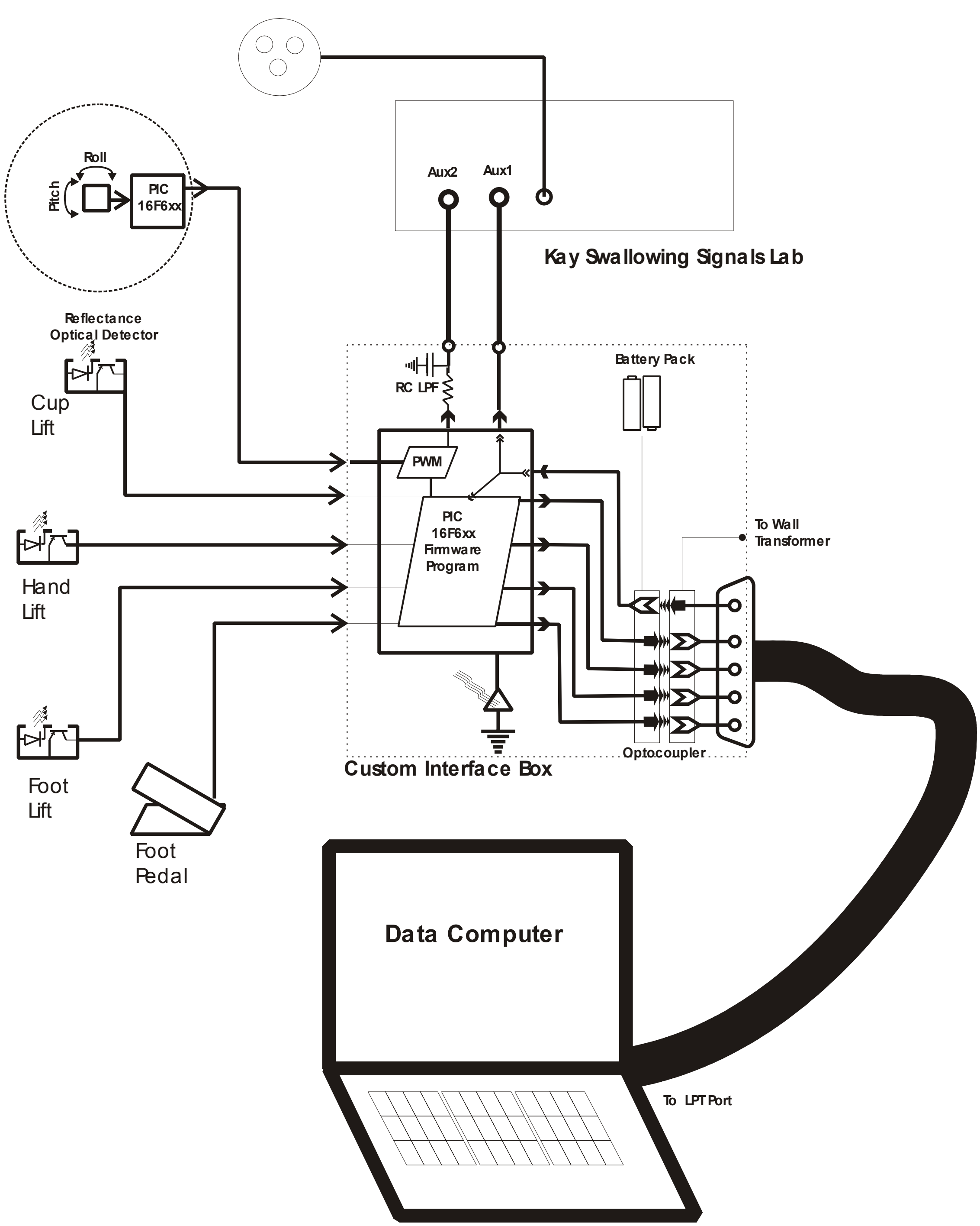


*Figure 5*. Electrical schematic for the hardware connections used.

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Power and ground omitted for clarity.

was implemented as core for the execution of this investigation due to its precision in timing using PC hardware. With this software, and in conjunction with the *Windows*® *ME* operating system, timings for both the presentation of stimuli and the collection of data are made reliably within tenths of a millisecond precision. Additionally, as a part of the software package, *Presentation* verifies and reports all timings to detect operating system discrepancies. A Microsoft® *Access*® script and database were constructed to work in tandem with *Presentation* for the purposes of experimental control (e.g., commencement of baseline/single-task and dual-task trials, delivery of auditory stimuli), data recording, and off-line data compilation and analysis. Visual Basic scripts were written and compiled to run *Presentation* through an *Access*® interface, whereby the stimuli were able to be administered and online timing error and participant error analyses could be completed.

Specific to this investigation, *Presentation* was programmed to provide the experimenter with the ability to begin experimental trials and immediately introduce the digitally recorded, word-level stimuli on command by depressing the keyboard's space bar. *Presentation* recorded the onsets of all sensors and timing pulses, including the critical angle of the cup, presentations of the auditory stimuli via the speakers directly adjacent to the computer monitor and depression of the foot pedal. These timings were then imported to the *Access*® database. In addition to database entry of the event timings being recorded, all sensors and timing pulses mentioned above were sent to the *Swallowing Signals Lab* to be recorded graphically as pulses in both auxiliary windows and time-linked with the sEMG trace. Errors in system timing were recorded in *Presentation* and subsequently imported into *Access*®. The redundancy in the system was purposefully programmed as such to provide backup to the data collected. Software testing prior to participant enrollment revealed that the graphic pulses recorded by the *Workstation* using a sampling rate of 1000 Hz are identical to the numerical data recorded by *Access*®.

### 3. Data security

All data collected for this investigation were safely stored using password protected computer systems. To ensure confidentiality, participants' names were kept in a Microsoft® *Excel*® file separate from the database. Though the database contained some demographic data (e.g., gender, study group, dominant hand, dominant foot, age), participants' names were not included as part of this information. Only numbers assigned at the time data were collected can identify the participants in the database. These participant identification numbers began at "01" and continued serially in 1-unit increments. All folders and written materials associated with this investigation were stored in a locked filing cabinet in the researcher's office. Access to these files and the computer data files was limited to the researchers.

### 4. Physical setup

This investigation took place in a quiet, distraction-free environment. The participant testing area was split between a table setup and a floor setup. The table setup was comprised of a table, 17-inch, color, CRT computer monitor, hand sensor, cup, cup sensor, cup module, and two powered, satellite computer speakers. The computer monitor, connected to the data computer for stimulus presentation, was placed at eye-level on the table approximately 18 in. from the participant. On the table between the seated participant and the monitor was one hand lift sensor, one cup lift sensor, and one 8-oz. disposable drinking cup containing the microcontroller and accelerometer for measuring change in cup orientation (i.e., cup module). The hand lift sensor was placed flush with the front edge of the table. The cup lift sensor was placed 12 in. from the front edge of the table centered in line with the hand sensor and computer monitor. These two sensors were secured to the table with clear packaging tape for the duration of the investigation. The electronic cup module was placed in the bottom recess of the disposable cup and secured in place by a plastic jacket and adhesive tape. Finally, each of the two satellite computer speakers was placed on either side of the computer monitor at a distance of approximately 36 in. from the participant's ear to the front of the speaker. The speakers were connected to the data computer's audio output (Figure 6).

The floor setup was adjusted on a participant-by-participant basis. On the floor and immediately in front of the participant's dominant lower extremity were a foot sensor and a foot pedal used for the RT portions of this investigation. With the participant seated at the table and able to comfortably reach the cup containing water, his or her upper and lower leg was placed at an approximate 90-degree angle of flexion to determine placement of the foot sensor. The foot sensor was placed under the participant's foot and secured to the floor. Once the foot sensor was in place, a distance of 6 in. was measured from the tip of the participant's shoe when placed on the foot sensor to the front edge of the foot pedal and secured for placement (Figure 7).

Beside the table holding the monitor was a table for the *Workstation*. Electrode wires for bi-polar (plus one reference) submental sEMG were connected to the *Swallowing Signals Lab,* which was connected to the *Workstation* (Figure 1). Consequently, the *Swallowing Signals Lab* was set close to the participant, allowing him or her to move relatively freely and remain comfortable while the electrodes were connected. The *Workstation's* computer monitor was

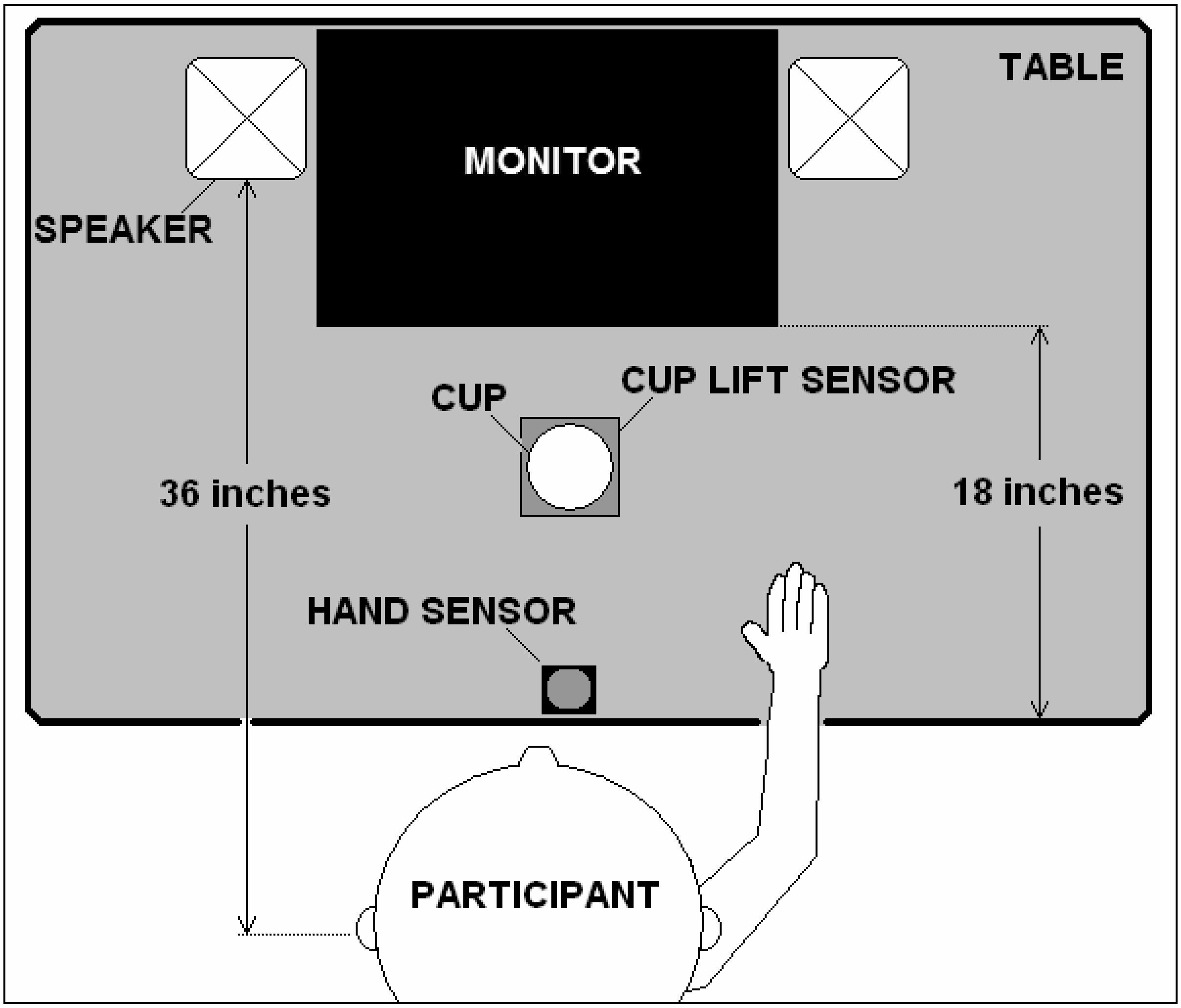


*Figure 6*. Physical setup of the investigation—Table.

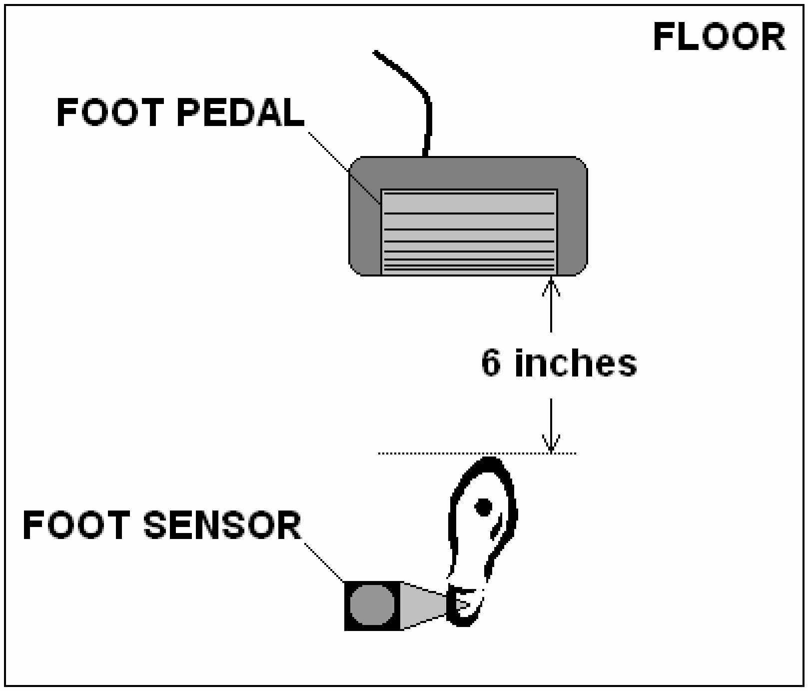


*Figure 7*. Physical setup of the investigation—Floor.

angled toward the researcher and away from the participant to disallow viewing of the *Workstation's* computer monitor. By positioning the monitor in this manner, the researcher was able to observe the computer's functions while eliminating potential visual distractions and/or influence from the testing environment. The data computer, with external mouse connected, was set on the table adjacent to the *Workstation*. The researcher was seated behind and out of view from the participant, eliminating this as a potential visual distraction.

## C. BASELINE/SINGLE-TASK CONDITION

The purposes of this portion of the investigation were to: (a) reduce the learning on trials during the experimental task and (b) provide controlled, baseline/single-task data for comparison with dual-task data collected later in the investigation. Two sets of 19 trials each were collected for this phase of the investigation: swallowing trials and non-word discrimination trials. For each trial type, the initial 3 trials were expected to contribute to an extinction of learning for the task (Schmidt & Lee, 1999). The last 16 trials for each set provided information about reaction times and phase times in swallowing and non-word discrimination in the baseline/single-task condition. The order of swallowing and non-word discrimination trials during the baseline/single-task conditions was counterbalanced across participants in an attempt to control for order effects.

### 1. Swallowing

The underside of the participant's mandible was prepared with an alcohol swab. Following this preparation, electrode gel was placed on the electrode surfaces of the self-adhering patch containing 3 electrode disks for sEMG. The prepared patch with electrode disks then was placed over the area commensurate with the digastric-mylohyoid-geniohyoid muscle complex (Figure 8). The 6-ft. lead wire for the sEMG signal was connected to the *Swallowing Signals Lab*, leaving enough slack to allow the participant relatively free movement, then to each of the electrode disks by clip on the participant. Data acquisition was accomplished employing the hardware and software furnished with the *Workstation*, allowing the sEMG signal to be

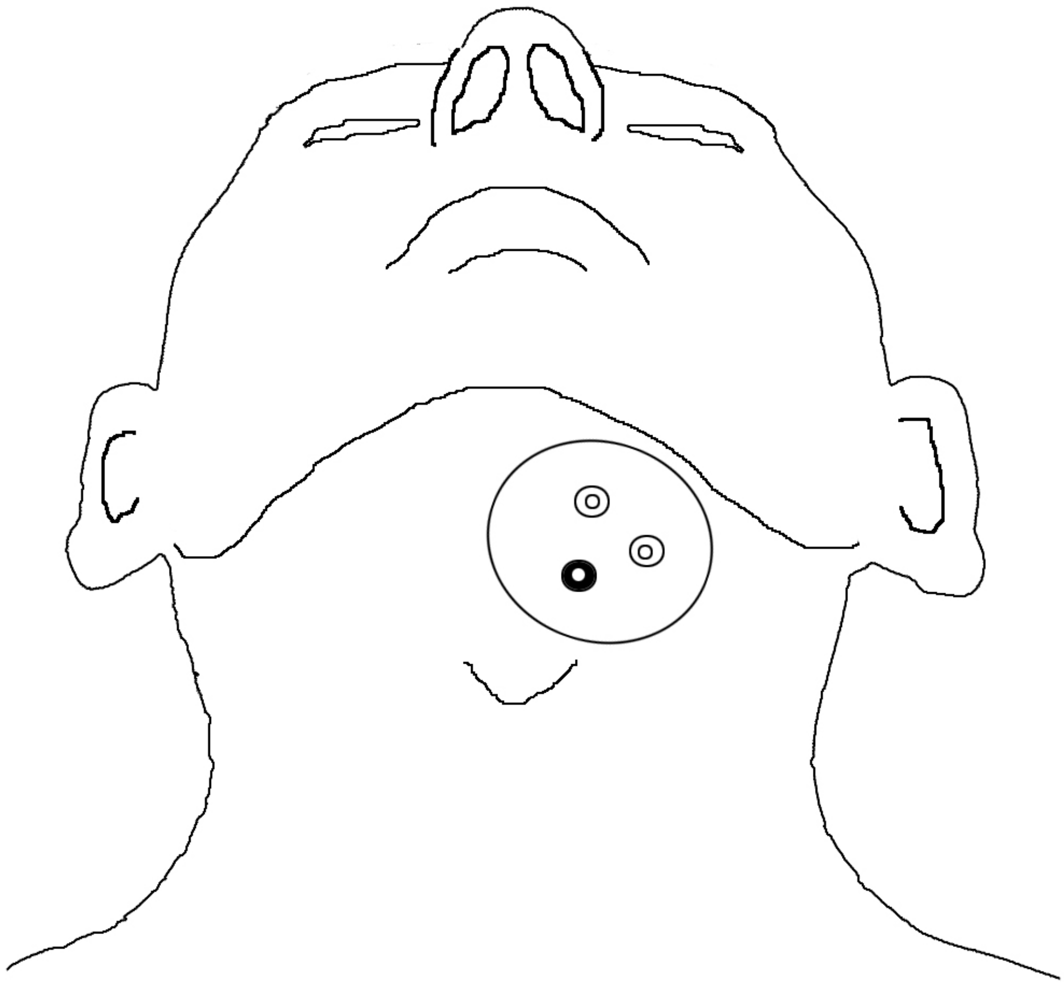

*Figure 8*.  Typical placement of the sEMG electrode patch and alignment of the electrodes.

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The two white disks on the adhesive patch represent the two active electrodes and the blackened disk represents the reference disk.

amplified, rectified, and subsequently displayed automatically in a separate, time-linked window from the auxiliary channels that displayed the pulses from events sent by *Presentation* and the custom interface box (Figure 2).

Once the sEMG was setup, the participant was given instructions for the baseline/single-task trials. For all swallowing baseline/single-task trials, the participant was instructed to place his or her dominant hand with the palm resting comfortably on the hand sensor fixed to the table. For the RT baseline/single-task trials, the participant was asked to place his or her foot comfortably on the foot sensor in the same position that was explained in the physical setup. Because the food pedal was under the table and out of plain sight, the researcher asked each participant to move his or her foot back and forth between the foot sensor and the foot pedal as if it were the brake pedal of an automobile. The purposes of this direction were to (a) familiarize the participant with the placement and feel of both devices and (b) to reduce learning that might have taken place during the experimental trials.

After the initial setup was completed, participant information was input to the database in the data computer. Baseline/single-task trials, as all trials, were coded using unique identifiers for input to the computer. Next, the participant's gender, age, group (viz., NI or PD), stage of PD (if applicable), dominant hand, and testing date were entered. Participants then were read the following instructions by the researcher for the baseline/single-task swallowing trials:

> *"For this part of the experiment, you will be swallowing about 20 times. For all swallowing trials, you will face the computer monitor, and place your hand on the sensor as it is placed right now. You will be given a visual countdown from '3' to '1' to prepare you for an upcoming green 'go' circle. As soon as you see the green 'go' circle, take the cup in hand and drink the teaspoon of water that is in it*

*in one swallow in a normal manner. When you are finished, place the cup back on the table. Are you ready?"*

A *Presentation* script, specifically written for this investigation, was used. This script was a researcher-initiated and researcher-controlled interface. To begin these baseline/single-task trials, the program commenced with a 3-s countdown once the participant indicated his or her readiness verbally. The countdown, displayed on the 17-in. monitor, proceeded with the word "Ready," followed by the characters "3," "2," and "1" in 72-point, white, Times New Roman font on a black background. A randomly imposed delay between 500 ms and 2000 ms following this countdown then appeared, during which time the computer screen was completely black. This delay forced unpredictability in the task whereby participants were unable to anticipate the timing for the response, ultimately discouraging reduced reaction times through learning (Rizzo & Robin, 1990, 1996; Robin, Max, Stierwalt, Guenzer, & Lindgren, 1999). After this delay, a green circle 3 in. in diameter appeared in the center of the computer screen, prompting the participant to begin his or her response to drink the water in the cup. During this baseline/single-task procedure, participants drank 5 ml of filtered water (measured using a graduated syringe) immediately following the green cue. Prior to the start of the next trial, the experimental cup was refilled and returned to the cup lift by the researcher and the participant returned his or her hand to the starting position on the hand sensor.

The study by Adnerhill et al. (1989) influenced the volume of water used for each experimental trial. They demonstrated that the average size of a water bolus is 20 ml for women and 25 ml for men. Further, they showed the size of an average liquid bolus (using water, Coca-Cola, and liquid barium) to be 21 ml (*SD* ± 5 ml; range 8 - 59 ml) across all of their subjects. For this investigation, it was essential that the participants did not perform multiple swallows when drinking the water. Also, to avoid difficulties with undiagnosed swallowing disorders, specifically in the participants with PD, a smaller, safer, and more clinically relevant and representative volume of 5 ml was selected—the size of a standard teaspoon (Martin-Harris, Logemann, McMahon, Schleicher, & Sandidge, 2000).

All data were recorded electronically, with a sampling rate of 1000 Hz per channel, allowing millisecond accuracy for data collection. As such, the computer software and database used for this investigation recorded timings in milliseconds. The primary dependent measures for the baseline/single-task swallow were timing of the anticipatory phase and timing of the oropharyngeal phase of swallowing. Duration of the anticipatory phase is operationally defined as time between onset of hand displacement from the hand sensor to the time at which the critical angle of the cup is reached. Duration of the oropharyngeal phase is operationally defined as time between onset of critical angle of the cup and the return of the submental sEMG signal to baseline following the completion of the swallow (i.e., sEMG offset). The first 3 trials of the 19 presented during this baseline were used to help extinguish learning. The remaining 16 trials were considered to represent the baseline/single-task swallowing condition.

As noted, each participant received at least 19 trials of the baseline/single-task condition. More trials were presented, taking into consideration computer malfunction, sensor malfunction, and participant error. The task's instructions were not repeated prior to the commencement of trials 2 through 19. However, the participants were allowed to ask for, and consequently received, repeated instructions. Baseline/single-task condition trials, as all trials in the investigation, were experimenter-initiated, however participant-directed (i.e., the trials began when the participant stated they were ready to begin).

Following completion of the baseline swallowing trials, the participant was given a short break so the researcher could set up the equipment for the next set of trials, orient the participant to the new task, and provide the participant with an opportunity to use the restroom if desired.

**2. Non-word discrimination reaction time**

**a. Procedure** The participant was seated comfortably in the chair at the table, with the dominant lower extremity at approximately 90 degrees of flexion. With the participant's foot in this position, the foot sensor was placed under the participant's heel. The foot pedal was then placed on the floor as well with the front edge of the pedal 6 in. from the tip of the participant's shoe. Both devices were secured to the floor using clear packing tape to prevent movement between trials. At the outset of all trials, the participant was instructed to place his or her foot on the sensor. The researcher visually confirmed this positioning for all trials.

After the initial setup was completed, participant information was input to the database in the data computer as previously described. Participants then were read the following instructions by the researcher:

> *"For this set of about 20 trials, you will sit facing the monitor, resting your arms comfortably. You will position your foot, as it is positioned now, on the foot sensor. You will be given a visual countdown from '3' to '1' to prepare you for the task. At some point after this countdown, you will hear a word that has no meaning. Pay close attention to this word. If you hear the word* /vɛv/ (*or* /zɑz/, *given the counterbalancing*), *tap the foot pedal as quickly as you can; DO*

*NOTHING for any other word. It is important that you tap the foot pedal when you hear the word* /vɛv/ (*or* /zaz/)*, only. Are you ready?"*

A *Presentation* script specifically written for this investigation was used. This script is a researcher-initiated and -controlled interface. To begin these baseline trials, the program commenced with a 3-s countdown once the participant indicated readiness verbally. The countdown, displayed on the 17-in. monitor, proceeded with the word "Ready," followed by the characters "3," "2," and "1" in 72-point, white, Times New Roman font on a black background. A randomly imposed delay between 500 and 7000 ms[3] following this countdown occurred, during which time the computer screen was completely black. At some point during this time interval, a non-word distractor, with the exception of trials that had the target word, was selected randomly and with replacement by the computer from a corpus of non-words (see the section *Non-word stimuli*). The target word was presented four times. Words were presented auditorily through the computer speakers adjacent to the computer monitor. Word presentation occurred at 85 dB SPL, slightly above the sound level of normal conversation (Gower, 2001; Hear-It.org, 2002; National Ag Safety Database, 1985) to compensate for ambient noises such as computer fans and noises outside the room, as measured by a portable sound-level meter placed near the participants' ears. Sound level was calibrated for each participant. If the target word was heard, the participant was expected to tap the foot pedal as quickly as possible using his or her dominant lower extremity. In the alternative, if the target word was *not* the word presented, the participant was expected to do nothing. Prior to the start of the next trial, the participant returned

[3] This interval was chosen to mimic the length of time under the dual-task condition, which includes swallowing time.

his or her foot to its original starting position on the foot sensor and the researcher checked placement.

All data were recorded electronically, with a sampling rate of 1000 Hz per channel, allowing millisecond accuracy for data collection. As such, the computer software and database used for this investigation recorded timings in milliseconds. The dependent variable for all trials in this set is RT, measured as the time between onset of the auditory stimulus and the participant's depression of the foot pedal. The first 3 trials of the 19 presented were used to help extinguish learning. All participants were given, in order, 1 distractor trial, 1 target trial, and finally 1 distractor trial as his or her first three trials. The remaining 16 trials were considered to represent the baseline/single-task, non-word discrimination condition. Finally, only 4 of the 16 remaining trials contained the target non-word, simulating the dual-task condition of two target trials for each of the two phases of swallowing. Therefore, the potential for the target word to be heard four times started with trial 4. The task's instructions were not repeated prior to the commencement of trials 2 through 19. However, participants were allowed to ask for, and consequently receive, repeated instructions. The trials continued in a participant-directed manner, but experimenter-initiated. Following completion of the trials for this baseline/single-task, the participant was given a break so the researcher could set up for the next experiment, orient the participant to the new task, and provide the participant with an opportunity to use the restroom if desired.

