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Attentional resource allocation and swallowing safety in Parkinson's disease: A dual task study

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Background: Aspiration pneumonia is a leading cause of death in persons with Parkinson's disease (PD). Despite this, the mechanisms underlying dysphagia in this population are unclear. To date, researchers have not investigated the effects of varying cognitive demand on objective measures of swallowing safety. This study assessed whether swallowing safety could be disrupted by increasing cognitive demands during the task of swallowing.
Methods: Twenty participants with moderate PD and dysphagia were tested while completing a novel dual task experimental paradigm under videofluoroscopy. In the dual task condition, participants swallowed 10 cc of thin liquid barium while completing a digits forward task.
Results: Four females and 16 males completed the study. Results revealed differential effects to swallowing safety based on baseline measures of cognitive flexibility and attention. Participants with mild impairment in cognitive flexibility and attention demonstrated cognitive-motor interference with worsening of both swallowing and cognitive performance. In contrast, participants who were most impaired in the domains of cognitive flexibility and attention improved swallowing safety in the dual task condition. Additionally, decreased swallow timing durations existed in the dual task condition compared to the single task condition.
Conclusions: The results of this study support the hypothesis that supramedullary drive can influence the swallowing plan. Additionally, this study highlights the need for cognitive taxing during swallowing evaluations.

1. Introduction

Dysphagia, or disordered swallowing, leads to significant deterioration of health and quality of life, particularly in persons with neurodegenerative diseases, such as Parkinson's disease (PD) [1–3]. Despite this, there is an incomplete understanding of the mechanisms influencing dysphagia. PD leads to changes in all stages of swallowing with oral and pharyngeal deficits and resultant airway compromise [4–8]. These deficits appear to be exacerbated in persons with PD and dementia, often making them less responsive to management with swallowing compensations [9,10]. However, few studies have empirically explored the effects of cognition on swallowing function [11,12], although some have identified dysphagia in populations with cognitive dysfunction [13,14] and there is known activation of fronto-cortical structures during swallowing [15]. No empirical studies exist investigating how varying cognitive demand influences swallowing safety.

In one study a dual task paradigm was used to test the influence of cognition on oropharyngeal swallowing in PD [12]. The dual task condition consisted of participants listening for a target non-word presented aurally while they swallowed 5 ml of water from a cup. The results revealed significantly longer reaction times for the anticipatory stage of swallowing in the dual task condition. This was not observed for the oropharyngeal stage of swallowing. This study did not utilize videofluoroscopy (VFSS) or any other more

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direct swallow visualization technique. Therefore, little is known regarding swallowing safety when assessed under dual task conditions. This swallowing information is especially salient given the high incidence of silent aspiration in PD [16].

A comprehensive understanding of the mechanisms influencing swallowing function is important in order to address the deleterious effects of dysphagia on health and quality of life. Additionally, we can assume the likelihood that swallowing safety is influenced by modifications to attentional resource allocation is high. Therefore, studies designed to manipulate cognitive demand while measuring swallowing physiology serve to enrich our knowledge of swallowing mechanisms. This study tested the hypothesis that performing concurrent cognitive and swallowing tasks (via a dual task paradigm) would result in decrements to swallowing safety and timing in PD as visualized under videofluoroscopy.

2. Methods

2.1. Participants

This study was a prospective cohort study including 20 participants with idiopathic PD who were consecutively recruited from patients referred for swallowing evaluations at the University of Florida (UF) and Malcom Randall Veterans Administration Medical Center (VAMC) Movement Disorders Centers. Fellowship trained Movement Disorders Neurologists diagnosed PD using the United Kingdom (UK) brain bank criteria [17]. All participants had complaints of dysphagia with evidence of penetration of thin liquid barium on VFSS as assessed by a licensed and certified speech-language pathologist. Table 1 presents demographic information.

2.1.1. Inclusion/Exclusion criteria

Criteria for inclusion were: 1) diagnosis of idiopathic PD (either tremor-predominant or rigid-predominant) by a certified movement disorders neurologist; 2) Hoehn & Yahr stages II-III; 3) stabilization on one or more anti-PD meds; 4) adult between the ages of 60 and 85 years; 5) dysphagic as per criteria listed above; 6) non-demented as measured by the Dementia Rating Scale-II [18]; 7) willingness and capability of providing informed consent; 8) and normal hearing thresholds for the participant's age or when appropriately aided. Exclusionary criteria were history of any of the following: 1) Deep Brain Stimulation (DBS), pallidotomy, or thalamotomy; 2) other neurological disorder; 3) developmental speech or language disorder; 4) any other motor speech or language disorder; 5) Alzheimer's disease or semantic dementia; 6) severe depression, anxiety, or apathy; and 7) attention deficit disorder.

Table 1
Demographic information, including sex, age, UPDRS, Hoehn & Yahr (H & Y) score, years since diagnosis (PD Dx), and education for each participant. These data were compiled from medical record review and responses from participant inquiry.

Participant code	Sex	Age	UPDRS	H & Y	PD Dx	Education
1	M	66	32	2	11	14
2	M	74	23	2	6	20
3	M	65	58	3	9	20
4	M	80	37	3	9	20
5	M	65	22	2	4	20
6	M	66	43	2	10	20
7	F	76	33	2	8	12
8	F	77	29	2	4	12
9	M	60	27	2.5	8	16
10	M	80	44	2	5	16
11	M	71	25	2	1	11
12	F	75	24	2	4	16
13	M	74	25	2	1	20
14	M	75	48	3	10	20
15	M	70	28	2	5	16
16	M	73	33	3	11	20
17	M	67	24	2	2	20
18