**b. Non-word stimuli** The stimuli for both baseline/single-task and the dual-task conditions consisted of digitally recorded and presented, phonotactically legal, monosyllabic non-words. All words were in the form consonant-vowel-consonant (CVC) with the same lead (CV-) and different codas (--C). Because there is a tendency for voiced, final consonants to alter the length of the vowel in monosyllabic words (Shriberg & Kent, 1995), the lead part of the non-words were recorded separately and digitally mixed with the codas, ultimately forming identical length words of 550 ms each. Twelve different non-words were presented to the participant—11 of these stimuli were classified as *distractors*, requiring no response from the participant, and the remaining stimulus was considered the target. Two lists of words, containing 11 distractors and 1 target each, were used. List A contained the lead /vɛ-/ and target word /vɛv/. List B contained the lead /zɑ-/ and target word /zɑz/ (Table 2). Lists were counterbalanced between baseline/single-task and dual-task trials across participants.

**c. Validation of stimuli** The non-word stimuli were recorded by a native Midwestern, male speaker. Once digitally recorded and mixed into their appropriate lengths, the non-words were electronically presented to 10 volunteers for orthographic transcription. Eligible volunteers consisted of anyone over 18 years of age who passed a hearing screening at 30 dB HL. A criterion level of 70% or greater constituted keeping the word as presented for a stimulus in the baseline/single-task and in the dual-task experiment. Any word offering less than 70% accuracy in orthographic transcription necessitated the removal of that word.

Table 2

*Baseline/single-task and dual-task auditory stimuli*

| List A (/vɛ-/ non-words) | List B (/zɑ-/ non-words) |
|---|---|
| /vɛv/ - Target word | /zɑz/ - Target word |
| /vɛz/ | /zɑv/ |
| /vɛb/ | /zɑb/ |
| /vɛd/ | /zɑd/ |
| /vɛg/ | /zɑg/ |
| /vɛn/ | /zɑn/ |
| /vɛdʒ/ | /zɑdʒ/ |
| /vɛl/ | /zɑl/ |
| /vɛm/ | /zɑm/ |
| /vɛð/ | /zɑð/ |
| /vɛŋ/ | /zɑŋ/ |
| /vɛʒ/ | /zɑʒ/ |

## D. DUAL-TASK CONDITION

The dual-task condition followed the baseline/single-task condition for all participants. Counterbalancing order of baseline/single-task and dual-task conditions was not possible because the investigation was set up for the baseline/single-task condition to necessarily precede the dual-task condition to reduce learning and familiarize the participant with the experimental procedures. The dual-task condition combined both baseline/single-task conditions—swallowing and non-word, discrimination, RT trials. Similar techniques to those used in the baseline/single-task condition were used for this part of the investigation. The overall purpose of this dual-task condition was to determine whether attention is used in the anticipatory and oropharyngeal phases of swallowing and to what degree, relative to each other.

The participant was seated comfortably in a chair facing a computer monitor. Once seated, positioning of both the participant's hand and foot on their respective sensors was confirmed by the researcher as they were previously during baseline trials. At the outset of all trials in this condition, the participant was instructed to place his or her hand and foot in their respective positions.

After this setup was completed, participant information was input to the database in the data computer as previously described. The researcher then read the following instructions to the participants for the dual-task experiment:

> *"For the next trials, again you will be seated facing the monitor with your hand and foot in their appropriate locations. You will be given a visual countdown from '3' to '1' to prepare you for the presentation of a green 'go' circle. As soon as you see the green 'go' circle, take the cup in hand and drink the teaspoon of*

*water that is in it in your normal manner. At some point during this task, you will hear a word that has no meaning. Pay close attention to these sounds. If you hear the word /*vɛv*/ (or /*zɑz*/, given the counterbalancing), tap the foot pedal as quickly as you can; DO NOTHING for any other word. It is important that you tap the foot pedal when you hear the word /*vɛv*/ (or /*zɑz*/) only. When you are finished drinking, place the cup back on the table. Are you ready?"*

A *Presentation* script, specifically written for this experiment, was used. This script is a researcher-initiated and researcher-controlled interface. To begin these experimental trials, the program commenced with a 3-s countdown once the participant indicated his or her readiness verbally. The countdown, displayed on the 17-in. monitor, proceeded with the word "Ready," followed by the characters "3," "2," and "1" in 72-point, white, Times New Roman font on a black background. A randomly imposed delay between 500 and 2000 ms following this countdown occurred, during which time the computer screen was completely black. After this delay, a green circle 3 in. in diameter appeared in the center of the computer screen, prompting the participant to begin his or her response to drink the water in the cup. Participants drank 5 ml of filtered water (measured using a graduated syringe) immediately following the green cue. At some point during this act of drinking, between the green cue and the completion of the pharyngeal swallow, the participant was presented with a non-word from one of the two lists auditorily at 85 dB SPL. This sound level was previously calibrated during the baseline trials and, therefore, no further calibration was necessary. The presentation of the target non-word was pseudo-random, with respect to swallowing phase, across the 19 trials and across participants. Specifically, starting with trial 4, presentations of the target stimulus were evenly distributed between the two phases of swallowing (i.e., anticipatory and oropharyngeal): 2 presentations occurred at random moments during the anticipatory phase and 2 presentations occurred at random moments during the oropharyngeal phase for each participant. Additionally, the order of presentation for the phases of swallowing and the presentation trial number for these 4 target trials was random. Prior to the start of subsequent trials, the experimental cup was refilled and returned to its starting position by the researcher. The participant returned his or her hand and foot to their respective original positions on the sensors. Figure 9 illustrates the temporal arrangement of events during the dual-task paradigm.

All data were recorded electronically, with a sampling rate of 1000 Hz per channel, allowing millisecond accuracy for data collection. As such, the computer software and database used for this condition recorded timings in milliseconds. The dependent variables were the same as those used for the baseline/single-task conditions: RT to non-word discrimination stimuli during target trials, and duration of each of the anticipatory and oropharyngeal phases of swallowing for these target trials. Participants received 19 trials in the dual-task condition. The first three trials were not included in any of the analyses. Instructions for this dual-task were not repeated prior to the commencement of trials 2 through 19. However, the participant was allowed to ask for, and consequently receive, repeated instructions. Though all trials for all experiments within this investigation were experimenter-initiated, the trials were participant-directed. Participants were not told that there were 19 trials for this condition, nor were they privy to the fact that 4 trials contained the target word while the remaining trials contained words used as distractions. Data from distraction trials were not analyzed.

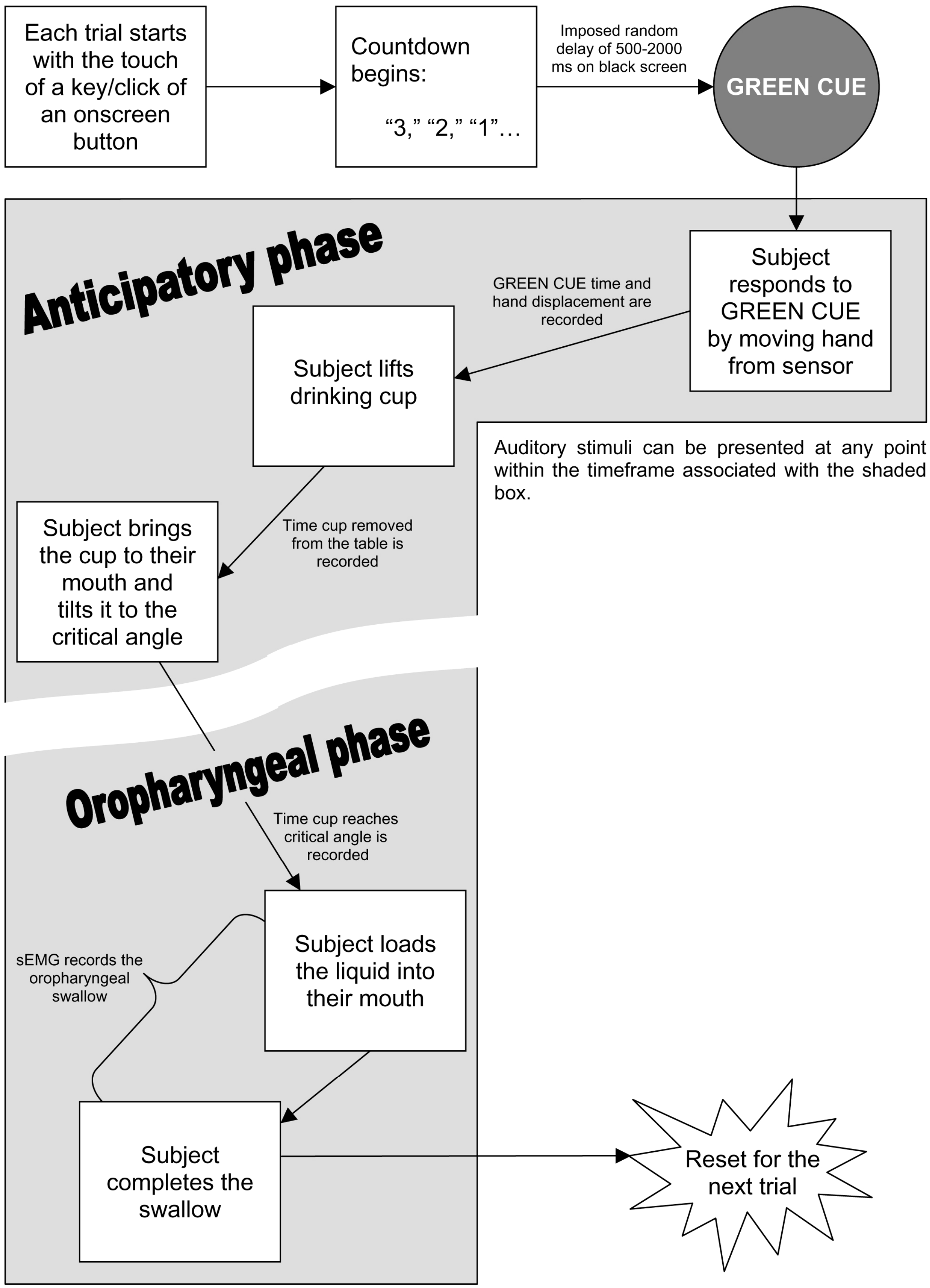


*Figure 9*. Temporal arrangement of events during the dual-task condition.

## E. RESPONSE SCORING

The core of the scoring method used for this investigation has been used previously (Rizzo & Robin, 1990, 1996; Robin, et al., 1999). Minor modifications were made based on changes in the experimental conditions. Any response to target stimuli occurring between 100 ms after the green cue and 2000 ms after a target stimulus was presented was considered a “hit” and appropriate for analysis (Rizzo & Robin, 1990, 1996; Robin et al., 1999). Additionally, two types of errors were recorded for dual-task trials—false alarms and missed targets. *False alarms* can occur in two manners, though not mutually exclusive of each other. In one manner, false alarms are trials where a participant moves his or her foot from the sensor *and* does not depress the foot pedal during distractor trials. The second type of false alarm is a response to target words occurring less than 100 ms from the completion of the target word stimulus. In either case, these trials were recorded as false alarms, though not analyzed in the pool of data collected. *Missed targets* were operationally defined as trials containing the target word without the participant depressing the foot pedal. These data, too, were tallied and recorded, but not analyzed.

The trials with the target word presented were done so in a ratio of 1:4 relative to the distractors in trials 4 - 19. This yielded a 25% chance (26% overall, including trial 2) that the stimulus could be presented, forcing the stimuli to be unexpected, and consequently minimizing learning of the task and over-reaction to it. A similar paradigm has been used in prior studies (M. Corbetta, personal communication, January 11, 2002; Hollerbach, et al., 1999; Schneider & Shiffrin, 1977).

## F. DATA REDUCTION AND STATISTICAL ANALYSIS

Event times were recorded as pulses in the *Workstation's* auxiliary windows and as millisecond measurements in the database (Figure 2). During the testing phases of the software, measurements using the graph on the *Workstation* and the numerical data collected in the database were identical for all timing events. Given agreement between instruments, database measures were used. Consequently, the opportunity for transposition errors from graph to database was prevented and reliability measures were not necessary for the pulsed events captured by the database.

Timing points for the sEMG data cannot be imported to the database electronically in a meaningful way. The completion of the oropharyngeal swallow was operationally defined as the offset ($t_{offset}$) of the submental sEMG signal (Figure 10). As a result, $t_{offset}$ was manually recorded and manually analyzed using the software on the *Workstation*. Because these data points needed to be identified subjectively through visual inspection and transferred as millisecond timings to the database manually, intrarater reliability was calculated. Reliability was calculated on 25% of the sEMG tracings from randomly chosen trials in both groups. Parametric descriptive statistics were calculated because the distributions of durations were generally found to be approximately normal (i.e., unimodal with no outliers, extreme values, or marked skewness). Distributions were analyzed for outliers using boxplots containing the median and standard deviation bars. In several instances, extreme outliers presented themselves in the data. Once identified, these were removed and the statistics were calculated based on the more normal subset of data.

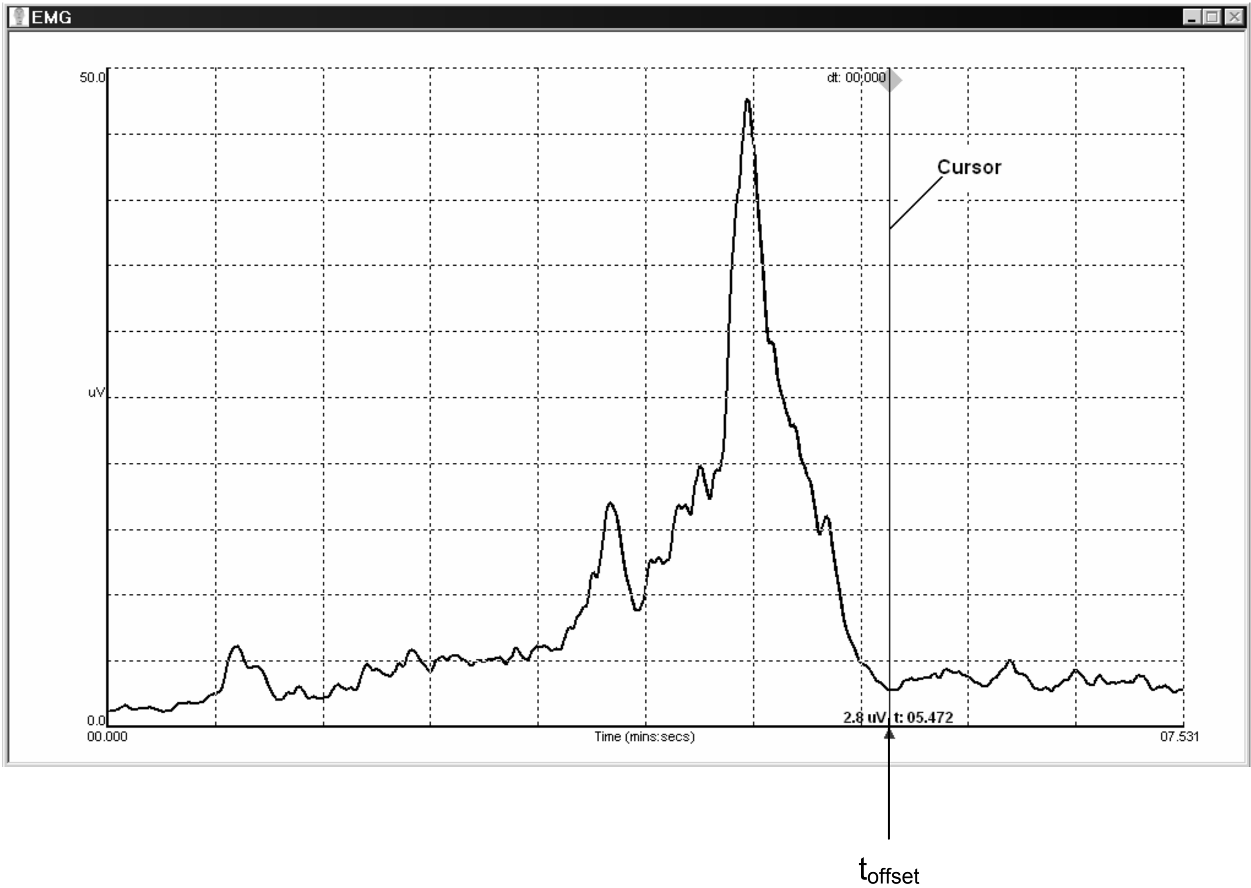


*Figure 10*. Screenshot of a 5 ml sample swallow sEMG tracing recorded by the *Kay Digital Swallowing Workstation*.

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$t_{offset}$ = offset of the submental sEMG signal, indicating the completion of the oropharyngeal phase.

To determine whether evidence is shown for sharing of cognitive resources (i.e., attention) across swallowing and verbal tasks, a repeated measures analysis of variance (RM ANOVA) was conducted to detect any statistically significant differences between trials within each group and statistically significant differences between groups, controlling for trials. The investigation-wide $\alpha$ was set at .20 due to the preliminary nature of the investigation. The four equations respectively assessed the following dependent variables in pre-planned comparisons: (1) differences in duration of phases of swallowing for the baseline/single-task condition, (2) baseline/single-task RT for non-word discrimination, (3) differences in duration of phases of swallowing during the dual-task condition, and (4) dual-task RT for non-word discrimination. Independent variables for each of the equations were condition (2; baseline/single-task versus dual-task), trials, and group (2; NI versus PD) (see Tables 3 - 5). Descriptive statistics were used to describe the remaining data (i.e., means, standard deviations, ranges).

An *a priori* statistical power analysis was computed for the RM ANOVAs using SamplePower™ (SPSS Inc., 1997). Ruthruff et al. (2001) suggested that dual-task interference effects typically occur with greater than 350 ms relative to single-tasks. In the researchers' plots of predicted dual-task RT and observed RT in their data, the range was broadened from over 400 ms in the easy tone task, to approximately 1000 ms at probabilities of .8. Based on a proposed effect size of .40 between groups, a rather conservative estimate of single-task versus dual-task, statistical power was estimated to be .82 with 14 cases per cell, yielding a total of 56 cases in a balanced design. In other words, 14 participants per group were needed for this study. Each factor included 2 levels. Factor A, groups, had NI participants and participants with PD. Factor B, condition, consisted of single-task and dual-task paradigms.

Table 3

*RM ANOVA for anticipatory phase swallowing duration*

| | Condition | |
|---|---|---|
| Group | Baeline/single-task | Dual-task |
| Non-impaired | $\theta_c - d_h$ | $\theta_c - d_h$ |
| Parkinson’s disease | $\theta_c - d_h$ | $\theta_c - d_h$ |

*Note*. $\theta_c$ = critical angle of cup; $d_h$ = displacement of the hand from the hand sensor.

Table 4

*RM ANOVA for oropharyngeal phase swallowing duration*

| | Condition | |
|---|---|---|
| Group | Baseline/single-task | Dual-task |
| Non-impaired | $t_{offset} - \theta_c$ | $t_{offset} - \theta_c$ |
| Parkinson’s disease | $t_{offset} - \theta_c$ | $t_{offset} - \theta_c$ |

*Note*. $t_{offset}$ = sEMG offset (i.e., completion of the oropharyngeal swallow; $\theta_c$ = critical angle of cup.

Table 5

*RM ANOVA for non-word discrimination RT*

| | Condition | |
|---|---|---|
| Group | Baseline/single-task | Dual-task |
| Non-impaired | $S_1 – S_0$ | $S_1 – S_0$ |
| Parkinson's disease | $S_1 – S_0$ | $S_1 – S_0$ |

*Note*. $S_0$ = onset of the non-word target; $S_1$ = depression of the foot pedal by the participant's foot.

After testing 10 participants in each group, preliminary statistical analyses revealed significant findings. The remaining 4 participants from each of the NI and PD groups were not recruited based on these findings. Effect sizes were calculated using Cohen's *d* (Cohen, 1988) *post hoc* for non-significant findings.

# III. RESULTS

## A. DATA COLLECTION

This investigation contained two studies and four conditions. The validation study contained one set of trials that determined appropriate auditory stimuli presented for both baseline/single-task and dual-task trials. The dual-task study contained three conditions. Each condition contained 19 trials presented to each participant (i.e., 3 conditions × 19 trials = 57 trials per participant) to test the hypotheses. The validation study results are presented first, followed by the dual-task results.

## B. STIMULUS VALIDATION

### 1. Demographics

Eleven participants (7 Caucasian; 4 Black/African American) participated in the stimulus validation portion of the study. All participants were female with an average age of 33 years (*SD* = 11 years, Range = 23 years - 52 years). Efforts were made to recruit participants from both genders and all races. Despite these attempts, participants were Caucasian and Black/African

American females.  Education levels for the participants ranged from high school graduate to Master's degree.

### 2.  Screening

No participant reported any neurological, cognitive, or psychological disorder.  All participants had their hearing screened for both ears via headphones at 30 dB HL for 500 Hz, 1 kHz, 2 kHz, and 4 kHz pure tones in a distraction-free room that was not sound-treated.  One participant did not pass the hearing screening and was consequently excluded, leaving a total of 10 participants for the final analysis.

### 3.  Auditory stimuli presentation and orthographic transcription

The auditory stimuli were presented at 70 dB SPL(A) as measured by a portable sound-level meter.  That is, the auditory stimuli were presented at approximately 40 db SL with the measurement of this level being taken at ear-level for each participant.  There were 12 /vɛ-/ non-words and 12 /zɑ-/ non-words that were presented for validation.  Validation of the non-words used in the dual-task study was based on participants' accuracy in orthographically transcribing the auditory stimuli presented as judged by the principal investigator.

Four of the 12 /vɛ-/ non-words were orthographicaly transcribed with less than 70% agreement from the intended target and removed as possible distractor stimuli.  They were /vɛð/ (20% agreement), /vɛʒ/ (50% agreement), /vɛm/ (60% agreement), and /vɛŋ/ (60% agreement).

The target /vɛ-/ non-word, /vɛv/, was transcribed with 80% agreement. The remaining seven words were used as distractors in both the baseline/single-task reaction time trials and in the dual-task trials.

Three of 12 /zɑ-/ non-words were orthographically transcribed with less than 70% agreement from the intended target and removed as distractor stimuli. They were /zɑð/ (20% agreement), /zɑŋ/ (30% agreement), and /zɑʒ/ (50% agreement). The target /zɑ-/ non-word, /zɑz/, was transcribed with 80% agreement. The remaining eight words were used as distractors in both the baseline/single-task non-words discrimination baseline trials and in the dual-task trials. The two final lists of stimuli with their respective orthographically transcribed percentage agreement are presented in Table 6.

## C. SWALLOWING STUDY

### 1. Data reduction

In this exploratory study, three conditions were devised to assess the potential involvement of attention in swallowing. A total of 19 trials for each of three conditions (i.e., baseline/single-task swallowing, baseline/single-task reaction time, and dual-task), or a total of 57 trials per participant, was selected based on balancing considerations of the amount of liquid that would be consumed relative to the number of trials presented within the timeframe of the study, and the potential for participant fatigue. At the time of study, results from all trials were

Table 6

*Auditory stimuli with orthographically transcribed percentage agreement*

| List A (/vɛ-/ non-words) | List B (/zɑ-/ non-words) |
|---|---|
| /vɛv/ - Target word (80%) | /zɑz/ - Target word (80%) |
| /vɛz/ (80%) | /zɑv/ (70%) |
| /vɛb/ (70%) | /zɑb/ (100%) |
| /vɛd/ (70%) | /zɑd/ (100%) |
| /vɛg/ (80%) | /zɑg/ (90%) |
| /vɛn/ (80%) | /zɑn/ (90%) |
| /vɛdʒ/ (90%) | /zɑdʒ/ (70%) |
| /vɛl/ (100%) | /zɑl/ (100%) |
| /vɛm/ (60% - REMOVED) | /zɑm/ (90%) |
| /vɛð/ (20% - REMOVED) | /zɑð/ (20% - REMOVED) |
| /vɛŋ/ (60% - REMOVED) | /zɑŋ/ (30% - REMOVED) |
| /vɛʒ/ (50% - REMOVED) | /zɑʒ/ (50% - REMOVED) |

electronically recorded and the status (or quality) type of the trial was electronically determined through the programmed code as "good," "bad," or "void," trials based on sensor signals and their consequent data recording. A *good* trial was defined as a trial in which all sensors were successfully triggered and the sEMG data were successfully recorded. *Bad* trials were those in which participants made an error (e.g., did not react to a target trial or anticipated the response to a target less than 100 ms). A *void* trial was defined as a trial in which at least one electronic sensor was not triggered or the sEMG signal was not valid. In addition to reporting the status for each trial, "repeat" trials were labeled in the database for those trials that were presented to the participant following a bad or void trial. At the time of study, immediate feedback for the trial's status type was presented to the researcher following each trial. Feedback for repeated trials was the same as any initially presented trial. If the status type were returned as either bad or void, the trial was immediately repeated, ultimately lengthening the data set and duration for any given condition.

Following the completion of data collection, the database was inspected for good, bad, void, and any repeated trials that were good, bad, or void. The first three trials in all three conditions, regardless of whether they were good, bad, or void, were immediately removed to control for any practice effects (Schmidt & Lee, 1999). The removal of these trials left at least[4] 16 possible trials for each participant in each condition. Void trials were then removed from the database because they were not complete and accurate data records and, consequently, invalid trials. Bad trials were removed from the database, owing to participant error and the fact that they do not accurately reflect the experimental objectives, ultimately resulting in outlier data.

[4] The term "at least" is used because the number of trials completed by a participant during any given condition varied relative to the number of repeated trials due to bad or voided trials.

Finally, good repeat trials were substituted for those trials that were bad or void. This restructuring of data sets was completed for each of the three experimental conditions in the dual-task study.

The data set was inspected trial-by-trial for complete data after restructuring the data sets for each condition according to the criteria specified above. Only those trials that contained complete data from all participants were included in the analyses for each condition. A total of 10 trials from the 16 possible trials (i.e., following the reduction of the first three trials due to learning) were used for analysis of the baseline/single-task swallowing condition. Only trials in which target words were presented (viz., target trials) were analyzed. For both baseline/single-task reaction time (RT) and dual-task conditions, 4 possible target trials were presented to each participant. During the dual-task trials, the 4 trials were further divided into 2 trials presented during the anticipatory phase and 2 trials during the oropharyngeal phase of swallowing. Following the identification of trials in each condition that contained only full sets of data for all participants, 3 of the 4 trials for the baseline/single-task RT and 1 trial for each of the two phases of swallowing during the dual-task condition were included in the final analyses.

## 2. Demographics

A total of 20 individuals participated in the study. Ten of the participants were non-impaired (NI) and 10 were diagnosed with Parkinson’s disease (PD), according to the criteria set forth by the United Kingdom Parkinson's Disease Society brain bank diagnostic criteria for Parkinson's disease (Hughes et al., 1992). All 20 participants were Caucasian. One participant in the NI group had an unknown ethnicity and one participant in the PD group was Hispanic. The remaining 18 participants were non-Hispanic. There were 7 males and 3 females in each group. The average age for NIs was 61.9 years (*SD* = 9.7 years, Range = 45 years - 76 years) and the average age for participants with PD was 61.8 years (*SD* = 10.1 years, Range = 45 years - 73 years). There was no significant difference in age between groups ($t$ = .023, $df$ = 18, $p$ = .982). A summary of selected demographics is presented in Table 7. Each group had 9 participants who were right-handed and 1 participant who was left-handed. Both left-handed participants were male. Education was self-reported as the highest completed grade level. This grade level was then converted to the number of years completed. That is, each grade through 12$^{th}$ grade was considered the same number of years, an Associate's degree was transformed to 14 years, undergraduate degree was 16 years, graduate degree was 18 years and a doctoral degree was 20 years. The average number of education years for the NIs was 16.4 years (*SD* = 4.3 years, Range = 8 - 20 years) and the average number of education years for PDs was 15.8 years (*SD* = 2.6 years, Range = 12 - 20 years). There was no significant difference in education ($t$ = .379, $df$ = 18, $p$ = .709) between groups.

**3. Screening**

All participants underwent hearing screening bilaterally via headphones at 30 dB HL for 500 Hz, 1 kHz, 2 kHz, and 4 kHz pure tones in a distraction-free room that was not sound-treated. All participants passed the hearing screening or had the sound level adjusted relative to their pure-tone average with no less than 35 dB SL to compensate for external noises (e.g. computer fan, hall noise). Results from the *Beck Depression Inventory* (*BDI*) suggested no frank depression was present in any participant for either group. Final scores from the *BDI* suggested

Table 7

*Summary of selected swallowing study demographics*

| | Participant group | |
|---|---|---|
| | Non-impaired (*n* = 10) | Parkinson's disease (*n* = 10) |
| Age | 61.9 years | 61.8 years |
| (*SD*) | (9.7 years) | (10.1 years) |
| Gender | | |
| Male | 7 | 7 |
| Female | 3 | 3 |
| Race | | |
| Caucasian | 10 | 10 |
| Ethnicity | | |
| Hispanic | 0 | 1 |
| Non-Hispanic | 9 | 9 |
| Unknown | 1 | 0 |

*Note*. No significant difference ($p > .05$) was found between groups for age.

that there was one participant from each group with a mild mood disorder (score = 13 for both participants) and one participant with borderline depression (score = 17) in the PD group. The remaining 17 participants scored between 0 and 10 (i.e., within normal limits). No participants were excluded based on these scores. The average score for the NI participants was 4.2 ($SD$ = 4.1, Range = 0 - 13) and the average score for participants with PD was 7.2 ($SD$ = 4.8, Range = 2 - 17). There was no significant difference between groups for *BDI* score ($t = -1.506$, $df = 18$, $p = .149$).

*COGNISTAT* was administered in full to all 20 participants. Five participants, 2 NIs and 3 PDs, scored outside normal limits on a total of three different ability areas. The ability areas with difficulties were naming (1 participant with PD), visual construction (2 participants with PD), and short-term memory (2 NI participants, 1 participant with PD). No participants were excluded based on these deficiencies because all participants had no greater than 2 impaired ability areas, suggesting a composite score within normal limits.

No NI participant reported a neurological, cognitive, or psychological disorder. No participant with PD reported a neurological (other than PD), cognitive, or psychological disorder.

The motor subsets of the *Unified Parkinson's Disease Rating Scale* (*UPDRS*) were used to describe and stage each participant with PD. Participants with PD were evaluated between 30 and 45 minutes following their dosage of medication (i.e., during the "on" phase of their medication regimen) by a nurse practitioner who had been working with patients with neurological disease, specifically those with PD, for 4 years. The nurse practitioner had been using the *UPDRS* during this same period of time to evaluate patients with PD. The 10 participants recruited for this study ranged between Stage 1 and Stage 3 on the scale developed by Hoehn and Yahr (1967). Individually, there was one participant who was evaluated as being in Stage 1, one participant in Stage 1.5, five participants in Stage 2 and three participants in Stage 3 (Median = Stage 2). Table 8 summarizes the individual scores on the *UPDRS* and associated Hoehn and Yahr staging for each participant with PD.

**4. Intrarater reliability for sEMG offset**

There were a total of 822 swallows analyzed for sEMG offset value in the full data set. That is, all sEMG signals for baseline/single-task swallowing and all dual-task data (distractor trials and target trials) were analyzed. A randomized sample containing 10 participants' baseline trials was analyzed for intrarater reliability. In all, 190 swallows were reanalyzed, yielding 23.1% of the total data set. Descriptively, 177 swallows (93.2%) were within 1000 ms of the originally analyzed sEMG offset time ($M$ = 79 ms, $SD$ = 203 ms, Range = 0 ms - 982 ms). There were 13 reanalyzed swallows (6.8%) that were outside the 1000 ms range. The average for these values was 2142 ms ($SD$ = 856 ms, Range = 1155 ms - 3962 ms). Intrarater reliability was high with a Pearson product moment correlation coefficient of $r = .999$ ($p < .0005$). Figure 11 displays the scatter plot for test-retest sEMG data.

**5. Baseline/single-task data**

**a. Swallowing** Following data reduction, there were a total of 10 trials (from a possible 16 trials) with complete data points for each of the 20 participants (n = 200 trials). The data were inspected for outliers. Boxplots of the trial data revealed 4 outliers in 4 separate trials—one for each of the two participant groups in each of the two swallowing phases. These 4 outliers were

Table 8

*Summary of UPDRS scores for each participant with Parkinson's disease*

| | | Participant with PD | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Subtest | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| Speech | | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 2 | 2 | 2 |
| Facial expression | | 1 | 1 | 2 | 1 | 1 | 2 | 2 | 2 | 2 | 2 |
| Tremor at rest: face, lips, chin | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Hands: | Right | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 |
| | Left | 0 | 2 | 0 | 0 | 0 | 0 | 4 | 0 | 0 | 0 |
| Feet: | Right | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | Left | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 0 |
| Action tremor: | Right | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | Left | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 0 | 0 | 0 |
| Rigidity: | Neck | 0 | 2 | 1 | 0 | 0 | 2 | 0 | N/A | 2 | 2 |
| Upper extremity: | Right | 2 | 0 | 2 | 1 | 0 | 3 | 1 | 0 | 3 | 3 |
| | Left | 1 | 2 | 1 | 2 | 2 | 2 | 3 | 1 | 3 | 4 |
| Lower extremity: | Right | 0 | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 2 | 2 |
| | Left | 0 | 1 | 0 | 0 | 0 | 1 | 2 | 0 | 2 | 2 |

Table 8

*Continued: Summary of UPDRS scores for each participant with Parkinson's disease*

| | | Participant with PD | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Subtest | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| Finger taps: | Right | 1 | 0 | 1 | 0 | 1 | 1 | 1 | 2 | 2 | 1 |
| | Left | 0 | 2 | 0 | 1 | 2 | 1 | 3 | 1 | 3 | 1 |
| Hand grips: | Right | 1 | 0 | 2 | 0 | 1 | 1 | 1 | 1 | 2 | 1 |
| | Left | 0 | 2 | 0 | 1 | 1 | 1 | 3 | 1 | 2 | 1 |
| Hand pronate/supinate: | Right | 1 | 0 | 2 | 0 | 0 | 1 | 1 | 2 | 2 | 1 |
| | Left | 0 | 1 | 0 | 1 | 1 | 1 | 3 | 2 | 2 | 1 |
| Leg agility: | Right | 1 | 0 | 1 | 0 | 0 | 1 | 1 | 1 | 2 | 1 |
| | Left | 0 | 0 | 0 | 0 | 0 | 1 | 2 | 1 | 3 | 1 |
| Arise from chair | | 0 | 0 | 0 | 1 | 0 | 0 | 1 | 2 | 1 | 0 |
| Posture | | 0 | 0 | 1 | 1 | 0 | 1 | 0 | 2 | 0 | 1 |
| Gait | | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 2 | 1 | 1 |
| Postural stability | | 0 | 0 | 0 | 2 | 0 | 1 | 1 | 2 | 1 | 1 |
| Body bradykinesia | | 1 | 1 | 1 | 1 | 0 | 1 | 3 | 2 | 2 | 2 |
| Hoehn & Yahr Stage | | 1 | 1.5 | 2 | 2 | 2 | 2 | 2 | 3 | 3 | 3 |

*Note*. "N/A" = not assessed. Each subtest is based on a 5-point scoring system from "0" (i.e., absent, none, normal) to "4" (i.e., marked, severe, can barely perform). See Fahn & Elton (1987) or National Parkinson Foundation (1996-2004) for details.

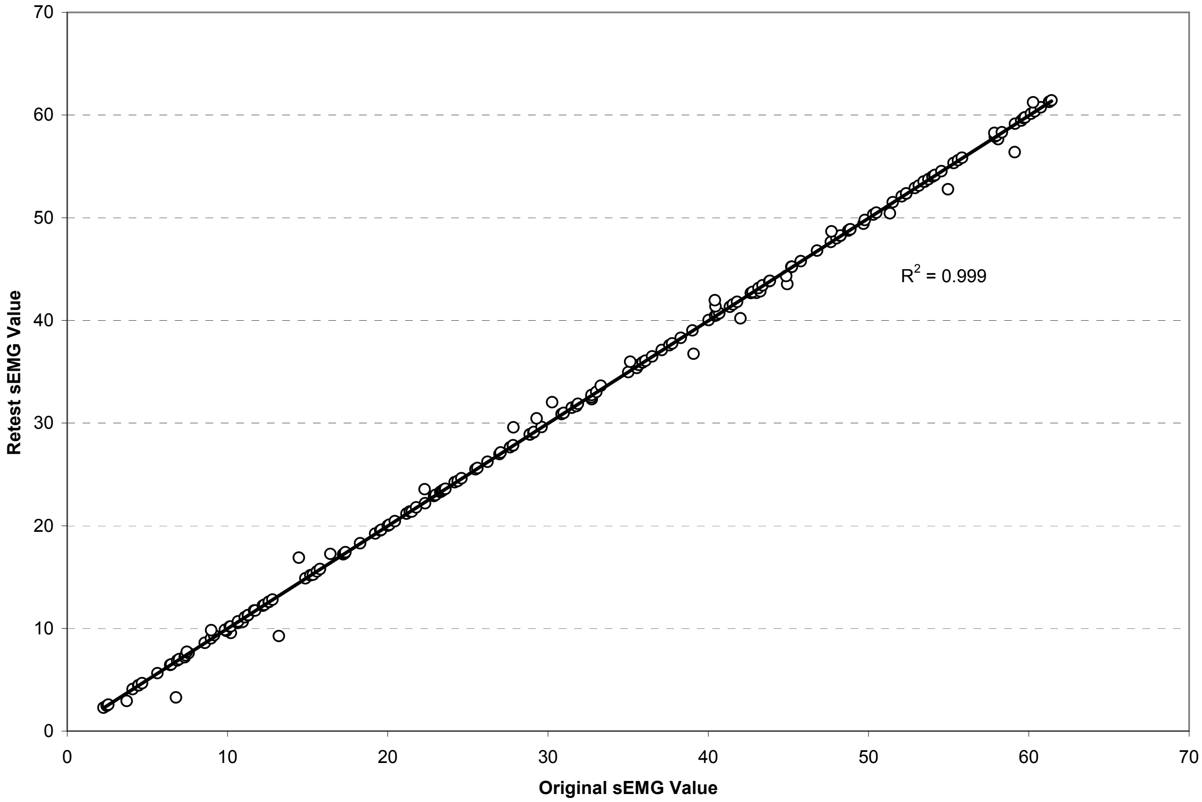


*Figure 11*. Intrarater reliability scatter plot for sEMG offset values.

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*r* = .999 (*p* < .0005)

omitted from the final analyses. The average time for the anticipatory phase of swallowing for NIs was 2538 ms (*SD* = 431 ms, Range = 1690 ms - 3597 ms) and 2538 ms (*SD* = 684 ms, Range = 1463 ms - 4395 ms) for PDs. A repeated measures analysis of variance (RM ANOVA) was performed to determine whether any statistically significant difference between trials and between groups, controlling for trials, was detectable for baseline/single-task swallowing phase times. Due to a significant Mauchly's Test of Sphericity ($W$ = .002, $df$ = 44, $p$ = .001), the Greenhouse-Geisser correction was used for the anticipatory phase data. There was no significant difference between trials ($F$ = .796, $df$ = 3.872, $p$ = .529) or between groups, controlling for trials ($F$ = .511, $df$ = 3.872, $p$ = .722) for anticipatory phase time (Table 9). These results suggest that participants tended to repeat their performance across trials. A *post hoc* estimated effect size calculated using Cohen's *d* was 0, indicating that even large sample studies would not demonstrate significant differences. Figure 12 shows the average anticipatory phase time across trials by group.

Table 9

*RM ANOVA for baseline/single-task anticipatory phase durations*

| | *SS* | *df* | *F* | *p* |
|---|---|---|---|---|
| Trial | 382257.898 | 3.872 | .796 | .529 |
| Trial × Group | 245279.167 | 3.872 | .511 | .722 |
| Error (Trial) | 7685127.362 | 61.950 | | |

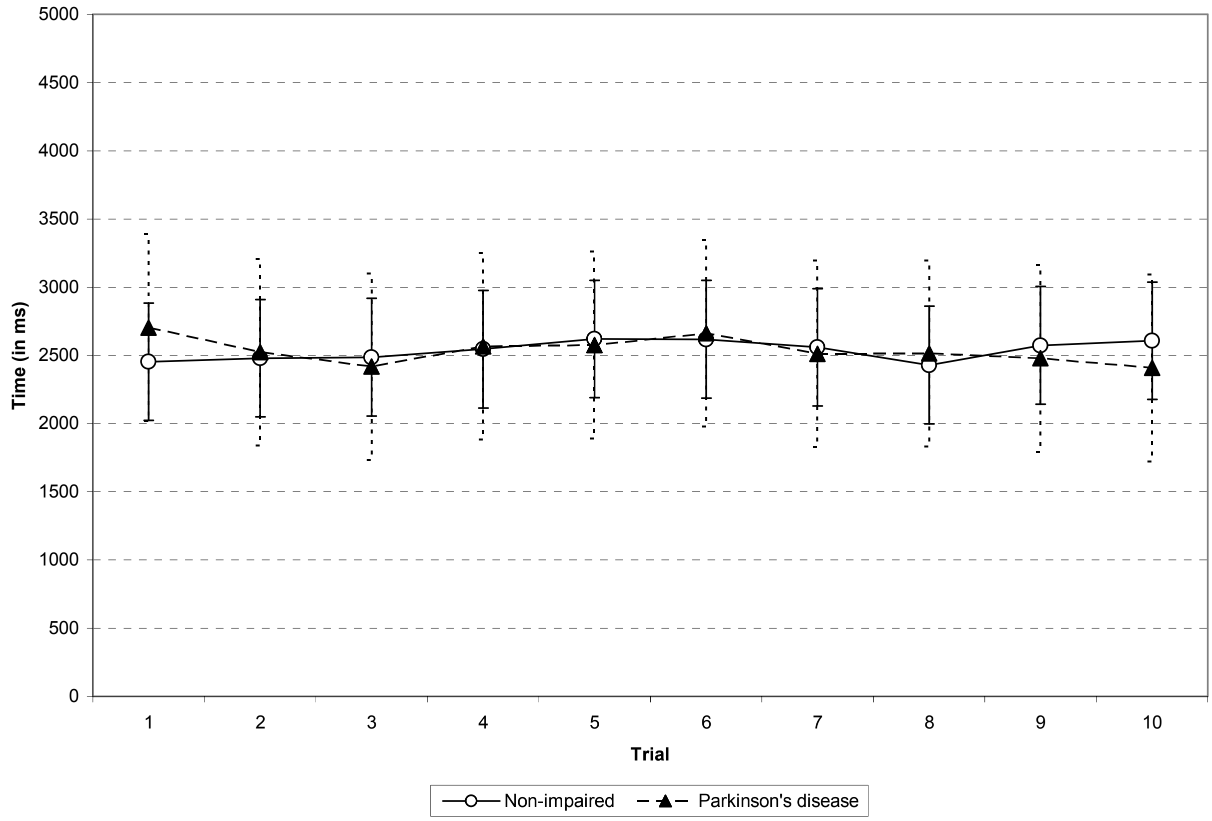


*Figure 12*. Average anticipatory phase times by trial for baseline/single-task swallowing.

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Solid error bars reflect 1 *SD* for non-impaired participants; broken error bars reflect 1 *SD* for participants with PD.

No significant difference between trials ($p > .05$) or between groups, controlling for trials ($p > .05$).

The average time for the oropharyngeal phase of swallowing for NIs was 2225 ms (*SD* = 748 ms, Range = 746 ms - 5098 ms) and an average of 2733 ms (*SD* = 1420 ms, Range = 503 ms - 6210 ms) for PDs. A significant Mauchly's Test of Sphericity was found ($W$ = .000, $df$ = 44, $p$ < .0005) and the Greenhouse-Geisser correction was used for the oropharyngeal phase data. There was no significant difference between trials ($F$ = 1.413, $df$ = 3.944, $p$ = .240) or between groups, controlling for trials ($F$ = .433, $df$ = 3.944, $p$ = .781) for oropharyngeal phase time (Table 10). Again, these data suggest that participants repeated their performance across trials. A *post hoc* estimated effect size calculated using Cohen's $d$ was .44. Based on this estimated effect size and alpha set at .05, a sample of approximately 27 participants in each of the two groups would be necessary to demonstrate a statistically significant difference between groups. Figure 13 shows the average oropharyngeal phase time across trials by group. A summary of results for the baseline/single-task swallowing condition is presented in Table 11.

Table 10

*RM ANOVA for baseline/single-task oropharyngeal phase durations*

| | *SS* | *df* | *F* | *p* |
|---|---|---|---|---|
| Trial | 3062690.228 | 3.944 | 1.413 | .240 |
| Trial × Group | 939572.672 | 3.944 | .433 | .781 |
| Error (Trial) | 34687055.20 | 63.104 | | |

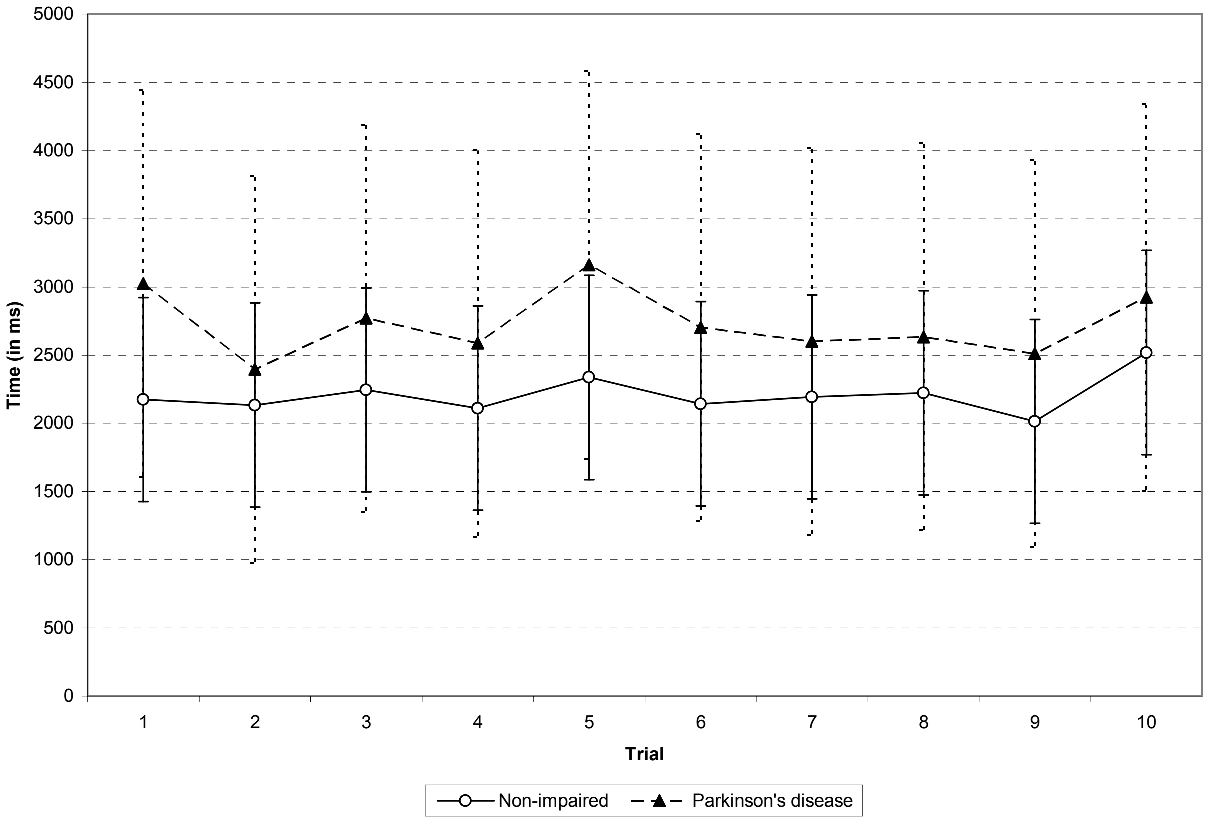


*Figure 13.* Average oropharyngeal phase times by trial for baseline/single-task swallowing.

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Solid error bars reflect 1 *SD* for non-impaired participants; broken error bars reflect 1 *SD* for participants with PD.

No significant difference between trials ($p > .05$) or between groups, controlling for trials ($p > .05$).

Table 11

*Mean anticipatory and oropharyngeal phase times for baseline/single-task swallowing*

| | Phase of swallowing | |
|---|---|---|
| | Anticipatory | Oropharyngeal |
| NI participants | 2538 | 2225 |
| (SD) | (431) | (748) |
| Participants with PD | 2538 | 2733 |
| (SD) | (684) | (1420) |

*Note*. All times shown are in ms. No significant differences ($p > .05$) were found between groups for either phase of swallowing.

**b. Non-word discrimination reaction time** There were a total of 3 trials from 4 possible trials with complete data points following data reduction (n = 60). The data were inspected for outliers. Boxplots of the trial data revealed 2 outliers. Both outliers were NI participants and each occurrence was in a separate trial. These outliers were removed for the final analyses. The average RT in target trials for NIs was 825 ms (*SD* = 348 ms, Range = 406 ms - 1887 ms) and 921 ms (*SD* = 426 ms, Range = 402 ms - 2190 ms) for PDs. A RM ANOVA was performed to determine any significant difference between trials and any difference between groups, controlling for trials, was detectable for baseline/single-task non-word discrimination RT. Due to a significant Mauchly's Test of Sphericity ($W = .559$, $df = 2$, $p = .013$), the Greenhouse-

Geisser correction was used. There was no significant difference between trials ($F$ = 2.460, $df$ = 1.388, $p$ = .122) or between groups, controlling for trials ($F$ = 1.934, $df$ = 1.388, $p$ = .176) for RT (Table 12). Again, these results suggest participants' repeated performance across trials. A *post hoc* estimated effect size calculated using Cohen's $d$ was .25. Figure 14 shows the average RT across trials by group.

Table 12

*RM ANOVA for baseline/single-task non-word discrimination RT*

| | *SS* | *df* | *F* | *p* |
|---|---|---|---|---|
| Trial | 209997.859 | 1.388 | 2.460 | .122 |
| Trial × Group | 165066.841 | 1.388 | 1.934 | .176 |
| Error (Trial) | 1365801.132 | 22.206 | | |

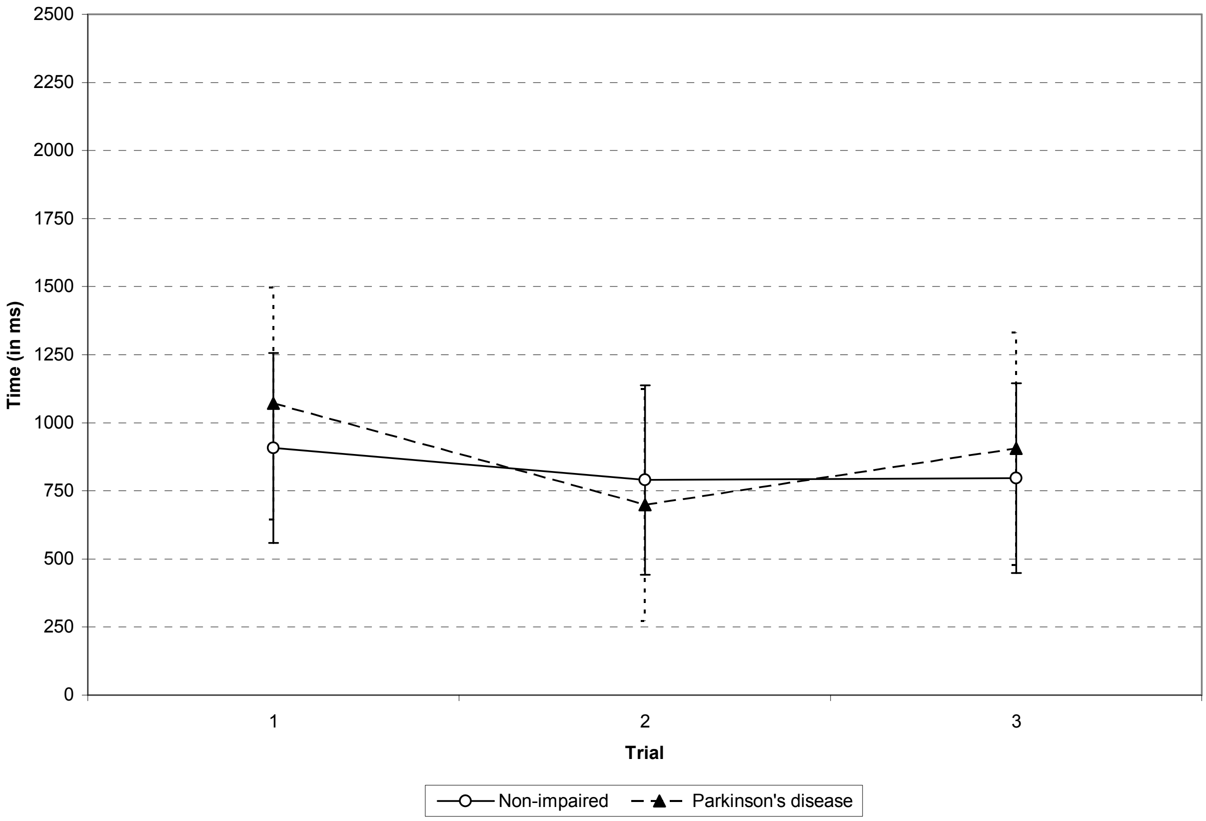


*Figure 14*. Average RT by trial for baseline/single-task non-word discrimination.

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Solid error bars reflect 1 *SD* for non-impaired participants; broken error bars reflect 1 *SD* for participants with PD.

No significant difference between trials ($p > .05$) or between groups, controlling for trials ($p > .05$).

### 6. Dual-task data

**a. Swallowing** There were two possible RT target trials for the anticipatory phase of swallowing and two possible RT target trials for the oropharyngeal phase of swallowing. From the two target trials in anticipatory phase, only the first trial contained a full set of data for all 20 participants. This was the only trial used in the final analyses. The two target trials in the oropharyngeal phase, however, contained data for just 19 of the 20 participants because one participant with PD had incomplete data for both RT target trials. A choice was made prior to the analyses to use only the first RT target trial in the oropharyngeal phase because the first of the two target trials was used for anticipatory phase RT analysis. Each of these trials was inspected for outliers. Boxplots for each set of target trials data revealed 1 outlier in the NI group for the anticipatory phase and 1 outlier in the NI group for the oropharyngeal phase. These two outliers and the outliers mentioned in the results section for both baseline/single-task swallowing and baseline/single-task non-word discrimination RT data (above) were removed from the final analyses.

NIs demonstrated an average anticipatory phase duration of 2248 ms ($SD$ = 325 ms, Range = 1729 ms - 2860 ms), whereas PDs demonstrated an average of 2585 ms ($SD$ = 663 ms, Range = 1497 ms – 3233 ms) for the duration of the dual-task, anticipatory phase of swallowing. For the dual-task, oropharyngeal phase duration for NIs averaged 2020 ms ($SD$ = 1278 ms, Range = 515 ms - 4098 ms), whereas PDs had a duration averaging 2136 ms ($SD$ = 1505 ms, Range = 544 ms - 4996 ms).

A standard ANOVA was not completed because it was determined that averaging the 10 trials of data for each participant's response would be inappropriate due to the artificial reduction of the standard deviation of the averaged responses, ultimately understating the true variability. Hence, a RM ANOVA was the analysis chosen to determine differences between trials and trial by group.

A RM ANOVA was performed to determine any differences between baseline/single-task and dual-task conditions for trials and groups, controlling for trials, in each of the two phases of swallowing. There was no significant difference found between dual-task anticipatory phase time trials ($F$ = .015, $df$ = 1, $p$ = .905) and between groups, controlling for trials ($F$ = .511, $df$ = 1, $p$ = .484) when compared with baseline/single-task anticipatory phase times (Table 13), with an estimated effect size of .09. Also, there was no significant difference found between dual-task oropharyngeal phase time trials ($F$ = 2.925, $df$ = 1, $p$ = .107) and between groups, controlling for trials ($F$ = .520, $df$ = 1, $p$ = .481) when compared with baseline/single-task oropharyngeal phase times (Table 14), with an estimated effect size of .51. Figures 15 and 16 plot the average anticipatory phase and oropharyngeal phase times for baseline/single- and dual-task conditions by both trial and group, respectively.

Table 13

*RM ANOVA comparing baseline/single-task to dual-task anticipatory phase swallowing times*

| | *SS* | *df* | *F* | *p* |
|---|---|---|---|---|
| Trial | 1570.009 | 1.000 | .015 | .905 |
| Trial × Group | 54878.464 | 1.000 | .511 | .484 |
| Error (Trial) | 1931742.397 | 18.000 | | |

Table 14

*RM ANOVA comparing baseline/single-task to dual-task oropharyngeal phase swallowing times*

| | *SS* | *df* | *F* | *p* |
|---|---|---|---|---|
| Trial | 1493202.534 | 1.000 | 2.925 | .107 |
| Trial × Group | 265190.668 | 1.000 | .520 | .481 |
| Error (Trial) | 8167057.158 | 16.000 | | |

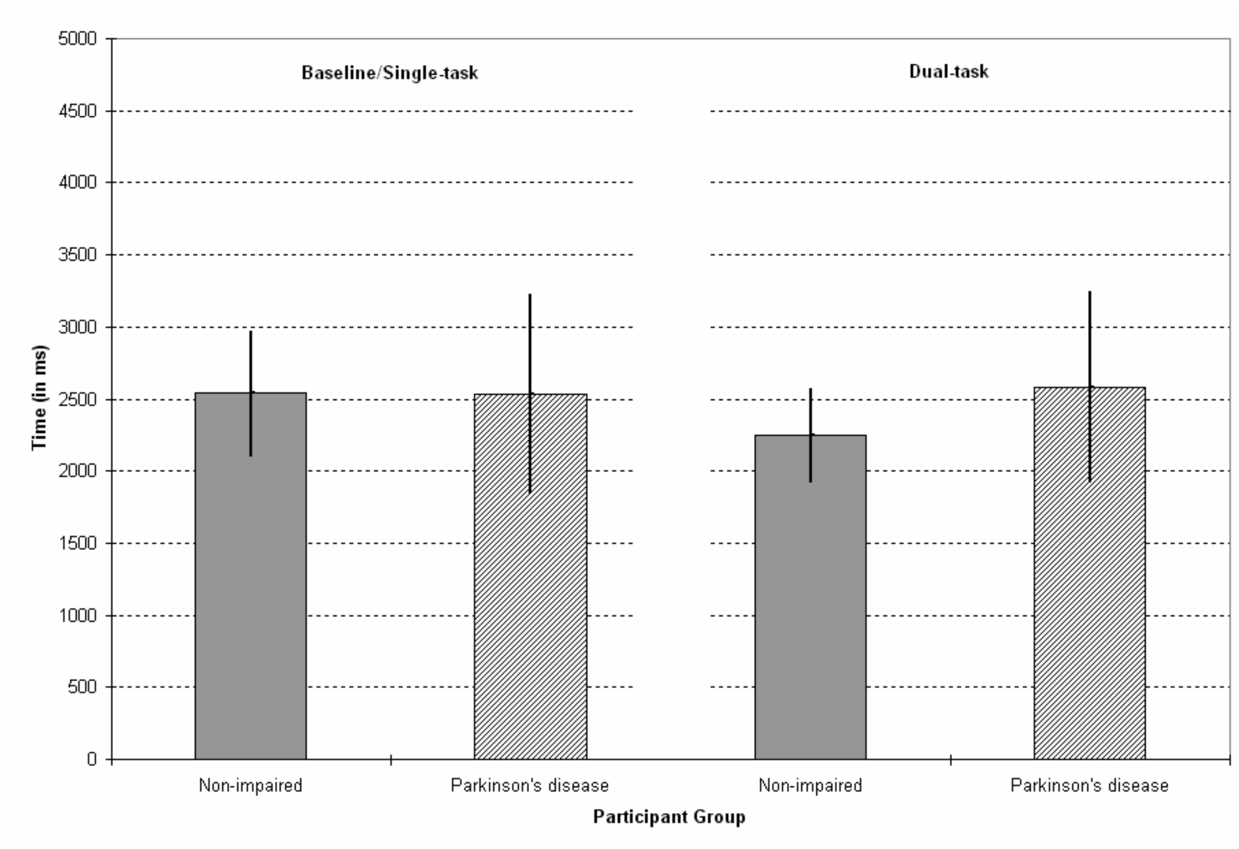


*Figure 15*. Comparison between baseline/single-task and dual-task average anticipatory phase swallowing times by trial.

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Vertical bars represent mean duration of the anticipatory phase of swallowing. The vertical lines represent ±1 *SD* from the mean. No significant difference between groups for condition ($p > .05$).

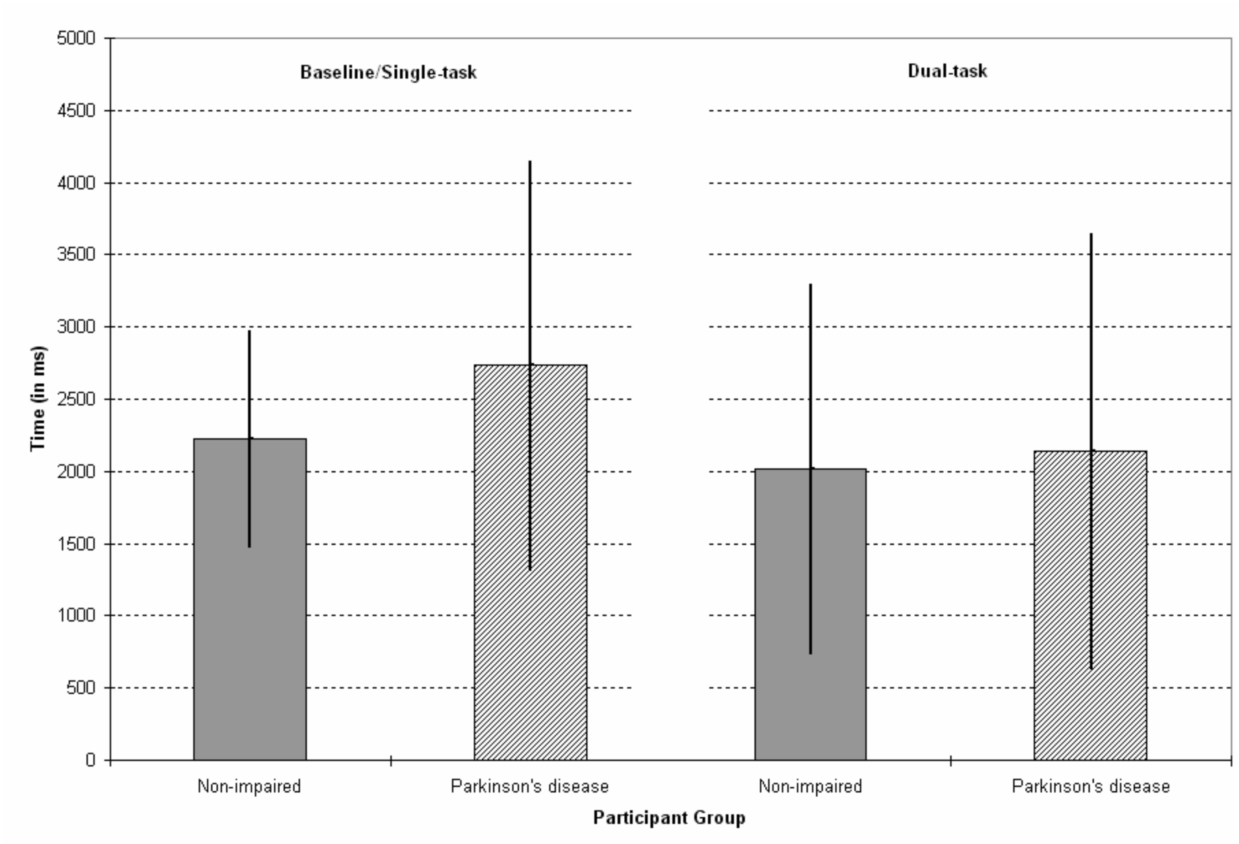


*Figure 16*. Comparison between baseline/single-task and dual-task average oropharyngeal phase swallowing times by trial.

---

Vertical bars represent mean duration of the anticipatory phase of swallowing. The vertical lines represent ±1 *SD* from the mean. No significant difference between groups for condition ($p > .05$).

**b. Non-word discrimination reaction time** The average RT for targets presented in the anticipatory phase of swallowing for NIs was 872 ms (*SD* = 368 ms, Range = 463 ms - 1672 ms) and 1448 ms (*SD* = 895 ms, Range = 402 ms - 3347 ms) for PDs. Again, to avoid artificial reduction of the standard deviation, a RM ANOVA was performed to determine any difference between trials and trial by group for RT measures relative to each phase of swallowing. There was a significant difference in dual-task RT between trials ($F$ = 8.683, $df$ = 1, $p$ = .009) and between groups, controlling for trials ($F$ = 5.054, $df$ = 1, $p$ = .039) for stimuli presented during the anticipatory phase of swallowing when compared with baseline/single-task RT (Table 15), with an estimated effect size of .77. That is, the participants with PD demonstrated significantly longer RTs to target auditory stimuli during the dual-task condition and significantly longer RTs than those of the NIs. Figure 17 shows the average RT for the anticipatory phase across trial type by group.

Table 15

*RM ANOVA comparing baseline/single-task to dual-task anticipatory phase RT*

| | *SS* | *df* | *F* | *p* |
|---|---|---|---|---|
| Trial | 1254879.753 | 1.000 | 8.683 | .009 |
| Trial × Group | 730479.753 | 1.000 | 5.054 | .039 |
| Error (Trial) | 2312446.859 | 16.000 | | |

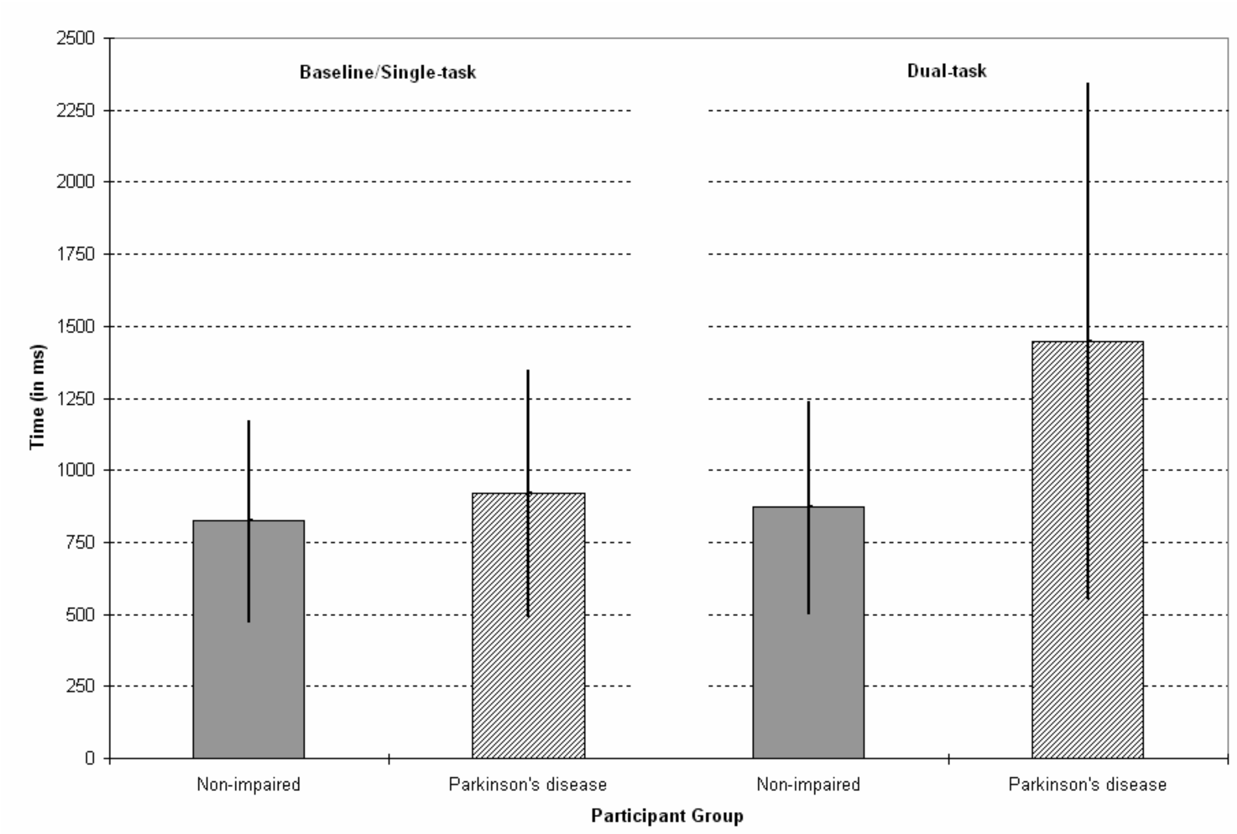


*Figure 17*. Comparison between baseline/single-task and dual-task average RT for anticipatory phase swallowing.

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Vertical bars represent mean duration of the anticipatory phase of swallowing. The vertical lines represent ±1 *SD* from the mean. There was a significant difference between trials and between groups, controlling for trials, across condition ($p < .05$).

The average RT for targets presented in the oropharyngeal phase of swallowing for NIs was 888 ms (*SD* = 176 ms, Range = 689 ms - 1209 ms) and 1143 ms (*SD* = 811 ms, Range = 399 ms - 2724 ms) for PDs. There was a significant difference in RT between trials ($F = 5.279$, $df = 1$, $p = .038$) for stimuli presented during the oropharyngeal phase of swallowing, though there was no significant difference between groups, controlling for trials ($F = 1.706$, $df = 1$, $p = .213$) (Table 16). Figure 18 shows the average RT for the oropharyngeal phase across trials by group. Table 17 provides a summary of the results for the dual-task condition. There was no significant difference in RT between the anticipatory and oropharyngeal phases of swallowing among groups ($F = .001$, $df = 1$, $p = .976$) or between groups, controlling for trials ($F = 1.567$, $df = 1$, $p = .233$) (Table 18).

Table 16

*RM ANOVA comparing baseline/single-task to dual-task oropharyngeal phase RT*

| | *SS* | *df* | *F* | *p* |
|---|---|---|---|---|
| Trial | 662573.161 | 1.000 | 5.279 | .038 |
| Trial × Group | 214119.680 | 1.000 | 1.706 | .213 |
| Error (Trial) | 1757318.669 | 14.000 | | |

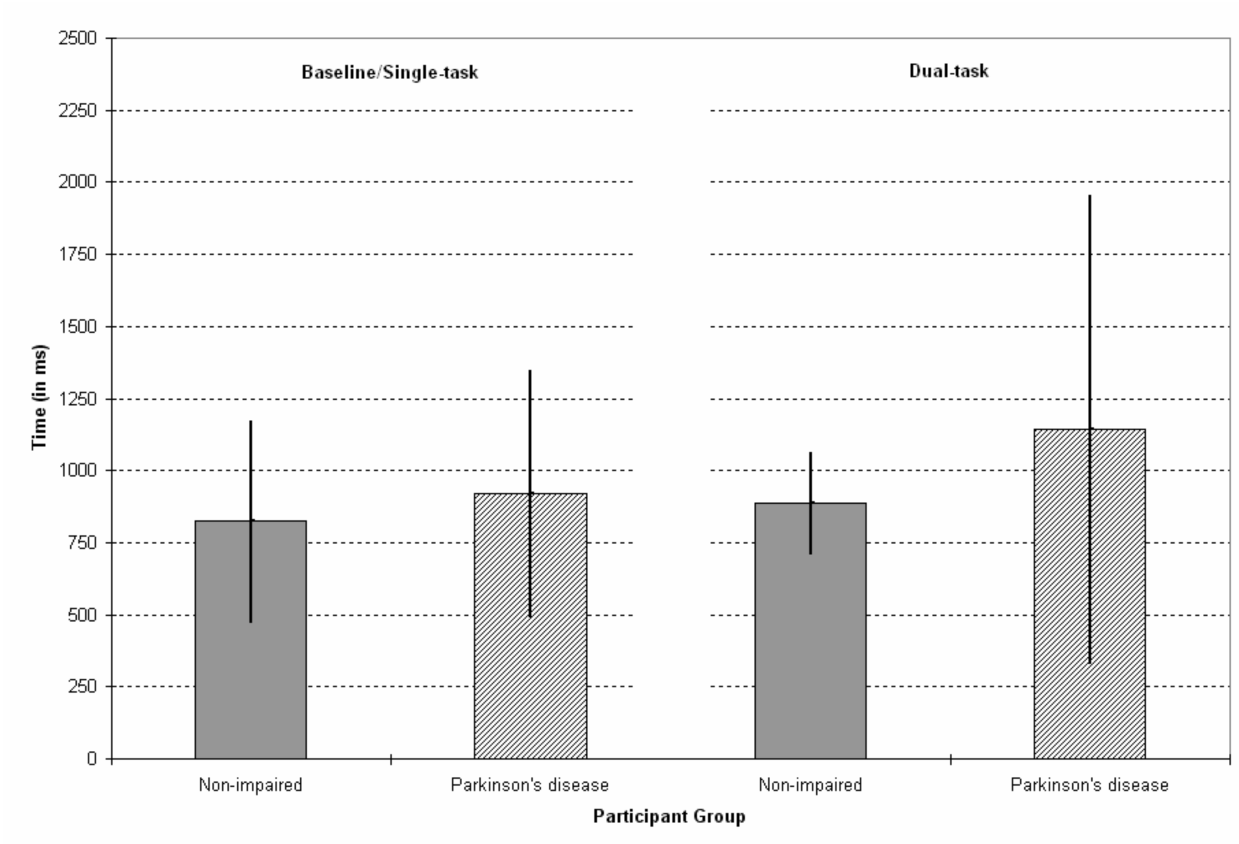


*Figure 18.* Comparison between baseline/single-task and dual-task average RT for oropharyngeal phase swallowing.

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Vertical bars represent mean duration of the anticipatory phase of swallowing. The vertical lines represent ±1 *SD* from the mean. There was a significant difference between groups for condition ($p < .05$).

Table 17

*Mean dual-task swallowing times and RTs*

| | Anticipatory phase | | Oropharyngeal phase | |
|---|---|---|---|---|
| | Swallow | RT | Swallow | RT |
| NI participants | 2248 | 872 | 2020 | 888 |
| (*SD*) | (325) | (368) | (1280) | (176) |
| Participants with PD | 2585 | 1448* | 2136 | 1143* |
| (*SD*) | (663) | (895) | (1505) | (811) |

*Note*. All times shown are in ms. No significant differences ($p > .05$) were found between trial type or between groups, controlling for trials, for either phase of swallowing. There were significant differences ($p < .05$) between trial type and between groups, controlling for trials, for RT in both phases for participants with PD.

Table 18

*RM ANOVA comparing dual-task anticipatory and oropharyngeal phase RT*

| | *SS* | *df* | *F* | *p* |
|---|---|---|---|---|
| Trial | 94.810 | 1.000 | .001 | .976 |
| Trial × Group | 154938.259 | 1.000 | 1.567 | .233 |
| Error (Trial) | 1285425.319 | 13.000 | | |

## 7. PD staging differences

**a. Baseline/single-task swallowing** The group of participants with PD was subcategorized into their respective stages based on Hoehn & Yahr's (1967) staging of Parkinson's disease, as derived by the *UPDRS*, and reanalyzed for differences within the PD group and when compared with the NIs. The average time for the anticipatory phase of swallowing for participants in PD Stage 1 ($PD_1$) was 2222 ms (*SD* = 290 ms, Range = 2017 ms - 2427 ms), Stage 2 ($PD_2$) was 2302 ms (*SD* = 624 ms, Range = 1672 ms - 3185 ms), and Stage 3 ($PD_3$) was 3190 ms (*SD* = 603 ms, Range = 2563 ms - 3765 ms). The average time for the oropharyngeal phase of swallowing for participants in PD Stage 1 ($PD_1$) was 2018 ms (*SD* = 1089 ms, Range = 1248 ms - 2788 ms), Stage 2 ($PD_2$) was 2614 ms (*SD* = 1377 ms, Range = 804 ms - 3829 ms), and Stage 3 ($PD_3$) was 3561 ms (*SD* = 1659 ms, Range = 1646 ms - 4552 ms). Swallowing times progressively lengthened for each phase of swallowing relative to the progression of PD (Figures 19 and 20). That is anticipatory and oropharyngeal phases of swallowing during the dual-task showed the longest duration for participants in Stage 3 of the disease, followed by Stage 2, and finally Stage 1. A RM ANOVA was completed to determine whether there was a significant difference in either the anticipatory or oropharyngeal phase times between NIs and PDs in the various stages of the disease. There was no significant difference between NIs and the three stages of PD represented in the participant sample for the anticipatory phase ($F = 2.443$, $df = 3$, $p = .102$) or the oropharyngeal phase ($F = 1.283$, $df = 3$, $p = .314$) of swallowing. The ANOVA tables are presented in Tables 19 and 20.

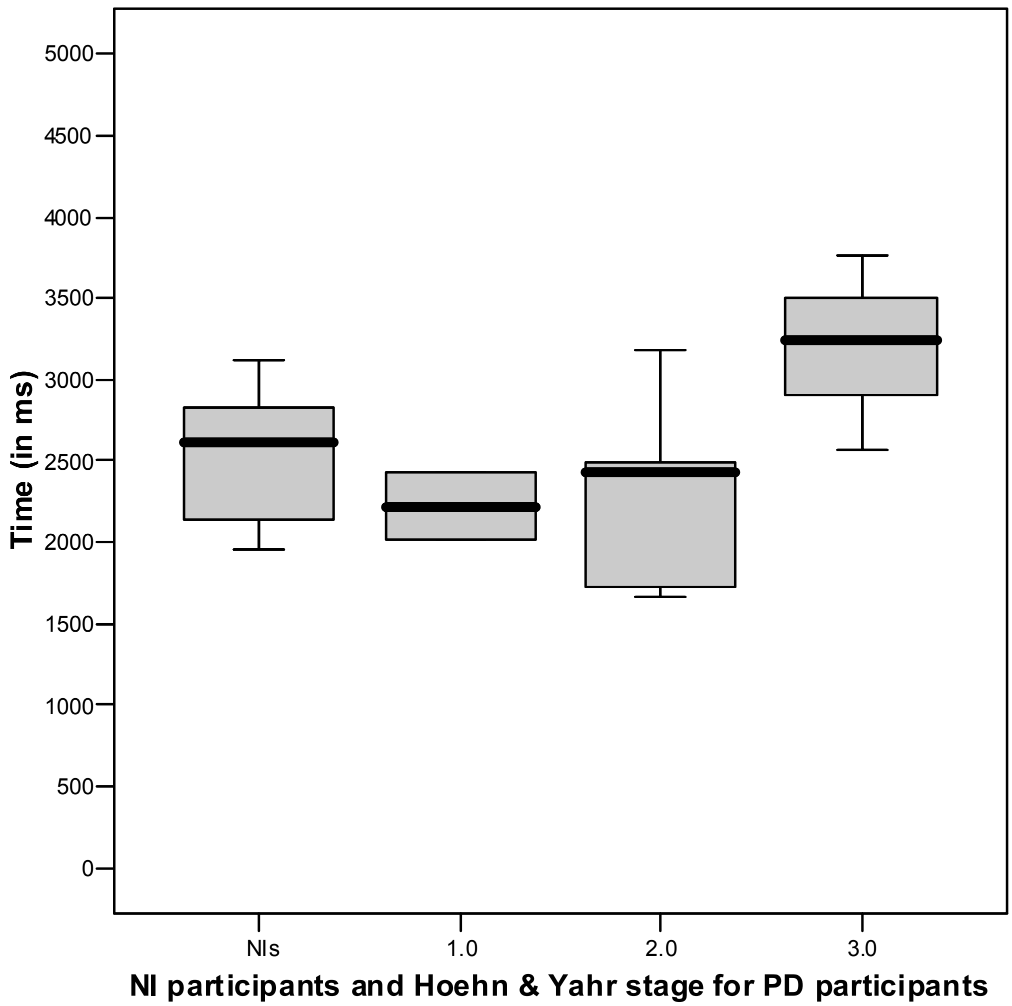


*Figure 19.* Distribution of baseline/single-task swallowing anticipatory phase times by Hoehn and Yahr (1967) stage.

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The dark, black, horizontal bars in each of the boxes represent the median duration of the anticipatory phase for each subgroup of participants. Error bars represent ±1 *SD*.

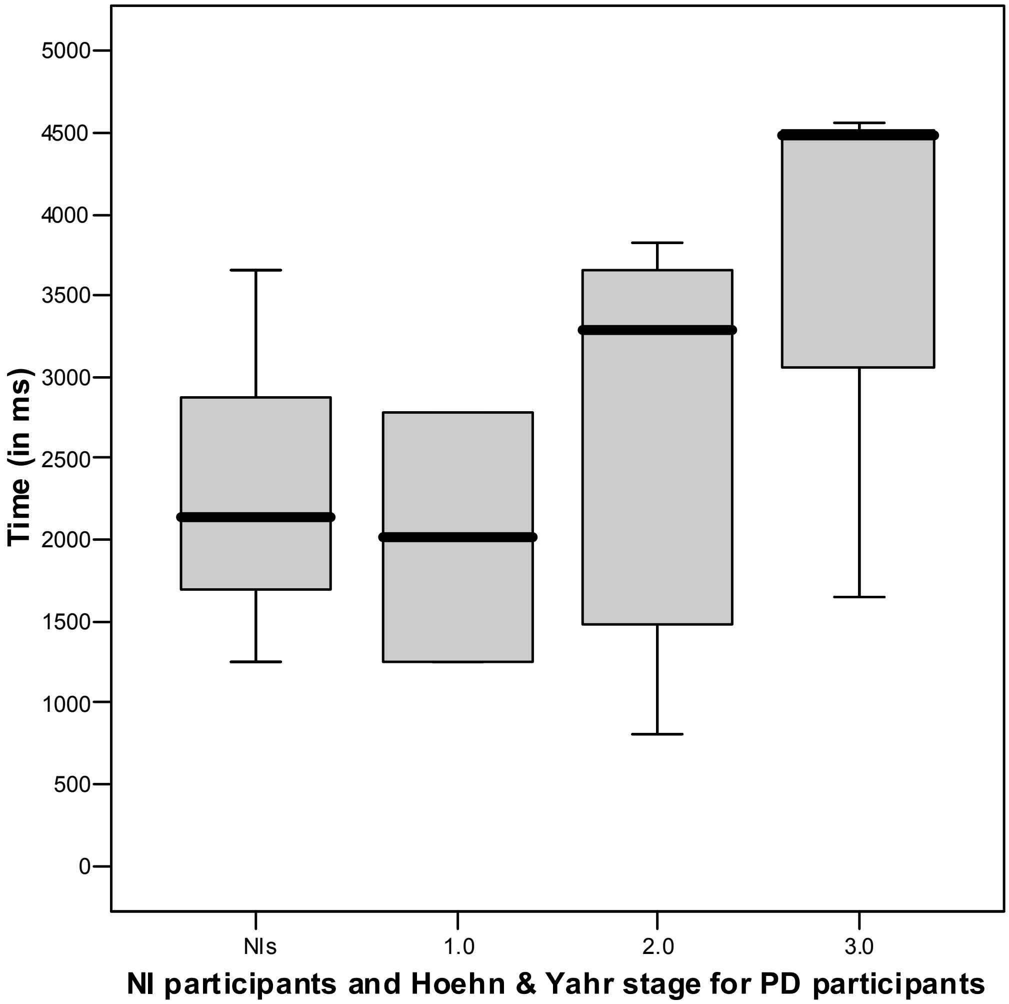


*Figure 20*. Distribution of baseline/single-task swallowing oropharyngeal phase times by Hoehn and Yahr (1967) stage.

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The dark, black, horizontal bars in each of the boxes represent the median duration of the anticipatory phase for each subgroup of participants. Error bars represent ±1 *SD*.

Table 19

*ANOVA comparing dual-task anticipatory phase time between NIs and stages of PD*

| | *SS* | *df* | *F* | *p* |
|---|---|---|---|---|
| Between Groups | 1752013.7 | 3 | 2.443 | .102 |
| Within Groups | 3824706.4 | 16 | | |
| Total | 5576720.1 | 19 | | |

Table 20

*ANOVA comparing dual-task oropharyngeal phase time between NIs and stages of PD*

| | *SS* | *df* | *F* | *p* |
|---|---|---|---|---|
| Between Groups | 4553217.2 | 3 | 1.283 | .314 |
| Within Groups | 18920742 | 16 | | |
| Total | 23473959 | 19 | | |

**b. Baseline/single-task non-word discrimination** The group of participants with PD was subcategorized into their respective stages based on Hoehn & Yahr's (1967) staging of Parkinson's disease, as derived by the *UPDRS*, and reanalyzed for differences within the PD group and when compared with the NIs. This closer look at the data revealed RT differences within the group of participants with PD. An increase in RT was noted during the baseline/single-task non-word discrimination with advanced PD staging (Figure 21). An ANOVA was conducted to determine whether the differences between NI participants and each of the participants with PD relative to the disease stages were significant. There were significant differences between NIs and staging of PD ($F$ = 4.576, $df$ = 3, $p$ = .020) (Table 21). *Post hoc* analyses using the Bonferroni correction revealed significant differences ($p$ < .05) between NIs and $PD_3$ and between $PD_2$ and $PD_3$ groups.

**c. Dual-task** One final time the group of participants with PD was subcategorized into their respective stages based on Hoehn & Yahr's (1967) staging of Parkinson's disease, as derived by the *UPDRS*, and reanalyzed for differences within the PD group and when compared with the NIs. RTs for the anticipatory and oropharyngeal phases of swallowing during the dual-task showed a slowing for those participants in Stage 3 disease relative to the other two stages. The average RT in the anticipatory phase of swallowing for PD stage 1 ($PD_1$) was 956 ms ($SD$ = 123 ms, Range = 869 ms - 1043 ms), stage 2 ($PD_2$) was 970 ms ($SD$ = 454 ms, Range = 402 ms - 1455 ms), and stage 3 ($PD_3$) was 2574 ms ($SD$ = 685 ms, Range = 2043 ms - 3347 ms). In order to determine whether the differences between NI participants and each of the participants with PD relative to the disease stages were significant, an ANOVA was completed. For this analysis, participants in Hoehn and Yahr stages 1 and 2 were combined into one group ($PD_{1\text{-}2}$)

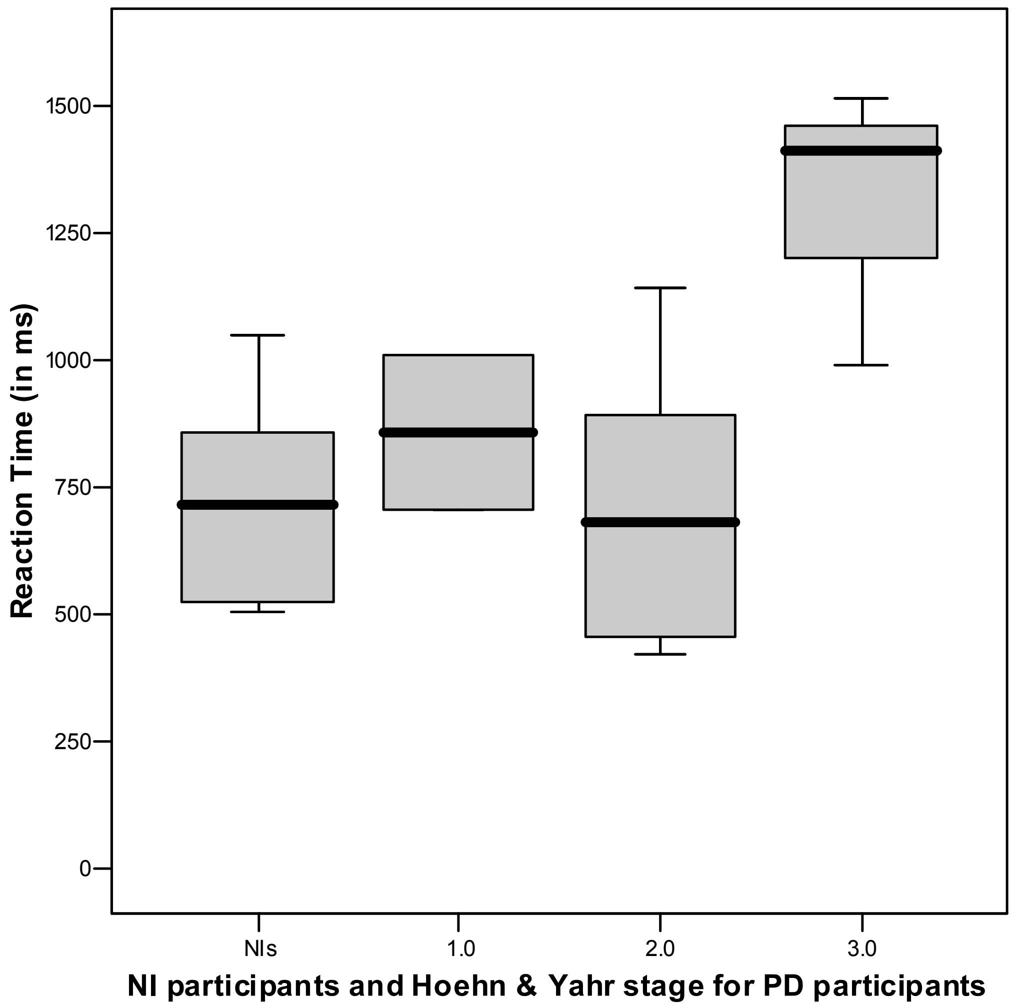


*Figure 21*. Distribution of baseline/single-task RTs by Hoehn and Yahr (1967) stage.

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The dark, black, horizontal bars in each of the boxes represent the median duration of the anticipatory phase for each subgroup of participants. Error bars represent ±1 *SD*.

Table 21

*ANOVA comparing dual-task non-word discrimination RT between NIs and stages of PD*

| | *SS* | *df* | *F* | *p* |
|---|---|---|---|---|
| Between Groups | 841769.87 | 3 | 4.576 | .020 |
| Within Groups | 858362.61 | 14 | | |
| Total | 1700132.5 | 17 | | |

because an independent *t*-test revealed no differences between groups for either the anticipatory ($t$ = -.041, $df$ = 4.939, $p$ = .952) and oropharyngeal ($t$ = -.521, $df$ = 4, $p$ = .630) phases of swallowing. The average RT during the anticipatory phase for $PD_{1\text{-}2}$ was 966 ms ($SD$ = 374 ms, Range = 402 ms - 1455 ms) and 825 ms ($SD$ = 528 ms, Range = 399 ms -1829 ms) for the oropharyngeal phase. Comparing NIs, $PD_{1\text{-}2}$ and $PD_3$, the ANOVAs (Tables 22 and 23) revealed a significant difference for RT in the anticipatory phase ($F$ = 18.978, $df$ = 2, $p$ < .0005) and oropharyngeal phase ($F$ = 7.245, $df$ = 2, $p$ = .008) between the three groups. *Post hoc* analyses using the Bonferroni correction revealed significant differences in RT for the anticipatory phase of swallowing between $PD_3$ and $PD_{1\text{-}2}$ ($p$ < .0005) and between $PD_3$ and NIs ($p$ < .0005), with the $PD_3$ group demonstrating longer RTs. There were also significant differences in the oropharyngeal phase of swallowing between $PD_3$ and $PD_{1\text{-}2}$ ($p$ < .0005) and between $PD_3$ and NIs ($p$ < .0005), again with the $PD_3$ group demonstrating longer RTs than each of the other groups. Figures 22 and 23 show the distributions of RT for NIs and each of the participants with PD based on Hoehn and Yahr staging of Parkinson's disease.

Table 22

*ANOVA comparing dual-task, anticipatory phase RT between NIs, $PD_{1\text{-}2}$, and $PD_3$*

| | *SS* | *df* | *F* | *p* |
|---|---|---|---|---|
| Between Groups | 6906521.5 | 2 | 18.978 | < .0005 |
| Within Groups | 2729358.4 | 15 | | |
| Total | 9365879.8 | 17 | | |

Table 23

*ANOVA comparing dual-task, oropharyngeal phase RT between NIs, $PD_{1\text{-}2}$, and $PD_3$*

| | *SS* | *df* | *F* | *p* |
|---|---|---|---|---|
| Between Groups | 2679764.1 | 2 | 7.245 | .008 |
| Within Groups | 2404296.6 | 13 | | |
| Total | 5084060.7 | 15 | | |

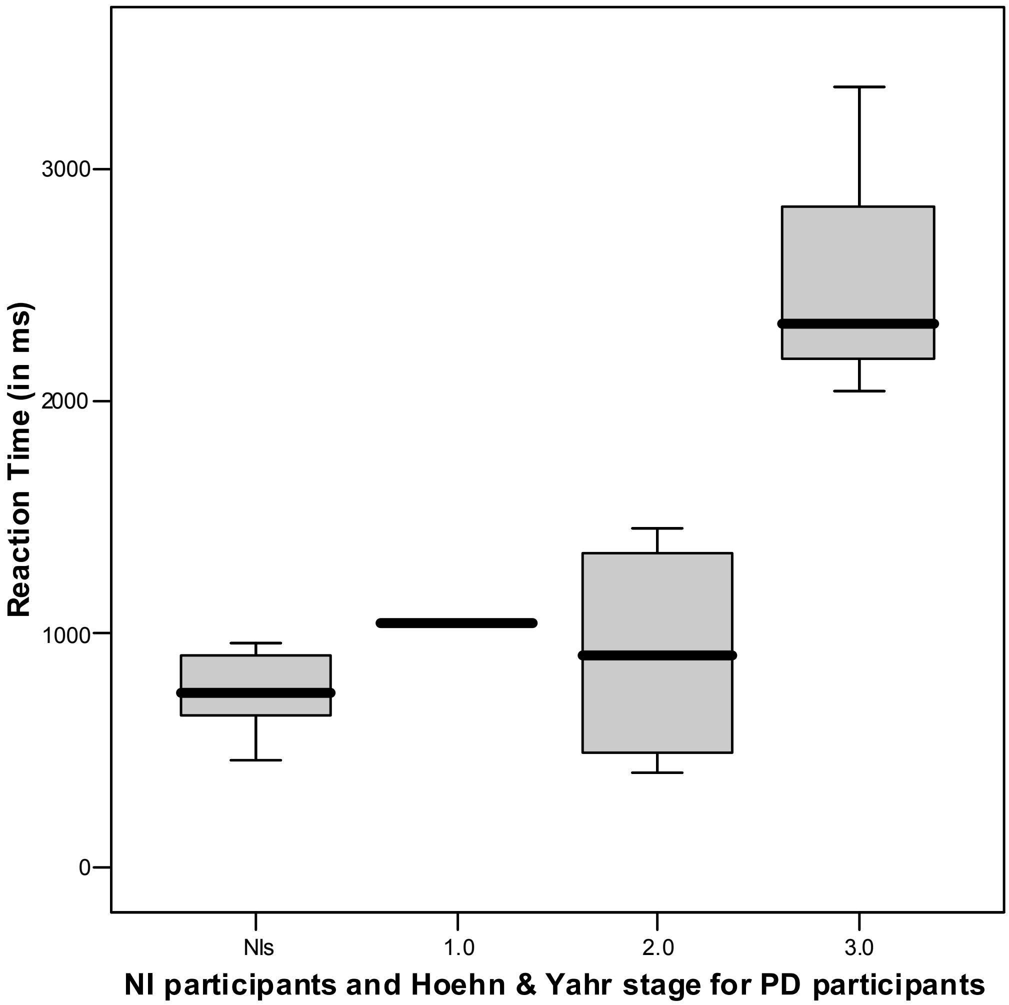


*Figure 22*. Distribution of dual-task anticipatory phase RTs by Hoehn and Yahr (1967) stage.

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The dark, black, horizontal bars in each of the boxes represent the median duration of the anticipatory phase for each subgroup of participants. Error bars represent ±1 *SD*.

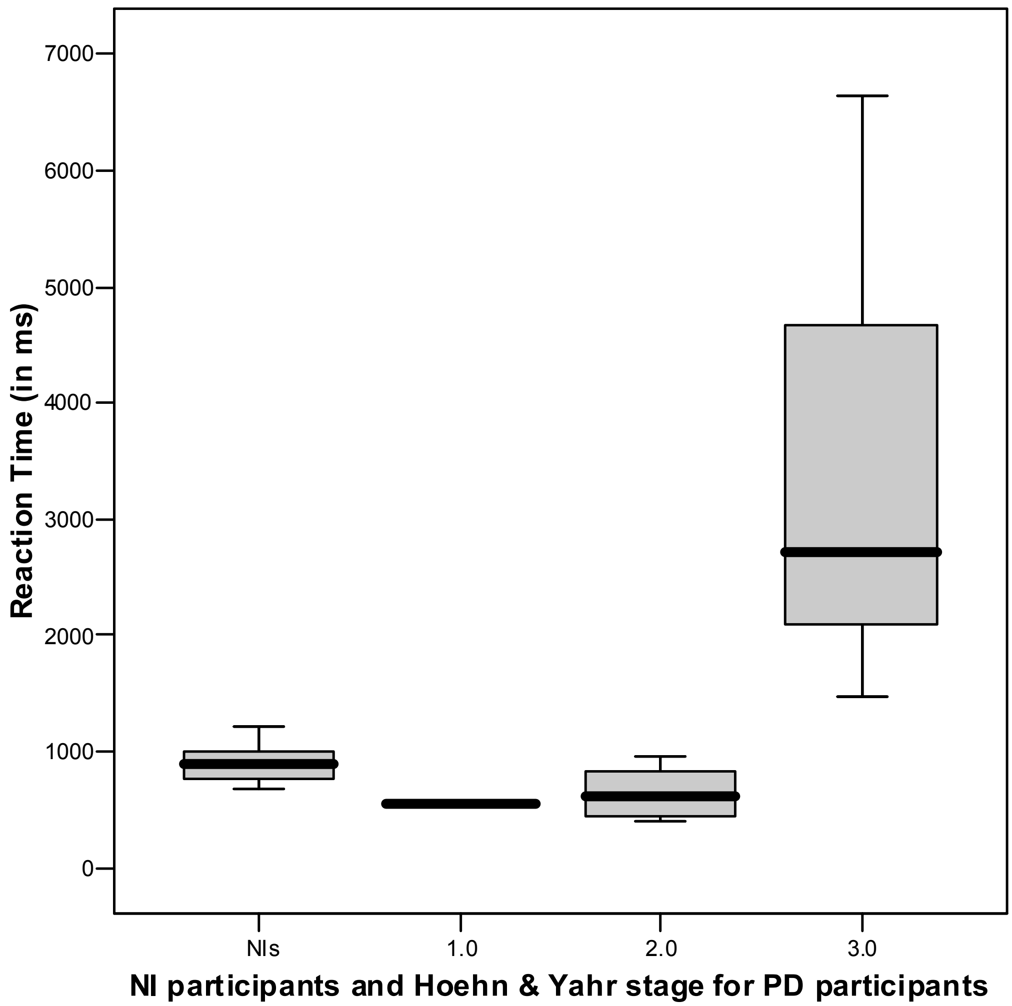


*Figure 23*. Distribution of dual-task oropharyngeal phase RTs by Hoehn and Yahr (1967) stage.

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The dark, black, horizontal bars in each of the boxes represent the median duration of the anticipatory phase for each subgroup of participants. Error bars represent ±1 *SD*.

## IV. DISCUSSION

The fundamental question posed in this research was whether cognitive resources are involved in swallowing. The question's relevance has to do with the historically pervasive view that swallowing is a reflexive, vegetative, and/or automatic physiological function. An implicit assumption in that view is that cognition plays no role in swallowing, especially in the "reflexive" oropharyngeal phase. The goal of the present study was to provide data to support the validity of that assumption by assessing the potential involvement of attention in swallowing. A dual-task reaction time (RT) paradigm was used with non-impaired, (NI) control participants age-matched to participants with idiopathic Parkinson's disease (PD) in the absence of other complicating factors and diagnoses, and who were in the "on" phase of their PD medication regimen.

Contrary to common thinking, the data from the study did point to the involvement of cognitive resources in swallowing in some cases. Evidence of attention was seen in the anticipatory phase, which arguably comes under "voluntary" control, and in the oropharyngeal phase of swallowing, which was argued in the Literature Review, may indeed be seen as automatic if not reflexive or vegetative and do not require cognitive control. The clearest evidence to that effect was seen by an increase in dual-task compared to baseline/single-task RTs to a secondary task in the pooled PD group—in which participants were shown to have general motor deficits. Interestingly, dual-task RTs were unchanged compared to baseline/single-task

RTs in the NI group, and durations of both anticipatory and oropharyngeal phases were generally invariant across baseline/single-task and dual-task conditions in both NI and PD groups. The most straightforward interpretation of this finding—which will be unpacked shortly—is that RTs were slowed in the pooled PD group during dual-task performance because the motor demands of swallowing were sufficiently great that cognitive support (i.e., attention) was required to achieve it competently. In fact, at a global level, the findings are consistent with emerging data from the physical therapy literature suggesting that motor tasks previously thought to be automatic or overlearned, such as walking, are subject to the influence of cognition (Camicioli et al., 1997; Dault et al., 2003; Hausdorff et al., 2005; O'Shea et al., 2002; Verghese et al., 2002; Woollacott & Shumway-Cook, 2002; Yardley et al., 2001; Yogev et al., 2005). Those data indicate that the introduction of an additional task to walking (i.e., a dual-task) can not only affect gait, speed, and posture in patients with PD and Alzheimer's disease, but also in young and aged, healthy individuals.

A second experimental question was whether there is a disparity in the demand for attention between different phases of swallowing (i.e., anticipatory versus oropharyngeal). Greater involvement of attention was expected in the anticipatory phase due to the observation that the anticipatory phase is generally thought to come under some degree of "voluntary control." Compared with the anticipatory phase, the commonly considered "reflexive" oropharyngeal phase was not expected to require as much cognitive involvement, and therefore fewer resources for attention would be necessary. Interestingly, no evidence was found to support this prediction. Dual-task RTs were equivalent for anticipatory and oropharyngeal phases of swallowing in both NI and PD groups.

The third experimental question was whether general sensorimotor status appeared to increase the involvement of attention required for swallowing and if so, which phase of swallowing would be most implicated. Findings relative to this question were among the most important ones in the study, and will dominate much of the remaining discussion. First, participants with Parkinson's disease–who were shown to have some degree of motor impairment without evident effects on swallowing–performed more poorly on dual-task reaction-time tasks than healthy control participants. Second, participants with Hoehn and Yahr's (1967) Stage 3 disease, who had greater global motor deficits than participants with Stages 1 and 2 disease, based on the *Unified Parkinson's Disease Rating Scale (UPDRS)*, displayed sharply increased dual-task RTs and RT variability in both the anticipatory and oropharyngeal phases of swallowing in comparison to baseline/single-task performance, whereas neither NI nor participants with PD in Stages 1 or 2 disease showed such increases. Decrements in dual-task RTs for participants with Stage 3 disease imply that attention was involved to a greater extent in those individuals, in both phases of swallowing, as compared with their less motorically impaired cohorts. Interestingly, in contrast to expectations, dual-task RT increases in the Stage 3 group were actually numerically greater during the so-called "reflexive" oropharyngeal phase as compared to the "voluntary" anticipatory phase, further reducing enthusiasm for the proposal that attention might have less involvement in a "reflexive" stage of swallowing.

Several issues are noteworthy to discuss in the findings. First, the statistical equivalence of baseline/single-task swallowing durations that was found across PD and NI groups was unanticipated. The literature is clear that hallmark characteristics of PD include stiffness, slowness, speech disturbance, and dysphagia, even in early stages (Goldman et al., 1998; Mir, et al., 2005; Hoehn & Yahr, 1967; Jahanshahi & Marsden, 2000; Parkinson, 1817), especially in cognitively demanding tasks (Fern-Pollak, Whone, Brooks, & Mehta, 2004; Wylie, Stout, & Bashore, 2005). Moreover, although none of the participants with PD had any known dysphagia, participants with PD *did* display general motor deficits based on results of the *UPDRS*. The differences in severity of those deficits were noted across Stage 1-3 participants (see Table 7). Thus, one would have expected baseline swallowing to be slower in the pooled PD group as compared to the NI group. In fact, Bird et al. (1994) and Ertekin et al. (2002) reported that patients with PD who were not symptomatic for dysphagia presented with delayed swallow initiation times. Similarly, Robbins et al. (1986) reported delayed pharyngeal swallow response in early-stage PD, which they attributed, in part, to difficulties with initiation of bolus propulsion to the pharynx. A study reported by Tison et al. (1996) also reported increases in total swallowing duration in early stage PD, which were improved with the administration of apomorphine, a dopamine receptor agonist used to pharmacologically imitate the action of dopamine as opposed to more typical dopamine replacement drugs (for reports of increased swallowing times in early PD, see Bushman et al., 1989; Hunter, Crameri, Austin, Woodward, & Hughes, 1997; Leopold & Kagel, 1997b; Robbins et al., 1986).

In the present investigation, numeric increases in anticipatory and oropharyngeal phase durations for Stage 1 and Stage 2 participants compared to controls were relatively trivial, on the order of about 225-350 ms. They were considerably larger for Stage 3 participants (about 650-1300 ms). However, even those differences, relative to controls, were not statistically significant due to small sample size and large variability in the data. Thus, perhaps the finding of “no difference” in baseline/single-task swallowing durations for participants with PD versus controls is a statistical anomaly, and differences do exist even for early-stage disease as the literature suggests (Bird et al., 1994; Bushman et al., 1989; Ertekin et al., 2002; Leopold & Kagel, 1997b;

Nagaya et al., 1998; Robbins et al., 1986; Stroudley & Walsh, 1991; for a review, see Johnston, Li, Castell, & Castell, 1995). However, the data can also be viewed in another light. In the studies by Bird et al. (1994) and Robbins et al. (1986), timing deviations in PD swallows were implicitly related to norms from previous studies for younger and older adults combined, as there was no control group in either study. Thus, perhaps previous reports of increased swallowing durations in PD are at least a partial artifact of age. In fact, in another investigation, Nagaya et al., (1998) found that swallowing durations in patients with dysphagia and Stages 3-5 PD were similar to those for age-matched controls. The data from the present investigation, which used age-matched controls, are in general accord with those findings. The data are also consistent with the suggestion that relatively stable timing features may characterize swallowing within a given age group (e.g., Tracy et al., 1989; Hiss, Strauss, Treole, Stuart, & Boutilier, 2000; Hiss et al., 2001; Martin-Harris et al., 2003, Martin-Harris, Brodsky, et al., 2005). Perhaps such stability was played out in the data presented here. Curiously, participants with PD showed an increased rate (i.e., a shorter duration) for the oropharyngeal phase of swallowing in the dual-task compared to baseline/single-task trials, although this was not a statistically significant finding.

Second, an extension of the prior observation is that despite the noted caveats, indeed, anticipatory and oropharyngeal phase durations were statistically equivalent across the groups under *all* experimental conditions, including baseline/single- and dual-task conditions. The most obvious point related to this finding is that in this study, considering the pooled PD data, swallowing appeared generally impervious to potential interference by a dual-task even in participants with PD. Therefore, even though those participants had some degree of general motor deficit, swallowing duration appeared generally unperturbed by the dual-task. Considering that dual-task RTs increased in the pooled PD group, the implication is that swallowing appeared to confiscate cognitive resources in that group. Stated differently, swallowing, which has critical survival value, appeared to seize resources from an irrelevant secondary task in participants with known global motor dysfunction. Further support of this resistant nature swallowing seems to have toward interruptions in attention can be garnered by future studies that alter the instructions of the present study to suggest different efforts of attention participants will place on each of the two tasks (i.e., swallowing and non-word discrimination) or by experimentally manipulating the difficulty of the task.

Third, the question arises as to the underlying reason that swallowing appeared to rob resources from a secondary task for the pooled PD group. Conceptually, several factors are potential candidates to explain the cause, including cognitive/attention, motor, or other factors. Cognitive factors are not strongly implicated, because all participants in PD and NI groups were cognitively normal and equivalent, based on results of *COGNISTAT* (Kiernan et al., 1987). Similarly, participant groups were equivalent demographically (i.e., age, gender, race, ethnicity) and in terms of general mood status, according to results from the *Beck Depression Inventory* (Beck et al., 1961, 1988). The primary difference that was assessed between the groups was overall motor function as indicated by tests of speech, tremor, rigidity, agility, posture, gait tremor, strength, and coordination using the *UPDRS* as measurement. Motor deficits were present in all participants with PD, although they were greatest in those with Stage 3 disease. Hence, although participants in the PD group did not display overt dysphagia, there was evidence that their motor functions were compromised at some general level, even in the "on" phase of their medication regimen. The observation that general motor deficits were the only known difference between the groups makes those deficits the most likely candidate to explain the cause of group differences in dual-task RTs. Specifically, a reasonable explanation is that participants in the PD group robbed attention resources from the secondary task during dual-task swallowing because their general motor dysfunctions somehow made the swallowing task difficult for them—despite the lack of any frank dysphagia—and resources were required for them to perform swallowing competently. In fact, some data indicate that the vast majority of patients with early-to-middle stages of PD may have subtle swallowing problems but remain asymptomatic (Bird et al., 1994).

The speculation that difficulties with swallowing could explain increased dual-task RTs that appeared most striking in Stage 3 participants appears reasonable. However, a few alternative hypotheses should be entertained as well. At the simplest level, one might argue that dual-task RTs, which required a foot pedal press, were slowed in the pooled PD group as compared to the NI group because of motor deficits in *limb* responses to secondary stimuli in the PD group—as opposed to motor difficulties associated with swallowing. Differential inspection of the data for participants with Stage 3 disease makes that hypothesis unsatisfying. Although Stage 3 participants indeed had poor limb responses based on baseline/single-task RTs (1304 ms as compared to 717 ms, 857 ms, and 717 ms for NI, Stage 1, and Stage 2 participants, respectively), participants in Stage 3 showed a disproportionate increase in RTs for the dual-task condition (increases of about 1270 ms and 790 ms for anticipatory and oropharyngeal phases, respectively, in comparison to roughly 100-250 ms increases for NI and participants with Stage 1-2 PD). Slower foot responses *alone* cannot account for the disproportionate increases in dual-task RTs in the Stage 3 participants. Thus, if motor deficits were involved in the modulation of dual-task RTs in those subjects, it seems more likely that they would have involved the swallowing mechanism itself.

A third hypothesis to explain why dual-task RTs increased, especially in Stage 3 participants, is that perhaps those participants had fewer resources to start with. Sharpe (1992) suggested that deficits of attention may be the result of degenerative changes in *ascending* pathways related to dopamine transmission. Certainly, if such deficits were present, the argument could be made that there may be degenerative changes in *descending* pathways affecting motor output. Thus, not only motor difficulties associated with the limb and possibly swallowing response, but possibly also a limitation in attentional resources could have required participants in Stage 3 to expend most available resources on the swallowing task, leaving few resources available for responses to the secondary auditory stimuli. Alternatively, instead of having an insufficient amount of resources, it might be suggested that participants with PD were unable to deploy or allocate the resources appropriately.

Fourth, it should be noted that all of the findings for participants with PD in the present study were obtained from participants with idiopathic disease during “on” cycles in the medication regimen. The literature suggests that both swallowing and RT characteristics might be quite different for patients in “off” phases of medication cycles or having a different form of PD (e.g., hypokinetic Parkinson’s disease; Bushman et al., 1989; Heilman, Bowers, Watson, & Greer, 1976; Hunter et al., 1997). Additionally, greater impairments in both baseline/single-task and dual-task swallowing and RTs would likely be seen with advanced disease, despite an active medication phase.

Fifth, there is need to revisit the previously advanced hypothesis that increases in dual-task RTs in the PD group—particularly for Stage 3 participants—were attributable to issues of resource allocation. Specifically, the proposal is that dual-task RTs increased for participants with PD because the motor difficulties associated with swallowing for those individuals commanded attention resources, which were then less available for responses relative to the secondary task. Implicit in this suggestion is, in fact, a "resource" model of cognition that views cognitive resources (i.e., attention) as limited, as sharable across tasks, and as differentially able to be allocated (Kahneman, 1973; Navon & Gopher, 1979; Navon & Miller, 2002; Tombu & Jolicœur, 2002; Wickens, 1980). In fact, the capacity model is the predominant one that has been used to explain RT effects in dual-tasks paradigms (e.g. Kahneman, 1973). In greater detail, capacity-sharing theory suggests that simultaneous tasks share a limited pool of available mental resources. If one task requires a great amount of those resources, limited resources will be available for processing of a second task. One result would be degradation in the quality of performance for the second task. Pertinent to the present investigation, another result might be a delay in response to the secondary task, because resource allocation is thought to potentiate not only performance quality but also response speed (Posner, 1980; Posner & Boies, 1971; Siddle & Lipp, 1997). This model explains anecdotal observations, for example, that an individual might have a delayed response to a spouse when engrossed by an interesting television show, and the model has the ability to explain the present findings. The most straightforward explanation is indeed that participants with PD may have had subtle motoric difficulties with swallowing, requiring that they allocate considerable attention to it to complete it competently. When an additional task was added, resources were insufficient to maintain normal response times to that task (Figure 24). Another possibility within the capacity sharing model is that participants with

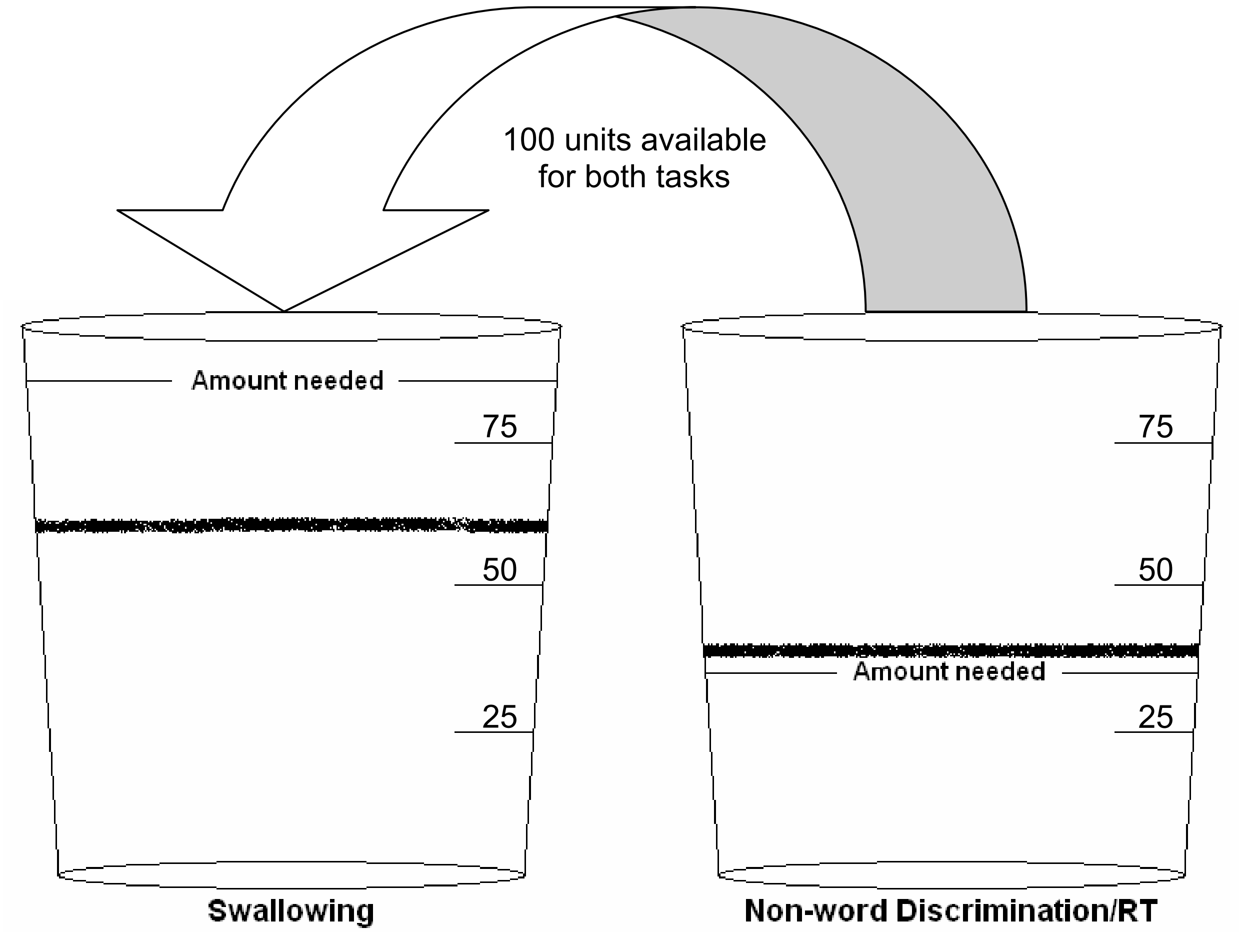


*Figure 24.* First scenario for capacity sharing.

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This scenario assumes that the participant has 100 mental resource units to use for the dual-task. Once swallowing is challenged by the non-word discrimination/RT task, swallowing claims a great number of resources from the RT task, leaving the resource units available for the non-word discrimination/RT reduced. Consequently, RT suffers.

PD may have had limited resources available and the dual-task condition overloaded the participants even if motoric difficulties were not present with swallowing. Therefore, they allocated available resources to the primary task—swallowing—and secondary task performance suffered as a result (Figure 25). A third possibility is that both motoric and resource limitations contributed to the present pattern of results (Figure 26). All of these possibilities are interesting to entertain, but the study was not set up to differentiate between them. These scenarios should be pursued with specifically designed studies. In the meantime, the most easily defensible conclusion based on the present data set is that motoric difficulties with swallowing contributed to the results, because evidence of motor difficulties was seen in the PD group. Although resource limitations may also have been present, general cognitive capabilities were normal in the PD group and no evidence was seen that might point to resource limitations.

Having said as much, at least one other conceptual framework should be examined for its potential to explain dual-task RT findings in the present study. That framework relates to a "bottleneck" model that has been proposed as an alternative to capacity models to explain classic dual-task RT results such as those reported here (Pashler, 1984, 1994; Ruthruff, et al., 2001). In brief, the fundamental proposal is that some mental operations may not allow for parallel processing (McCann & Johnston, 1992; Pashler, 1984, 1994; Schweickert, 1978). Rather, some operations may require dedication from a single mechanism for a period of time. An overview of the model and its predictions is shown in Figure 27A, which references a dual-task in which one task involves a simple *choice* response to the presence of a tone and the second task involves responding whether a letter presented upside down is a normal or mirror image of the letter. In brief, the model is built around the notion that cognitive operations exist between perception and response execution, and some of those operations require dedicated serial processing. Therefore,

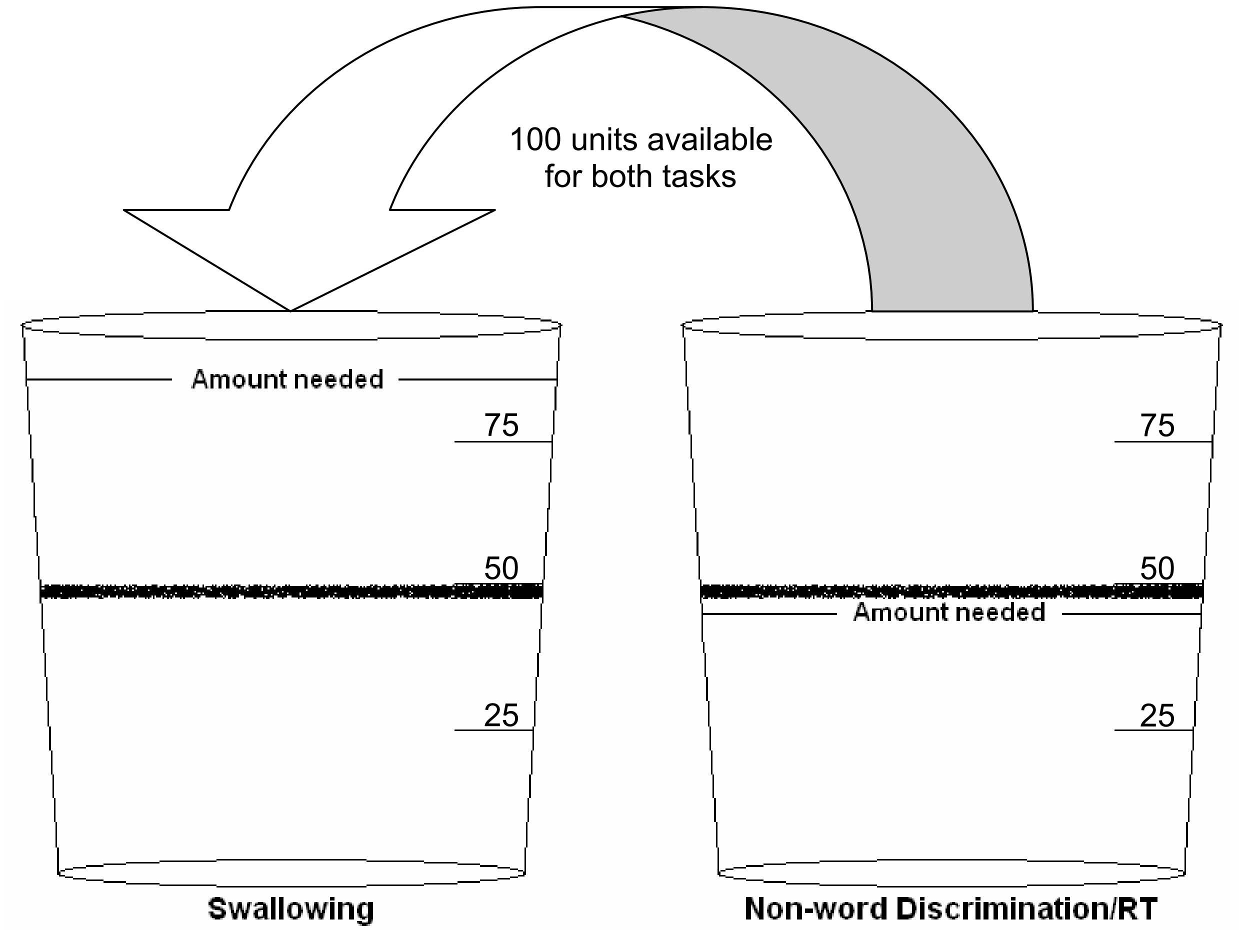


*Figure 25.* Second scenario for capacity sharing.

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This scenario assumes that the participant has 100 mental resource units able to be used at any given time. For purposes of the dual-task, swallowing begins at a reduced capacity because of disease, forcing swallowing to be even more aggressive at claiming resource units available from the non-word discrimination/RT task. Consequently, RT suffers.

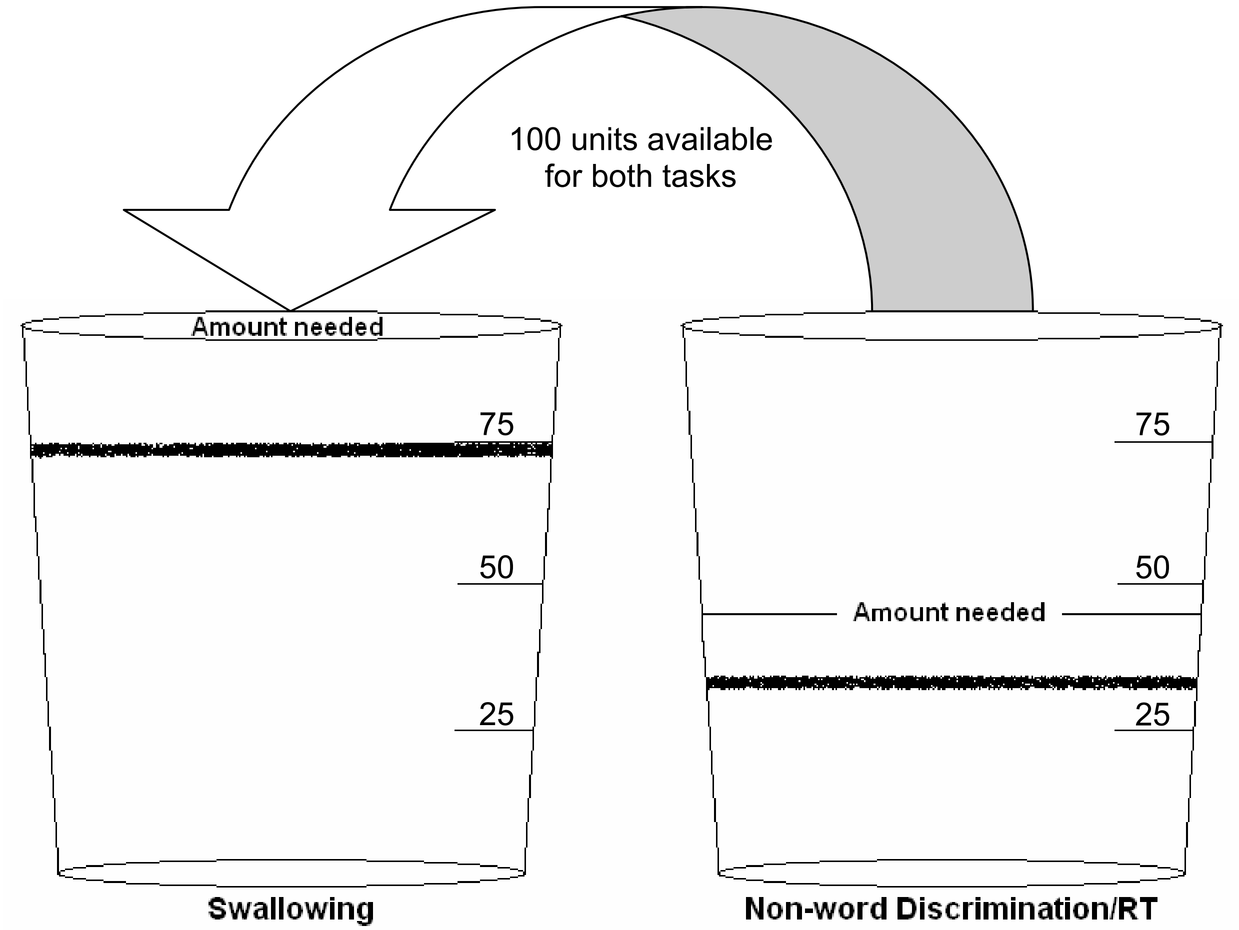


*Figure 26.* Third scenario for capacity sharing.

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This scenario assumes that the participant has 100 mental resource units able to be used at any given time. For purposes of the dual-task, swallowing and discrimination begin at reduced capacities because of disease, forcing swallowing to claim as many resource units as possible from the non-word discrimination/RT task. However, in this scenario, it takes more resources for swallowing. Consequently, RT suffers because swallowing depletes the resources available to the non-word discrimination/RT task.

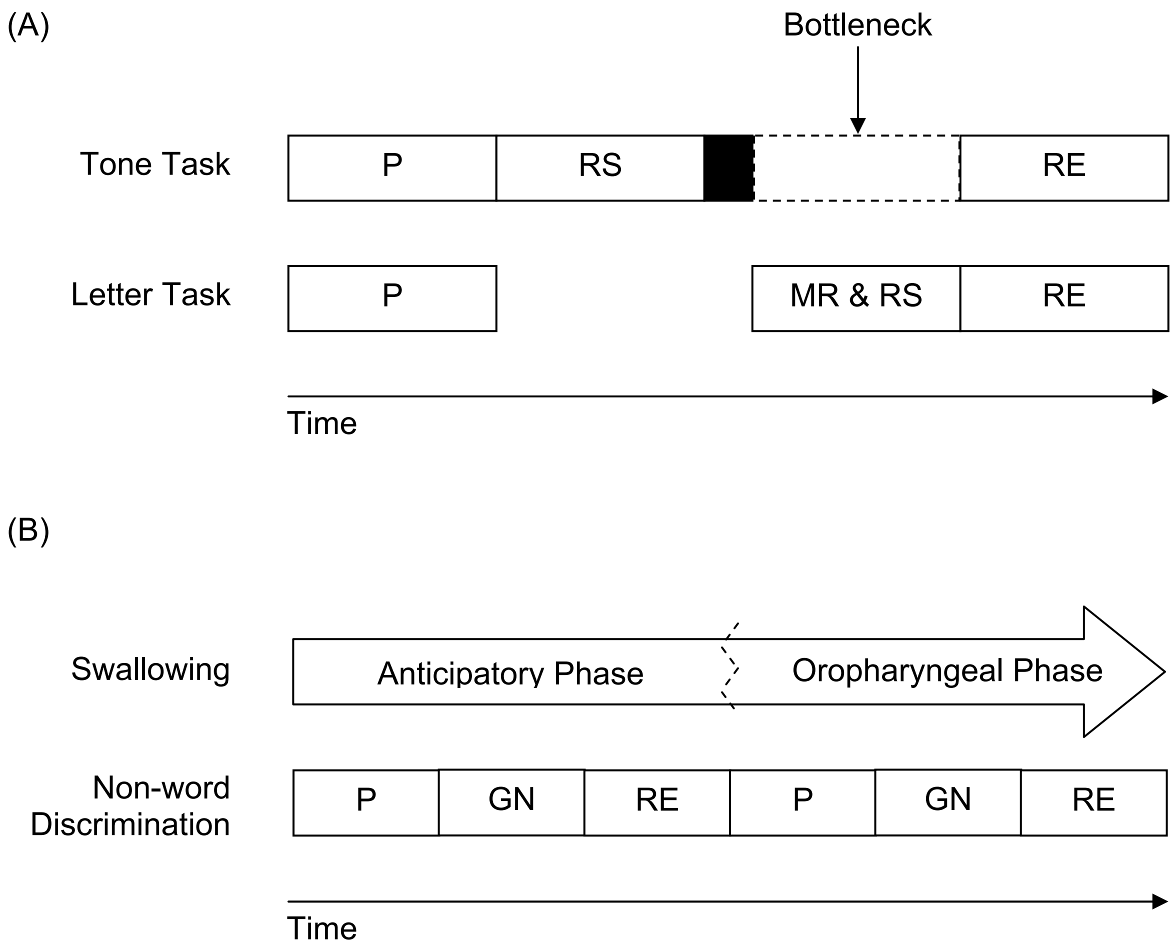


*Figure 27.* Dual-task central bottleneck processing diagram and current investigation paradigm comparison.

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(A) Dual-task with a structural central bottleneck adapted from Pashler (1984, 1994) and Ruthruff et al. (2001). P = perception; RS = response selection; MR = mental rotation; RE = response execution. (B) Model of the present investigation's dual-task paradigm, P = perception; GN = "go/no go" decision during swallowing (a continuous motor task); RE = response execution. The GN differs from the RS of model A because there is no choice. There is only a decision to withhold a response or engage a response. Additionally, swallowing has two phases in which the GN decision can be made. Pashler's model requires a *choice* to be made as a response for all trials and the same condition across trials. The present investigation's paradigm requires a single *decision* for a response on all trials, either in the anticipatory phase or oropharyngeal phase of swallowing.

if two stimuli are presented and perceived at the same time, and each one requires a response selection, the response selection for one of the stimuli will proceed while response selection for the second stimulus will be delayed until selection for the first stimulus has been completed. Similarly, response execution for both stimuli has to await completed response selection from both stimuli. However, response execution *times* themselves are not expected to be affected by the dual-task. Although some data support the bottleneck model over capacity-sharing models, extension of it to the dual-task paradigm in the present investigation is cumbersome and inappropriately placed. First, the bottleneck model speaks to paradigms in which RTs are related to two stimuli presented in parallel, each requiring a motor response. In the present study, the dual-task paradigm required a reaction to a secondary stimulus that was presented during the response *execution* phase of the primary task (swallowing), which according to bottleneck theory should not be affected by dual-tasks. Additionally, bottleneck models require a *choice RT* task. The present investigation did not use a choice RT task. Instead, it required a "go/no go" response. Although the go/no-go paradigm has been compared to and complements the bottleneck model (Netick & Klapp, 1994), the bottleneck model appears irrelevant for the present study and cannot be applied in a clear, meaningful, or helpful way (see Figure 26B).

## A. LIMITATIONS

As noted, data from the present investigation suggest that despite its overlearned, "reflexive" nature, swallowing appears to require cognitive resources in some motorically impaired individuals. Moreover, swallowing appeared to be broadly unyielding in its maintenance of at least temporal stability in the present participant groups. However, conclusions about such homeostasis may be premature. Durations of baseline anticipatory and oropharyngeal phases were numerically greater among Stage 3 participants as compared to normal controls, but statistical power was poor to capture those differences in the present study. To overcome this limitation, future studies should acquire a larger sample size of both patients with PD and non-impaired controls.

A second limitation of the present study lies with difficulties in the interpretation of the findings based on the current experimental paradigm. Several approaches exist to elucidate the effects of attention in RT experiments. The approach chosen here used the subtraction method. This method, simply stated, statistically subtracts baseline/single-task RT measures from dual-task RTs. If a significant difference is found between single- and dual-task RTs, the inference is that capacity negotiations occurred. Unfortunately, several caveats exist with this approach. Among them is the caveat that attempts should be made to modulate subjects' attentional focus. Specifically, the most rigorous approaches to RT research alter instructions to participants across conditions to suggest a priority of one versus another task, in effect shifting "primary" versus "secondary" tasks across conditions. In the present study, no such manipulation of instructions was used, primarily because of the need to limit the duration of the study for participants, and especially the number of swallowing trials and amount of liquids consumed. Instead, participants were instructed to drink when they were presented a "go" signal and drink in a "normal manner" and they were instructed to depress the foot pedal when they heard the target word "as quickly as they could." Both of those instructions are subjective in nature and neutral with respect to task primacy. Future studies should consider altering the experimental methods to determine whether a shift in task emphasis would affect outcomes.

A third limitation is that the present study did not allow for any finely grained examination of cognitive influences related to the individual physiologic events of swallowing, for example bolus collection, bolus propulsion, oral transit time, initiation of the pharyngeal swallow, or pharyngeal transit time. Such issues should be pursued with more detailed approaches to the evaluation of swallowing such as videofluorography, videoendoscopy, and needle or surface EMG sampling of specific muscle regions. The relevance is that if particular physiological events are found to be more dependent on cognition than others, there could be implications for the management of different patient populations.

In fact, one way of looking at the participant groups and the failure to find differences in swallowing durations across NI controls and participants with PD is that this study did not explore onset or duration changes as a function of detailed aspects of the swallow, such as pharyngeal swallow initiation, tongue base retraction, and hyolaryngeal excursion. The present findings are interesting because, based on group data, they indicate that even if such disturbances exist, there may be some type of neural or mechanical constraint that dictates a constant total swallow duration except in advanced cases of dysphagia. That is, the prolonged duration of the anticipatory phase may have resulted in earlier onset or shorter durations of physiologic components comprising the oropharyngeal phase (Martin-Harris, Michel, et al., 2005). This explanation fits with the lack of variance found in the overall swallow duration. Nagaya et al. (1998) found a significant difference in *stage transition duration* (i.e., the duration from bolus passage across the ramus of the mandible until onset of hyolaryngeal excursion, radiographically assessed) between patients with PD who did not aspirate during modified barium swallow and both young and elderly healthy controls. However, when considering the *total swallow duration* for these participants, no significant difference was found between participants with PD and elderly controls. Superficially, the data from the present investigation are consistent with those from Nagaya et al. in the sense that no difference in swallowing durations was found between NIs and grouped participants with PD. However, grouping patients with PD *en bloc* may not be an accurate way of studying patients with PD because numerical differences were present in the data when considering a participant's stage of PD. Future studies should provide expanded assessment of participants with PD as a function of disease stage (e.g., Hoehn & Yahr, 1967). With that approach, the data can be better evaluated for the relevance of disease stage.

Another related limitation of the study was the small sample size for both the NI and PD participant groups. Group size was determined based on *a priori* calculations of power relative to previous RT research. However, effect sizes turned out to be small relative to the third experimental question regarding the influence of motor deficits on dual-task RT and thus some potential findings may have been obscured. Specifically, findings around numeric differences in both swallowing and RT data in Stage 3 may have been elusive to detect because of the sample size factor. Thus, external validity is threatened in the present data set. Clearly, a larger sample should be planned for future studies.

A next limitation is that in this exploratory work, the presentation order of conditions to participants may have introduced bias from fatigue and diminishing effects of PD medications. Stated differently, because the order of baseline/single-task conditions was not counterbalanced with the dual-task due to concerns about limiting the number of subjects and trials in this initial subjects, an order effect is possible in the data. This concern should be addressed in future studies.

Another consideration that should be taken into account with regard to external validity is that this investigation limited the consistency and volume of the bolus and the manner in which it was administered. All swallowing trials used 5 ml of water that was self-administered by cup. Protocols for swallowing diagnostics (Logemann, 1998) suggest a range of volumes and bolus textures should be used to obtain a relatively functional representation of the patient's skills. Although the intent of this investigation was not diagnostic, future studies should address the effects of varying bolus volume and consistency and the manner in which the bolus is administered to determine differential cognitive effects in swallowing.

Finally, of somewhat less concern, the argument could be made that the approach taken to select the auditory stimuli used for the secondary task may have been compromised by the use of only female transcribers to validate the stimulus set, whereas the experimental arm of the study used participants with both genders. This concern is offset by the relatively wide range of ages and demographic diversity of the transcribers (i.e. race, ethnicity, and geographic origin broadly representing both rural and urban areas). Moreover, all of the transcribers had normal hearing based on hearing screening. Further, transcription errors were highly consistent across /vɛ-/ and /zɑ-/ nonsense word lists (/ð/, /ŋ/ and /ʒ/ were poorly understood by the listeners across lists). Thus, there do not appear to be substantial concerns about the potential that the all-female transcriber team compromised the validity of the study. The sensitivity of the task relative to the auditory stimuli comes into question as well. The fact that there was no change in RT for NIs and participants in the early stages of PD (Stages 1 and 2) during the dual-task raises the question of whether the task was sensitive enough to elicit an increased RT at all. Offsetting this possibility is the fact that increases in RT were seen in the participants with Stage 3 disease. The answer to whether the secondary task was sensitive enough to challenge swallowing in NIs and the early stages of PD, unfortunately, remains elusive. A more complex task than the one presented in this investigation may be necessary to demonstrate cognitive involvement in swallowing in non-impaired individuals and patients in early stage disease.

## B. CLINICAL IMPLICATIONS AND FUTURE RESEARCH

The present findings suggest that attention may be involved in both anticipatory and oropharyngeal stages of swallowing, at least in individuals with general motor deficits. The specific function of such involvement, however, is not clearly elucidated from the present data set. The outcomes of this investigation are consistent with standard practice in speech-language pathology that promotes the creation of treatment environments (e.g., clinic rooms) that are largely free from distraction so that patients' cognitive resources may be allocated to swallowing. Clinicians typically close doors, turn off radios, close windows, and attempt to quiet conversations nearby for patients with cognitive or swallowing difficulties. Caution should continue to be exercised with these patients. Additionally, results from this study suggest that, even in the absence of a known cognitive disorder, the presence of a sufficiently severe motor disorder may be worthy of similar concerns relative to patients with dysphagia.

Several avenues of treatment presented may be appropriate for patients with dysphagia and cognitive and/or motor disorders. Conceptually, one route of treatment for patients with cognitive compromise would be to orient goals directed toward improving cognitive function (e.g., attention, high-level executive functions). With proper medical care and therapy, patients with these types of disorders, depending on the severity, may be able to be taught how to reduce risk and/or improve their cognitive abilities, perhaps ultimately affecting the safety and/or efficiency of swallowing (Yogev et al., 2005). Patients are already in therapy to improve their motor and/or cognitive function. In an effort to gain a more focused attention, removal of distractions from the eating/drinking environment is typically practiced by therapists and should probably be extended to the mealtime environment. Doing so may not necessarily affect the patient's overall cognitive status, but may improve the possibility of success he or she has with swallowing by not allowing other tasks to compete with swallowing. In cases in which distractions and interruptions cannot be entirely removed (e.g., dining with family members during conversation; eating at a public restaurant), patients can be trained to compensate by working to improve their concentration and/or by recommending a therapeutic swallowing maneuver. The alternative may lead to isolation, which may lead to feelings of depression, further complicating the patient's cognitive functioning (Kuzis et al., 1997).

The data from the present investigation also provide vague support for clinical observations—in the absence of data in the literature—that intact cognitive skills may allow patients to modulate a failing swallowing system. That is, swallowing tactics such as the Mendelsohn maneuver (Ding et al., 2002; Kahrilas et al., 1991; Neumann et al., 1995), supraglottic swallow, and effortful swallow (Bülow et al., 1999; Hind et al., 2001; Logemann, 1998; Martin, Logemann, Shaker, & Dodds, 1993; Neumann et al., 1995) that are prescribed to address physiologic impairments of swallowing demand cognitive resources for patients to understand how to perform the task and how to organize and motorically coordinate relative efforts relative, all while swallowing a bolus of food or drink. It is clear that mental faculties can help keep unhealthy swallowing systems from deteriorating, at minimum, and in the best-case scenarios, assist with improvement or facilitation of swallowing.

In addition to behavioral treatments to improve swallowing skills, medical treatments have recently focused on cholinesterase inhibitors to improve swallowing function in the face of cognitive disorders (Yogev et al., 2005). Originally developed in a mouse model, rivastigmine, a cholinesterase inhibitor, was found to benefit conditions of edema, neurological function, and motor function (Chen, Shohami, Constantini, & Weinstock, 1998). Since then, human studies have suggested that improvements in cognition, or at least a slowing of the deterioration of cognitive disorders and motor dysfunction, can occur with rivastigmine (de Tommaso, Specchio, Sciruicchio, Difruscolo, Specchio, 2004; Emre et al., 2004; Giladi et al., 2003; Serrano & García-Borreguero, 2004). Whereas these investigations assessed cognition and motor function in various forms, none of the studies addressed any effects rivastigmine had on swallowing. Moreover, as with most drugs, some side effects are important to consider. Although benefits appear to clearly outweigh such effects, risk factors include nausea, vomiting, and increased tremor (Emre et al., 2004). Of note is that in the study completed by Emre et al., PD stage was not controlled and thus, staging may have influenced study outcomes. Future studies need to address not only the pharmaceutical effects of rivastigmine on cognition and motor function, but also on swallowing function, and studies should take into consideration disease staging in the chosen patient sample.

## C. SUMMARY

The first experimental question was to determine whether attention is involved in swallowing. Findings from the present study suggest attention may be involved in both anticipatory and oropharyngeal phases of swallowing for participants with early-to-mid-stage PD, considering pooled data. This finding was demonstrated by a slowing of RTs to a secondary task during swallowing for participants with PD. Swallowing appeared to confiscate cognitive resources from the secondary task, whereby performance in the secondary task declined and swallowing duration was maintained. Dual-task RTs were unchanged in healthy, non-impaired, control participants. Thus, inferences about the involvement of attention in swallowing cannot be made for participants in that group.

The second experimental question asked whether the involvement of attention in anticipatory versus oropharyngeal phases of swallowing was measurably different. Numerically, the anticipatory phase demanded greater resources than the oropharyngeal phase (i.e., dual-task RTs for the anticipatory phase were longer than RTs for the oropharyngeal phase). However, that difference was not statistically meaningful.

The third experimental question was whether sensorimotor deficits would affect the utilization of attention in swallowing. Dual-task RTs for participants in early stages of PD (Stages 1 and 2), with relatively few sensorimotor deficits, were not statistically different from baseline/single-task RTs. Participants in mid-stage PD (Stage 3), who manifested greater general motor impairment, experienced a considerable delay in RT for dual-task as compared to the baseline/single-task condition. Numerically longer RTs were found in the Stage 3 PD group for the anticipatory as compared to oropharyngeal phase, suggesting greater attentional involvement for the anticipatory phase. Dual-task RTs for the participants with early disease (i.e., Stages 1 and 2) and normal controls were similar, emphasizing the robust and steadfast nature of swallowing.

# BIBLIOGRAPHY


Adnerhill, I., Ekberg, O., & Groher, M. E. (1989). Determining normal bolus size for thin liquids. *Dysphagia, 4,* 1-3.

American Psychiatric Association. (1994). *Diagnostic and statistical manual of mental disorders* (4th ed.). Washington, DC: Author.

Anderson, C. A., Dick, T. E., & Orem, J. (1995). Swallowing in sleep and wakefulness in adult cats. *Sleep, 18*(5), 325-329.

Atkinson, M., Kramer, P., Wyman, S., & Ingelfinger, F. (1957). The dynamics of swallow: I. Normal pharyngeal mechanisms. *Journal of Clinical Investigation, 36*, 581-598.

Bassotti, G., Germani, U., Pagliaricci, S., Plesa, A., Giulietti, O, Mannarino, E., et al. (1998). Esophageal manometric abnormalities in Parkinson's disease. *Dysphagia, 13*, 28-31.

Beauchet, O., Dubost, V., Hermann, F., Rabilloud, M., Gonthier, R., & Kressig, R. W. (2005). Relationship between dual-task related gait changes and intrinsic risk factors for falls among transitional frail older adults. *Aging Clinical and Experimental Research, 17*, 270-275.

Beck, A. T., Steer, R. A., & Garbin, M .G. (1988). Psychometric properties of the depression inventory: Twenty-five years of evaluation. *Clinical Psychology Review, 8*, 77-100.

Beck, A. T., Ward, C. H., Mendelson, M., Mock, J., & Erbaugh, J. (1961). An inventory for measuring depression. *Archives of General Psychiatry, 4*, 561-571.

Bieger, D. & Hockman, C. H. (1976). Suprabulbar modulation of reflex swallowing. *Experimental Neurology, 52*(2), 311-324.

Bine, J. E., Frank, E. M., & McDade, H. L. (1995). Dysphagia and dementia in subjects with Parkinson's disease. *Dysphagia, 10*, 160-164.

Bird, M. R., Woodward, M. C., Gibson, E. M., Phyland, D. J., & Fonda, D. (1994). Asymptomatic swallowing disorders in elderly patients with Parkinson's disease: A description of findings on clinical examination and videofluoroscopy in sixteen patients. *Age and Ageing, 23*, 251-254.

Bisch, E. M., Logemann, J. A., Rademaker, A. W., Kahrilas, P. J., & Lazarus, C. L. (1994). Pharyngeal effects of bolus volume, viscosity, and temperature in patients with dysphagia resulting from neurologic impairment and in normal subjects. *Journal of Speech and Hearing Research, 37,* 1041-1049.

Bransfield, R. C. (1997-1998). Brain. Retrieved January 23, 2002, from http://www .mentalhealthandillness.com/brain.html

Brauer, S. G., Woollacott, M., & Shumway-Cook, A. (2001). The interacting effects of cognitive demand and recovery of postural stability in balance-impaired elderly persons. *Journal of Gerontology, 56A*(8), M489-M496.

Bremner, R. M., Hoeft, S. F., Costantini, M., Crookes, P. F., Bremner, C. G., & DeMeester, T. R. (1993). Pharyngeal swallowing: The major factor in clearance of esophageal reflux episodes. *Annals of Surgery, 218*(3), 364-370.

Broadbent, D. E. (1958). *Perception and Communication*. London: Pergamon Press.

Brown, R. G. & Marsden, C. D. (1984). How common is dementia in Parkinson's disease? *Lancet, 1*, 1262-1265.

Bülow, M., Olsson, R., & Ekberg. O. (1999). Videomanometric analysis of supraglottic swallow, effortful swallow, and chin tuck in healthy volunteers. *Dysphagia, 14*, 67-72.

Bushmann, M., Dobmeyer, S. M., Leeker, L., & Perlmutter, J. S. (1989). *Neurology, 39*, 1309-1314.

Camicioli, R., Howieson, D., Lehman, S., & Kaye, J. (1997). Talking while walking: The effect of a dual task in aging and Alzheimer's disease. *Neurology, 48*(4), 955-958.

Chen, Y., Shohami, E., Constantini, S., & Weinstock, M. (1998). Rivastigmine, a brain-selective acetylcholinesterase inhibitor, ameliorates cognitive and motor deficits induced by closed-head injury in the mouse. *Journal of Neurotrauma, 15*(4), 231-237.

Christensen, C. M. & Navazesh, M. (1984). Anticipatory salivary flow to the sight of different foods. *Appetite, 5*, 307-315.

Cohen, J. (1988). *Statistical power analysis for the behavioral sciences* (2nd ed.). Hillsdale, NJ: Lawrence Earlbaum Associates.

Cole, G. & Cowie, V.A. (1987). Long survival after cardiac arrest: Case report and neuropathological findings. *Clinical Neuropathology, 6*(3), 104-109.

Cook, I. J., Dodds, W. J., Dantas, R. O., Kern, M. K., Massey, B. T., Shaker, R., et al. (1989). Timing of videofluoroscopic, manometric events, and bolus transit during the oral and phayrngeal phases of swallowing. *Dysphagia, 4*, 8-15.

Crary, M. A. & Baldwin, B. O. (1997). Surface electromyographic characteristics of swallowing in dysphagia secondary to brainstem stroke. *Dysphagia, 12*, 180-187.

Daniels, S. K. & Foundas, A. L. (1997). The role of the insular cortex in dysphagia. *Dysphagia, 12*, 146-156.

Dantas, R. O., Kern, M. K., Massey, B. T., Dodds, W. J., Kahrilas, P. J., Brasseur, J. G., et al. (1990). Effect of swallowed bolus variables on oral and pharyngeal phases of swallowing. *American Journal of Physiology, 258*(5), G675-G681.

de Tommaso, M., Specchio, N., Sciruicchio, V., Difruscolo, O., & Specchio, L. M. (2004). Effects of rivastigmine on motor and cognitive impairment in Huntington's disease. *Movement Disorders, 19*(12), 1516-1518.

Deutsch, J. A. & Deutsch, D. (1963). Attention: Some theoretical considerations. *Psychological Review, 70*, 80-90.

Ding, R., Larson, C. R., Logemann, J. A., & Rademaker, A. W. (2002). Surface eletromyographic and eletroglottographic studies in normal subjects under two swallow conditions: Normal and during the Mendelsohn manuever. *Dysphagia, 17*, 1-12.

Dodds, W. J. (1989). The physiology of swallowing. *Dysphagia, 3*, 171-178.

Doty, R. W. & Bosma, J. F. (1956). An electromyographic analysis of reflex deglutition. *Journal of Neurophysiology, 19*, 44-60.

Dualt, M., Yardley, L., & Frank, J. S. (2003). Does articulation contribute to modifications of postural control during dual-task paradigms? *Cognitive Brain Research, 16*, 434-440.

Earles, D., Vardaxis, V., & Koceja, D. (2001). Regulation of motor output between young and elderly subjects. *Clinical Neurophysiology. 112*(7), 1273-1279.

Edwards, L. L., Pfeiffer, R. F., Quigley, E. M. M., Hofman, R., & Balluff, M. (1991). Gastrointestinal symptoms in Parkinson's disease. *Movement Disorders, 6*(2), 151-156.

Emre, M., Aarsland, D., Albanese, A., Byrne, E. J., Deuschl, G., De Deyn, P. P., et al. (2004). Rivastigmine for dementia associated with Parkinson's disease. *New England Journal of Medicine, 351*, 2509-2518.

Engelhart, C., Eisenstein, N., & Meininger, J. (1994). Psychometric properties of the Neurobehavioral Cognitive Status Exam. *The Clinical Neuropsychologist, 8*(4), 405-415.

Epstein, L. H., Paluch, R., & Coleman, K. J. (1996). Differences in salivation to repeated food cues in obese and nonobese women. *Psychosomatic Medicine, 58*, 160-164.

Epstein, S. (1994). Integration of the cognitive and the psychodynamic unconscious. *American Psychologist, 49*(8), 709-724.

Ertekin, C., Kiylioglu, N., Tarlaci, S., Turman, A. B., Secil, Y., & Aydogdu, I. (2001). Voluntary and reflex influences on the initiation of swallowing reflex in man. *Dysphagia, 16*, 40-47.

Ertekin, C., Tarlaci, S., Aydogdu, I., Kiylioglu, N., Yuceyar, N., Turman, A. B., et al. (2002). Electrophysiological evaluation of pharyngeal phase of swallowing in patients with Parkinson's disease. *Movement Disorders, 17*(5), 942-949.

Fändriks, L., Mattsson, A., Dalenbäck, J., Sjövall, H., Olbe, L., & Svennerholm, A. M. (1995). Gastric output of IgA in man: Relation to the migrating motility complexes and sham feeding. *Scandinavian Journal of Gastroenterology, 30*, 657-663.

Fahn, S. & Elton, R. (1987). Members of the UPDRS Development Committee. In: S. Fahn, C. D., Marsden, D. B. Calne, & M. Goldstein (Eds.). *Recent developments in Parkinson's disease* (Vol. 2, pp. 153-163, 293-304). Florham Park, NJ: Macmillan Health Care Information.

Fern-Pollak, L., Whone, A. L., Brooks, D. J., & Mehta, M. A. (2004). Cognitive and motor effects of dopaminergic medication withdrawal in Parkinson's disease. *Neuropsychologia, 42*, 1917-1926.

Gautier, J.-F., Chen, K., Uecker, A., Bandy, D., Frost, J., Salbe, A. D., et al. (1999). Regions of the human brain affected during a liquid-meal taste perception in the fasting state: A positron emission tomography study. *American Journal of Clinical Nutrution, 70*, 806-810.

Ghez, C. & Krakauer, W. T. (2000). The organization of movement. In E. R. Kandel, J. H. Schwartz, & T. M. Jessell (Eds.), *Principles of Neural Science* (4$^{th}$ ed., pp. 653-673). New York, NY: McGraw-Hill.

Giduck, S. A., Threatte, R. M., & Kare, M. R. (1987). Cephalic reflexes: Their role in digestion and possible roles in absorption and metabolism. *Journal of Nutrition, 117*, 1191-1196.

Giladi, N., Shabtai, H., Gurevich, T., Benbunan, B., Anca, M., & Korczyn, A. D. (2003). Rivastigmine (Exelon) for dementia in patients with Parkinson's disease. *Acta Neurologica Scandinavica, 108*, 368-373.

Goldman, W. P., Baty, J. D., Buckles, V. D., Sahrmann, S., & Morris, J. C. (1998). Cognitive and motor functioning in Parkinson disease. *Archives of Neurology, 55*, 674-680.

Gower, T. (2001, October 8). Now hear this, while you can. *Los Angeles Times*. Retrieved November 5, 2002, from http://www.audiology.org

Guinard, J.-X., Zoumas-Morse, C., & Walchak, C. (1998). Relation between parotid saliva flow and composition and the perception of gustatory and trigeminal stimuli in foods. *Physiology & Behavior, 63*(1), 109-118.

Groher, M. E. (1992). *Dysphagia: Diagnosis and Management* (2nd ed.). Boston, MA: Butterwoth-Heinemann.

Gross, R. D., Atwood, C. W., Grayhack, J. P., Shaiman, S. (2003). Lung volume effects on pharyngeal swallowing physiology. *Journal of Applied Physiology, 95*, 2211-2217.

Hall, M. (1836). *Lectures on the nervous system*. Philadelphia, PA: E. L. Carey & A. Hart.

Hamdy, S., Aziz, Q., Rothwell, J. C., Singh, K., Barlow, J., Hughes, D. G., et al. (1996). The cortical topography of human swallowing musculature in health and disease. *Nature Medicine, 2*, 1217-1224.

Hamdy, S., Mikulis, D. J., Crawley, A., Xue, S., Lau, H., Henry, S., et al. (1999). Cortical activation during human volitional swallowing: An event-related fMRI study. *American Journal Of Physiology: Gastrointestinal and Liver Physiology, 277,* G219-G225.

Hamdy, S., Rothwell, J. C., Aziz, Q., & Thompson, D. G. (2000). Organization and reorganization of human swallowing motor cortex: Implications for recovery after stroke. *Clinical Science, 98,* 151-157.

Hamdy, S., Rothwell, J. C., Brooks, D. J., Bailey, D., Aziz, Q., & Thomspon, D. G. (1999). Identification of the cerebral loci processing human swallowing with $H_2\,^{15}O$ PET activation. *Journal of Neurophysiology, 81,* 1917-1926.

Hamdy, S., Xue, S., Valdez, D., & Diamant, N. E. (2001). Induction of cortical swallowing activity by transcranial magnetic stimulation in the anaesthetized cat. *Neurogastroenterology and Motility, 13,* 65-72.

Hamlet, S. L., Choi, J., Zormeier, M., Shamsa, F., Stachler, R. J., Muz, J., Jones, L. A. (1996). Normal adult swallowing of liquid and viscous material: Scintigraphic data on bolus transit and oropharyngeal residues. *Dysphagia, 11*, 41-47.

Hausdorff, J. M., Yogev, G., Springer, S., Simon, E. S., & Giladi, N. (2005). Walking is more like catching than tapping: Gait in the elderly as a complex cognitive task. *Experimental Brain Research, 164*, 541-548.

Hear-It. (2006). *Sounds are waves in the air*. Retrieved March 9, 2006, from http://www.medical.hear-it.org/page.dsp?page=943

Heilman, K. M., Bowers, D., Watson, R. T. & Greer, M. (1976). Reaction times in Parkinson's disease. *Archives of Neurology, 33*(2), 139-140.

Hiiemae, K. M. & Palmer, J. B. (1999). Food transport and bolus formation during complete feeding sequences on foods of different initial consistency. *Dysphagia, 14*, 31-42.

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

Hiss, S. G., Strauss, M., Treole, K., Stuart, A., & Boutilier, S. (2000). Effects of age, gender, bolus volume, bolus viscosity, and gustation on swallowing apnea onset relative to lingual bolus propulsion onset in normal adults. *Journal of Speech, Language, and Hearing Research, 47*, 572-583.

Hiss, S. G., Treole, K., Stuart, A. (2001). Effects of age, gender, bolus volume, and trial on swallowing apnea duration and swallow/respiratory phase relationships of normal adults. *Dysphagia, 16*, 128-135.

Hoehn, M. M. & Yahr, M. D. (1967). Parkinsonism: Onset, progression, and mortality. *Neurology, 15*, 427-442.

Hollerbach, S., Fitzpatrick, D., Shine, G., Kamath, M. V., Upton, A. R., & Tougas, G. (1999). Cognitive evoked potentials to anticipated oesophagel stimulus in humans: Quantitative assessment of the cognitive aspects of visceral perception. *Neurogastroenterology and Motility, 11,* 37-46.

Hsieh, S., Hwang, W.-J., Tsai, J.-J., & Tsai, C.-Y. (1996). Precued shifting of attention between cognitive sets in Parkinson patients. *Psychological Reports, 78*, 815-823.

Hughes, A. J., Daniel, S. E., Kilford, L., & Lees, A. J. (1992). Accuracy of clinical diagnosis of idiopathic Parkinson's disease: a clinico-pathological study of 100 cases. *Journal of Neurology, Neurosurgery, and Psychiatry, 55*, 181-184.

Hunter, P. C., Crameri, J., Austin, S., Woodward, M. C., & Hughes, A. J. (1997). Response of parkinsonian swallowing dysfunction to dopaminergic stimulation. *Journal of Neurology, Neurosurgery, and Psychiatry, 63*, 579-583.

Issa, F. G. (1994). Gustatory stimulation of the oropharynx fails to induce swallowing in the sleeping dog. *Gastroenterology, 107,* 650-656.

Jacob, P., Kahrilas, P. J., Logemann, J., Shah, V., & Ha, T. (1989). Upper esophageal sphincter opening and modulation during swallowing. *Gastroenterology, 97*(6), 1469-1478.

Jahanshahi, M. & Marsden, C. D. (2000). Parkinson's disease: A self-help guide. New York, NY: Demos Medical Publishing, Inc.

James, W. (1890). *The principles of psychology* (Vol. 1). New York, NY: Henry Holt and Company.

Jean, A. & Car, A. (1979). Inputs to the swallowing medullary neurons from the peripheral afferent fibers and the swallowing cortical area. *Brain Research, 178*, 567-572.

Jean, A., Car, A., & Roman, C. (1975). Comparison of activity in pontine vs. medullary neurons during swallowing. *Experimental Brain Research, 22*, 211-220.

Johnston, B. T., Colcher, A., Li, Q., Gideon, M., Castell, J. A., & Castell, D. O. (2001). Repetitive proximal esophageal contractions: A new manometric finding and a possible further link between Parkinson's disease and achalasia. *Dysphagia, 16*, 186-189

Johnston, B. T., Li, Q., Castell, J. A., & Castell, D. O. (1995). Swallowing and esophageal function in Parkinson's disease. *American Journal of Gastroenterology, 90*(10), 1741-1746.

Kahneman, D. (1973). *Attention and effort*. Englewood Cliffs, NJ: Prentice-Hall, Inc.

Kahrilis, P. J., Dodds, W. J., Dent, J., Logemann, L. A., & Shaker, R. (1988). Upper esophageal sphincter function during deglutition. *Gastroenterology, 95*, 52-62.

Kahrilas, P. J., Logemann, J. A., Krugler, C., & Flanagan, E. (1991). Volitional augmentation of upper esophageal sphincter opening during swallowing. *American Journal Of Physiology: Gastrointestinal and Liver Physiology, 260,* G450-G456.

Kazmark, P. (1997). Operating characteristics of the Neurobehavioral Cognitive Status Exam using neuropsychological assessment as the criterion. *Assessment, 4*(1), 1-8.

Kendall, K. A., McKenzie, S., Leonard, R. J., Goncalves, M. I., & Walker, A. (2000). Timing of events in normal swallowing: A videofluoroscopic study. *Dysphagia, 15*, 74-83.

Kern, M. K., Jaradeh, S., Arndorfer, R. C., & Shaker, R. (2001). Cerebral cortical representation of reflexive and volitional swallowing in humans. *American Journal of Physiology: Gastrointestinal and Liver Physiology, 280*, G354-G360.

Kiernan, R. J., Mueller, K, Langston, J. W., & Van Dyke, C. (1987). The Neurobehavioral Cognitive Status Examination: A brief but differentiated approach to cognitive assessment. *Annals of Internal Medicine, 107*(4)*,* 481-485.

Kline, P. (1993). *The handbook of psychological testing*. London, England: Routledge.

Kolb, B. & Whishaw, I. Q. (1990). *Fundamentals of Human Neuropsychology* (3rd ed.). New York, NY: W. H. Freeman and Company.

Korczyn, A. D., Inzelberg, R., Treves, T., Neufeld, M., Reider, I, & Rabey, P. M. (1987). Dementia of Parkinson's disease. *Advances in Neurology, 45*, 399-403.

Kuzis, G., Sabe, L., Tiberti, C., Leiguarda, R., & Starkstein, S. E. 1997. Cognitive functions in major depression and Parkinson's disease. *Archives of Neurology, 54*, 982-986.

Langmore, S. E. (1996). Dysphagia in neurologic patients in the intensive care unit. *Seminars in Neurology, 16*(4), 329-340.

Langmore, S. E., Terpenning, M. S., Schork, A., Chen, Y., Murray, J. T., Lopatin, D., et al. (1998). Predictors of aspiration pneumonia: how important is dysphagia? *Dysphagia, 13*(2), 69-81.

Lappalainen, R., Sjödén, P.-O., Karhunen, L., Gladh, V., & Lesinska, D. (1994). Inhibition of anticipatory salivation and craving in response to food stimuli. *Physiology & Behavior, 56*(2), 393-398.

Larson, C. R., Byrd, K. E., Garthwaite, C. R., Luschei, E. S. (1980). Alterations in the pattern of mastication after ablations of the lateral precentral cortex in rhesus macaques. *Experimental Neurology, 70*(3), 638-651.

Lazarus, C. & Logemann, J. A. (1987). Swallowing disorders in closed head trauma patients. *Archives of Physical Medicine and Rehabilitation, 68,* 79-84.

Legenbauer, T., Vögele, C., & Rüddel, H. (2004). Anticipatory effects of food exposure in women diagnosed with bulimia nervosa. *Appetite, 4*, 33-40.

Leonard, R. J., Kendall, K. A., McKenzie, S., Goncalves, M. I., & Walker, A. (2000). Structural displacements in normal swallowing: A videofluoroscopic study. *Dysphagia, 15*, 146-152.

Leopold, N. A. & Kagel, M. C. (1983). Swallowing, ingestion and dysphagia: A reappraisal. *Archives of Physical Medicine and Rehabilitation, 64,* 371-373.

Leopold, N. A. & Kagel, M. C. (1997a). Dysphagia—ingestion or deglutition?: A proposed paradigm. *Dysphagia, 12,* 202-206.

Leopold, N. A. & Kagel, M. C. (1997b). Pharyngo-esophageal dysphagia in Parkinson's disease. *Dysphagia, 12*, 11-18.

Levy, J. & Pashler, H. (2001). Is dual-task slowing instruction dependent? *Journal of Experimental Psychology: Human Perception and Performance, 27*(4), 862-869.

Lichter, I. & Muir, R. C. (1975). The pattern of swallowing during sleep. *Electroencephalograpy and Clinical Neurophysiology, 38*(4), 427-432.

Lieberman, A. N., Horowitz, L., Redmond, P., Pachter, L., Lieberman, I., & Leibowitz, M. (1980). Dysphagia in Parkinson's disease. *American Journal of Gastroenterology, 74*, 157-160.

Lipp, O. V., Blumenthal, T. D., & Adam, A. R. (2001). Attentional modulation of blink startle at long, short, and very short lead intervals. *Biological Psychology, 58,* 89-103.

Logemann, J. A. (1998). *Evaluation and treatment of swallowing disorders* (2nd ed.). Austin, TX: Pro-Ed, Inc.

Logemann, J., Kahrilas, P. J., Cheng, J., Pauloski, B. R., Gibbons, P. J., Rademaker, W., et al. (1992). Closure mechanism of laryngeal vestibule during swallowing. American Journal of Physiology (Reprinted from Gastrointestingal & Liver Physiology, 21, 262, G338-G-344.

Logemann, J. A., Pauloski, B. R., Colangelo, L., Lazarus, C., Fujiu, M., & Kahrilas, P. J. (1995). Effects of a sour bolus on oropharyngeal swallowing measures in patients with neurogenic dysphagia. *Journal of Speech of Hearing Research, 38,* 556-563.

Luchei, E. S. & Finnegan, E. M. (1997). Electromyographic techniques for the assessment of motor speech disorders. In M. R. McNeil (Ed.), *Clinical management of sensorimotor speech disorders* (pp. 149-176). New York, NY: Thieme.

Maeda, K., Ono, T., Otsuka, R., Ishiwata, Y., Kuroda, T., & Ohyama K. (2004). Modulation of voluntary swallowing by visual inputs in humans. *Dysphagia, 19*, 1-6.

Magendie, F. (1822). *Summary of physiology* (J. Revere, Trans.). Baltimore, MD: Edward J. Coale & Co.

Mameli, O. & Melis, F. (1992). Visual and somatosensory information to tongue motoneurons. *Brain Research Bulletin, 28*, 239-244.

Mameli, O., Melis, F., & De Riu, P. L. (1994). Visual and vestibular projections to tongue motoneurons. *Brain Research Bulletin, 33*, 7-16.

Mameli, O. & Tolu, E. (1985). Visual input to the hypoglossal nucleus. Experimental *Neurology, 90*, 341-349.

Marieb, E. (1998). *Human anatomy & physiology* (4th ed.). Menlo Park, CA: Addison Wesley Longman, Inc.

Marik, P. E., Kaplan, D. (2003). Aspiration pneumonia and dysphagia in the elderly. *Chest, 124*, 328–336.

Martin, B. J. W. (1991). The influence of deglutition on respiration. *University Microfilms International*. (UMI No. 9129031)

Martin, B. J., Corlew, M. M., Wood, H., Olson, D., Golopol, L. A., Wingo, M., et al. (1994). The association of swallowing dysfunction and aspiration pneumonia. *Dysphagia, 9*(1), 1-6.

Martin, B. J., Logemann, J. A., Shaker, R., & Dodds, W. J. (1993). Normal laryngeal valving patterns during three breath-hold maneuvers: a pilot investigation. *Dysphagia, 8*(1), 11-20.

Martin, B. J., Logemann, J. A., Shaker, R., & Dodds, W. J. (1994). Coordination between respiration and swallowing: respiratory phase relationships and temporal integration. *Journal of Applied Physiology, 76*(2), 714-723.

Martin, R. E., Goodyear, B. G., Gati, J. S., & Menon, R. S. (2001). Cerebral cortical representation of automatic and volitional swallowing in humans. *Journal of Neurophysiology, 85*, 938-950.

Martin, R. E., Kemppainen, P., Masuda, Y., Yao, D., Murray, G. M., & Sessle, B. J. (1999). Features of cortically evoked swallowing in the awake primate (*Macaca fascicularis*). *Journal of Neurophysiology, 82,* 1529-1541.

Martin-Harris, B., Brodsky, M. B., Michel, Y., Ford, C. L., Walters, B., & Heffner, J. (2005). Breathing and swallowing dynamics across the adult lifespan. *Archives of Otolaryngology-Head and Neck Surgery*, *131,* 762-770.

Martin-Harris, B., Brodsky, M. B., Price, C. C., Michel, Y., Walters, B. (2003). Temporal coordination of laryngeal dynamics and breathing during swallowing: Single liquid swallows. *Journal of Applied Physiology, 94*, 1735-1743.

Martin-Harris, B., Logemann, J. McMahon, S, Schleicher, M. A., & Sandidge, J. (2000). Clinical utility of the modified barium swallow. *Dysphagia, 15*(3), 136-141.

Martin-Harris, B., Michel, Y., & Castell, D. O. (2005). Physiologic model of oropharyngeal swallowing revisited. *Otolaryngology-Head and Neck Surgery, 133*, 234-240.

Martin-Harris, B. & Robbins, J. (1995). Physiology of swallowing: Protection of the airway. *Seminars in Respiratory and Critical Care Medicine, 16*(6), 448-458.

Martin-Harris, B., Sandidge, J., Heilig, C., McConnel, F., Haynes, R., Stoeckli, S., et al. (1999, October). The relationship between respiratory and laryngeal dynamics during swallow. Paper presentated at the annual meeting of the Dysphagia Research Society. Burlington, VT.

Mattes, R. D. (1997). Physiologic responses to sensory stimulation by food: Nutritional implications. *Journal of the American Dietetic Association, 97*(4), 406-413.

Mayeux, R., Marder, K., Cote, L. J., Denaro, J., Hemenegildo, N., Mejia, H., et al. (1988). The Frequency of Idiopathic Parkinson's Disease by Age, Ethnic Group, and Sex in Northern Manhattan, 1988–1993. *American Journal of Epidemiology, 142*(8), 820-827.

McCann, R. & Johnston, J. (1992). Locus of the single-channel bottleneck in dual-task interference. *Journal of Experimental Psychology: Human Perception and Performance, 18*, 471-484.

McConnel, F. M. S., Cerenko, D., & Mendelsohn, M. S. (1988). Manufluorographic analysis of swallowing. Otolaryngology Clinics of North America, 21, 625-637.

McGuire, T. L., & Rothenberg, M. B. (1986). Behavioral and psychosocial sequelae of pediatric head injury. *Journal of Head Trauma Rehabilitation, 1*(4), 1-6.

McKeown, M. J., Torpey, D. C., & Gehm, W. C. (2002). Non-invasive monitoring of functionally distinct muscle activations during swallowing. *Clinical Neurophysiology, 113*, 354-366.

McNeil, M. R., Odell, K, & Tseng, C.-H. (1991). Toward the integration of resource allocation into a general theory of aphasia. *Clinical Aphasiology, 20*, 21-39.

Miller, A. J. (1972). Significance of sensory inflow to the swallowing reflex. *Brain Research, 43*, 147-159.

Miller, A. J. (1982). Deglutition. *Physiological Review, 62*, 129-184.

Miller, A. J. (1999). *The neuroscientific principles of swallowing and dysphagia*. San Diego, CA: Singular Publishing Group, Inc.

Miller, F. R. & Sherrington, C. S. (1916). Some observations on the bucco-pharyngeal stage of reflex deglutition in the cat. *Quarterly Journal of Experimental Physiology, 9,* 147-186.

Miller, J. L. & Watkin, K. L. (1996). The influence of bolus volume and viscosity on anterior lingual force during the oral stage of swallowing. *Dysphagia, 11*, 117-124.

Mir, P., Matsunaga, K., Gilio, F., Quinn, N. P., Siebner, H. R., & Rothwell, J. C. (2005). Dopaminergic drugs restore facilitatory premotor-motor interactions in Parkinson disease. *Neurology, 64*, 1906-1912.

Murray, G. M., & Sessle, B. J. (1992a). Functional properties of single neurons in the face primary motor cortex of the primate: I. Input and output features of tongue motor cortex. *Journal of Neurophysiology, 67*, 747-758.

Murray, G. M., & Sessle, B. J. (1992b). Functional properties of single neurons in the face primary motor cortex of the primate: II. Relations with trained orofacial motor behavior. *Journal of Neurophysiology, 67*, 759-774.

Nagaya, M., Kachi, T., Yamada, T., & Igata, A. (1998). Videofluorographic study of swallowing in Parkinson's disease. *Dysphagia, 13*, 95-100.

National Ag Safety Database. (1985, September). *Noise—sound without value* (Publication No. F-007). Retrieved March 9, 2006, from National Ag Safety Database via Centers from Disease Control and Prevention: http://www.cdc.gov/nasd/docs/d001501-d001600/d001550/d001550.html

National Parkinson Foundation. (1996-2004). *Hoehn and Yahr staging of Parkinson's disease, Unified Parkinson Disease Rating Scale (UPDRS), and Schwab and England Activities of Daily Living*. Retrieved March 9, 2006, from the National Parkinson http://www.parkinson.org/site/pp.asp?c=9dJFJLPwB&b=123510

Navon, D. & Gopher, D. (1979). On the economy of the human processing system. *Psychological Review, 86*, 214-255.

Navon, D. & Miller, J. (2002). Queing or sharing? A critical evaluation of the single-bottleneck notion. *Cognitive Psychology, 44*, 193-251.

Netick, A. & Klapp, S. T. (1994). Hesitations in manual tracking: A single-channel limit in response programming. *Journal of Experimental Psychology: Human Perception and Performance, 20*(4), 766-782.

Neumann, S., Bartolome, G., Buchholz, D., & Prosiegel, M. (1995). Swallowing therapy of neurologic patients: Correlation of outcome with pretreatment variables and therapeutic methods. *Dysphagia, 10*, 1-5.

Neurobehavioral Systems, Inc. (December 5, 2002). Presentation. (Version 0.53) [Computer software]. San Francisco, CA: Author.

Nishino, T. (2000). Physiological and pathophysiological implications of upper airway reflexes in humans. *Japanese Journal of Physiology, 50*, 3-14.

Nishino, T. & Hiraga, K. (1991). Coordination of swallowing and respiration in unconscious subjects. *Journal of Applied Physiology, 70*(3), 988-993.

Norman, D. A. (1969). Memory while shadowing. *Quarterly Journal of Experimental Psychology, 21*, 85-93.

Oehlert, M. E., Hass, S. D., Freeman, M. R., Williams, M. D., Ryan, J. J., & Sumerall, S. W. (1997). The Neurobehavioral Cognitive Status Examination: Accuracy of the "screen-metric" approach in a clinical sample. *Journal of Clinical Psychology, 53*(7), 733-737.

Okada, S., Ouchi, Y., & Teramoto, S. (2000). Nasal continuous positive airway pressure and weight loss improve swallowing reflex in patients with obstructive sleep apnea syndrome. *Respiration, 67*, 464-466

Orr, W. C., Johnson, L. F., & Robinson, M. G. (1984). Effect of sleep on swallowing, esophageal peristalsis, and acid clearance. *Gastroenterology, 86,* 814-819.

O'Shea, S., Morris, M. E., & Iansek, R. (2002). Dual task interference during gait in people with Parkinson disease: Effects of motor versus cognitive secondary tasks. *Physical Therapy, 82*(9), 888-897.

O'Sullivan, T. & Fagan, S. C. (1998). Drug-induced communication and swallowing disorders. In A. F. Johnson & B. H. Jacobson (Eds.), *Medical speech-language pathology: A practitioner's guide* (pp. 176-191). New York, NY: Thieme.

Owen, A. M., Menon, D. K., Johnsrude, I. S., Bor, D., Scott, S. K., Manly, T., et al. (2002). Detecting residual cognitive function in persistent vegetative state. *Neurocase, 8*, 394-403.

Palmer, J. B., Tanaka, E., & Siebens, A. A. (1989). Electromyography of the pharyngeal musculature: Technical considerations. *Archives of Physical Medicine and Rehabilitation, 70*, 283-287.

Parkinson, J. (1817). *An essay on the shaking palsy*. London, England: Whittingham and Rowland.

Pashler, H. (1984). Processing stages in overlapping tasks: Evidence for a central bottleneck. *Journal of Experimental Psychology: Human Perception and Performance, 10*, 358-377.

Pashler, H. (1994). Dual-task interference in simple tasks: Data and theory. *Psychological Bulletin, 116*(2), 220-244.

Penfiled, W. & Boldrey, E. (1937). Somatic motor and sensory representation in the cerebral cortex of man as studies by electrical stimulation. *Brain, 60,* 389-443.

Perlman, A. L., Ettema, S. L., & Barkmeier, J. (2000). Respiratory and acoustic signals associated with bolus passage during swallowing. *Dysphagia, 15*, 89-94.

Perlman, A. L., Palmer, P. M., McCulloch, T. M., & Vandaele, D. J. (1999). Electromyographic activity from human laryngeal, pharyngeal, and submental muscles during swallowing. *Journal of Applied Physiology, 86*(5), 1663-1669.

Pimental, P. A., & Kingsbury, N. A. (1989). *Neuropsychological aspects of right brain injury*. Austin, TX: Pro-Ed, Inc.

Pinel, J. P. J. (2000). *Biopsychology* (4th ed.). Boston, MA: Allyn and Bacon.

Pinto, A., Yanai, M., Nakagawa, T., Sekizawa, K., & Sasaki, H. (1994). Swallowing reflex in the night. *The Lancet, 344*(8925), 820-821.

Preiksaitis, H. G. & Mills, C. A. (1996). Coordination of breathing and swallowing: effects of blus consistency and presentation in normal adults. *Journal of Applied Physiology, 81*(4), 1707-1714.

Prochazka, A., Clarac, F., Loeb, G. E., Rothwell, J. C., & Wolpaw, J. R. (2000). What do reflex and voluntary mean? Modern views on an ancient debate. *Experimental Brain Research, 130*, 417-432.

Posner, M. I. (1980). Orienting of attention. *Quarterly Journal of Experimental Psychology, 32*, 3-25.

Posner, M. I. (1986). *Chronometric explorations of mind.* New York, NY: Oxford University Press.

Posner, M. I. & Boies, S. J. (1971). Components of attention. *Psychological Review, 78*(5), 391-408.

Posner, M. I. & Snyder, C. R. R. (1975). Attention and cognitive control. In R. L. Solso (Ed.), *Information processing and cognition: The Loyola Symposium* (pp. 55-85). Hillsdale, NJ: Lawrence Erlbaum.

Purves, D., Augustine, G. J., Fitzpatrick, D., Katz, L. C., LaMantia, A.-S., McNamara, J. O. (1997). *Neuroscience*. Sunderland, MA: Sinauer Associates, Inc.

Ramsey, G. H., Watson, J. S., Gramiak, R., & Weinberg, S. A. (1955). Cinefluorographic analysis of mechanisms of swallowing. *Radiology, 64*, 498-518.

Raut, V. V., McKee, G. J., & Johnston, B. T. (2001). Effect of bolus consistency on swallowing—does altering consistency help? *European Archives of Otorhinolaryngology, 258*, 49-53.

Richter, P., Werner, J., Heerlein, A., Kraus, A., & Saur, H. (1998). On the validity of the Beck Depression Inventory. *Psychopathology, 31*, 160-168.

Rizzo, M. & Robin, D. A. (1990). Simultanagnosia: A defect of sustained attention yields insights on visual information processing. *Neurology, 40*, 447-455.

Rizzo, M. & Robin, D. A. (1996). Bilateral effects of unilateral visual cortex lesions in human. *Brain, 119*, 951-963.

Robbins, J. (1996). Normal swallowing and aging. *Seminars in Neurology, 16*(4), 309-317.

Robbins, J., Hamilton, J. W., Lof, G. L., & Kempster, G. B. (1992). Oropharyngeal swallowing in normal adults of different ages. *Gastroenterology, 103*, 823-829.

Robbins, J., Logemann, J. A., & Kirshner, H. S. (1986). Swallowing and speech production in Parkinson's disease. *Annals of Neurology, 19*, 283-287.

Robertson, I. H., Ward, T., Ridgeway, V., & Nimmo-Smith, I. (1994). *Test of Everyday Attention*. Suffolk, England: Thames Valley Test Co.

Robin, D. A., Max, J. E., Stierwalt, J. A. G., Guenzer, L. C., & Lindgren, S. D. (1999). Sustained attention in children and adolescents with traumatic brain injury. *Aphasiology, 13*(9-11), 701-708.

Rodríguez-Puertas, R., Herrera-Marschitz, M., Koistinaho, J., & Hökfelt, T. (1999). Dopamine $D_1$ receptor modulation of glutamate receptor messenger RNA levels in the neorcortex and neostriatum of unilaterally 6-hydroxydopamine-lesioned rats. *Neuroscience, 89*(3), 781-797.

Roper, B. L., Bieliauskas, L. A., & Peterson, M. R. (1996). Validity of the Mini-Mental State Examination and the Neurobehavioral Cognitive Status Examination in cognitive screening. *Neuropsychiatry, Neuropsychology, and Behavioral Neurology, 9*(1), 54-57.

Ross-Swain, D. (1996). *Ross Information Processing Assessment* (2nd ed.). Austin, TX: Pro-Ed, Inc.

Ruthruff, E., Pashler, H. E., & Klaassen, A. (2001). Processing bottlenecks in dual-task performance: Structural limitation or strategic postponement? *Psychonomic Bulletin and Review, 8*(1), 73-80.

Scanlon, V. C. & Sanders, T. (1997). *Understanding human structure and function*. Philadelphia, PA: F. A. Davis Company.

Schmidt, R. A. & Lee, T. D. (1999). *Motor control and learning: A behavioral emphasis* (3rd ed.). Champaign, IL: Human Kinetics.

Schneider, W., & Shiffrin, R. M. (1977). Controlled and automatic human information processing: I. Detection, search, and attention. *Psychological Review, 84*, 1-66.

Schumacher, E. H., Seymour, T. L., Glass, J. M., Fencsik, D. E., Lauber, E. J., Kieras, D. E., et al. (2001). Virtually perfect time sharing in dual-task performance: Uncorking the central cognitive bottleneck. *Psychological Science, 12*(2), 101-108.

Schwamm, L. H., Van Dyke, C., Kiernan, R. J., Merrin, E. L., & Mueller, J. (1987). The Neurobehavioral Cognitive Status Examination: Comparison with the Cognitive Capacity Screening Examination and the Mini-Mental State Examination in a neurosurgical population. *Annals of Internal Medicine, 107*(4), 486-491.

Schweickert, R. (1978). A critical path generalization of the additive factor method: Analysis of a Stroop task. *Journal of Mathematical Psychology, 18*, 105-139.

Serrano, C. & García-Borreguero, D. (2004). Fluctuations in cognition and alertness in Parkinson's disease and dementia. *Neurology, 63*(Suppl. 3), S31-S34.

Sessle, B. J. & Henry, J. L. (1989). Neural mechanisms of swallowing: Neurophysiological and neurochemical studies on brain stem neurons in the solitary tract region. *Dysphagia, 4*, 61-75.

Shaker, R., Dodds, W. J., Dantas, R. O., Hogan, W. J., & Arndorfer, R. C. (1990). Coordination of deglutitive glottic closure with oropharyngeal swallowing. *Gastroenterology, 98*, 1478-1484.

Shaker, R. & Lang, I. M. (1994). Effect of aging on the deglutitive oral, pharyngeal, and esophageal motor function. *Dysphagia, 9*, 221-228.

Shaker, R., Ren, J., Zamir, Z., Sarna, A., Liu, J., & Sui, Z. (1994). Effect of aging, position, and temperature on the threshold volume triggering pharyngeal swallows. *Gastroenterology, 107,* 396-402.

Sharpe, M. H. (1990). Distractibility in early Parkinson's disease. *Cortex, 26*, 239-246.

Sharpe, M. H. (1992). Auditory attention in early Parkinson's disease: An impairment in focused attention. *Neuropsychologia, 30*(1), 101-106.

Shingai, T., Miyaoka, Y., Ikarashi, R., & Shimada, K. (1989). Swallowing reflex elicited by water and taste solutions in humans. *American Journal of Physiology: Regulatory, Integrative, and Comparative Physiology, 256*, R822-R826.

Shriberg, L. D. & Kent, R. D. (1995). *Clinical phonetics* (2nd ed.). Boston, MA: Allyn & Bacon.

Siddle, D. A. T. & Lipp, O. V. (1997). Orienting, habituation, and information processing: The effects of omission, the role of expectancy, and the problem of dishabituation. In P. J. Lang, R. F. Simons, & M. Balaban (Eds.), *Attention and orienting: Sensory and motivational processes* (pp. 23-40). Mawah, NJ: Lawrence Erlbaum Assoc.

Sokol, E. M., Heitmann, P., Wolf, B. S., & Cohen, B. (1966). Simultaneous cineradiographic and manometric study of the pharynx, hypopharynx, and cervical esophagus. *Gastroenterology, 51*, 960-974.

Solso, R. L. (1995). *Cognitive psychology* (4th ed.). Boston, MA: Allyn & Bacon.

Sonies, B. C., Parent, L. J., Morrish, K., & Baum, B. J. (1988). Durational aspects of the oral-pharyngeal phase of swallow in normal adults. *Dysphagia, 3*, 1-10.

Speirs, R. L., Stanforth, A., & Sittampalam, G. (1988). Subjective assessment of liquid volumes by humans during swallowing. *Archives of Oral Biology, 33*(10), 701-706.

SPSS, Inc. (1997). SamplePower™ (Release 1.20) [Computer software]. Chicago, IL: Author.

Spudis, E. V. (1991). The persistent vegetative state – 1990. *Journal of the Neurological Sciences, 102*, 128-136.

Stachler, R. J., Hamlet, S. L., Mathod, R. H., Jones, L., Heilbrun, L. K., Manov, L. J., et al. (1994). Swallowing of bolus types by postsurgical head and neck cancer patients. *Head & Neck, 16*, 413-419.

Sternberg, S. (1966). High-speed scanning in human memory. *Science, 153*, 652-654.

Sternberg, S. (1969). Memory-scanning: Mental processes revealed by reaction-time experiments. *American Scientist, 57*, 421-457.

Sternberg, S., Monsell, S., Knoll, R. L., & Wright, C. E. (1978). The latency and duration of rapid movement sequences: Comparisons of speech and typewriting. In Stelmach, G. E. (ed.), *Information processing in motor control and learning*. (pp. 117-152). New York, NY: Academic Press.

Stevenson, R. D. & Allaire, J. H. (1991). The development of normal feeding and swallowing. *Pediatric Clinics of North America, 38*(6), 1439-1453.

Stroudley, J. & Walsh, M. (1991). Radiological assessment of dysphagia in Parkinson's disease. *British Journal of Radiology, 64*, 890-893.

Sumi, T. (1969). Some properties of cortically-evoked swallowing and chewing in rabbits. *Brain Research, 15,* 107-120

Svensson, P., McMillan, A. S., Graven-Nielsen, T., Wang, K., & Arendt-Nielsen, L. (1999). Modulation of an inhibitory reflex in single motor units in human masseter by tonic painful stimulation. *Pain, 83,* 441-446.

Teasell, R. W., Bach, D., & McRae, M. (1994). Prevalence and recovery of aspiration poststroke: A retrospective analysis. *Dysphagia, 9,* 35-39.

Teramoto, S., Sudo, E., Matsuse, T., Ohga, E., Ishii, T., Ouchi, Y., et al. (1999). Impaired swallowing reflex in patients with obstructive sleep apnea syndrome. *Chest, 116*, 17-21.

The Northern California Neurobehavioral Group, Inc. (1995). *Manual for COGNISTAT*. Fairfax, CA: Author.

Tison, F., Wiart, L., Guatterie, M., Fouillet, N., Lozano, V., Henry, P., et al. (1996). Effects of central dopaminergic stimulation by apomorphine on swallowing disorders in Parkinson's disease. *Movement Disorders, 11*(6), 729-732.

Titchener, E. B. (1908). *Lectures on the elementary psychology of feeling and attention*. New York, NY: The Macmillan Company.

Tombu, M. & Jolicœur, P. (2002). All-or-none bottleneck versus capacity sharing accounts on the psychological refractory period phenomenon. *Psychological Research, 66*, 274-286.

Tompkins, C. A. (1995). *Right hemisphere communication disorders: Theory and management.* San Diego, CA: Singular Publishing Group, Inc.

Tracy, J. F., Logemann, J. A., Kahrilas, P. J., Jacob, P., Kobara, M., & Krugler, C. (1989). Preliminary observations on the effects of age on oropharyngeal deglutition. *Dysphagia, 4,* 90-94.

Treisman, A. M. (1960). Contextual cues in selective listening. *Quarterly Journal of Experimental Psychology, 12*, 242-248.

Treisman, A. M. (1964). Monitoring and storage of irrelevant messages in selective attention. *Journal of Verbal Learning and Verbal Behavior, 3*, 449-459.

Treisman, A. M. (1969). Strategies and models of selective attention. *Psychological Review, 76*, 282-299.

van Gorp, W. G., Marcotte, T. D., Sultzer, D., Hinkin, C., Mahler, M., & Cummings, J. L. (1999). Screening for dementia: Comparison of three commonly used instruments. *Journal of Clinical and Experimental Neuropsychology, 21*(1), 29-38.

Verdolini, K. (2006). Compliance. In I. R. Titze & K. Verdolini (Eds.), *Vocology*. Iowa City, Iowa: National Center for Voice and Speech. Manuscript in preparation.

Verghese, J., Buschke, H., Viola, L., Katz, M., Hall, C., Kulansky, G., et al. (2002). Validity of divided attention tasks in predicting falls in older individuals: A preliminary study. *Journal of the American Geriatrics Society, 50*(9), 1572-1576.

Wallace, J. J., Caroselli, J. S., Scheibel, R. S., & High, W. M., Jr. (2000). Predictive validity of the Neurobehavioral Cognitive Status Examination (NCSE) in a post-acute rehabilitation setting. *Brain Injury, 14*(1), 63-69.

Watanabe, Y., Abe, S., Ishikawa, T., Yamada, Y., & Yamane, G.-Y. (2004). Cortical regulation during the early stage of initiation of voluntary swallowing in humans. *Dysphagia, 19*, 100-108.

Watts, C. R. & Dagenais, P. A. (2001). Attentional demands and speech timing in subgroups of speakers with Parkinson disease. *Journal of Medical Speech-Language Pathology, 9*(1), 55-61.

*Webster's new complete medical dictionary*. (1996). New York, NY: Smithmark Publishers.

Wickens, C. D. (1980). The structure of attentional resources. In R. Nickerson (Ed.), *Attention and performance VIII* (pp. 239-257). Englewood Cliffs, NJ: Erlbaum.

Willig, T. N., Paulus, J., Saint Guily, L., Béon, C, & Navarro, J. (1994). Swallowing problems in neuromuscular disorders. *Archives of Physical Medicine and Rehabilitation, 75,* 1175-1181.

Winsor, A. L., & Blane, T. L. (1929). Unconditioned salivary responses in man. *American Journal of Psychology, 41*, 271-276.

Wintzen, A. R., Badrising, U. A., Roos, R. A. C., Vielvoye, J., & Liauw, L. (1994). Influence of bolus volume on hyoid movements in normal individuals and patients with Parkinson's Disease. *Canadian Journal of Neurological Science, 21,* 57-59.

Woollacott, M. & Shumway-Cook, A. (2002). Attention and the control of posture and gait: A review of an emerging area of research. *Gait and Posture, 16*, 1-14.

Wylie, S. A., Stout, J. C., & Bashore, T. R. (2005). Activation of conflicting responses in Parkinson's disease: Evidence for degrading and facilitating effects on response time. *Neuropsychologia, 43*, 1033-1043.

Yamamoto, T., Matsuo, R., Kiyomitsu, Y., & Kitamura, R. (1988). Sensory inputs from the oral region to the cerebral cortex in behaving rats: An analysis of unit responses in cortical somatosensory and taste areas during ingestive behavior. *Journal of Neurophysiology, 60*(4), 1303-1321.

Yardley, I., Gardner, M., Bronstein, A., Davies, R., Buckwell, D., & Luxon, I. (2001). Interference between postural control and mental task performance in patients with vestibular disorders and healthy controls. *Journal of Neurology, Neurosurgery, and Psychiatry, 71*, 48-52.

Yogev, G., Giladi, N., Peretz, C., Springer, S., Simon, E. S., & Hausdorff, J. M. (2005). Dual tasking, gait rhythmicity, and Parkinson's disease: Which aspects of gait are attention demanding? *European Journal of Neuroscience, 22*, 1248-1256.

Zald, D. H. & Pardo, J. V. (1999). The functional neuroanatomy of voluntary swallowing. *Annals of Neurology, 46,* 281-286.

Zald, D. H. & Pardo, J. V. (2000). Cortical activation induced by intraoral stimulation with water in humans. *Chemical Senses, 25,* 267-275.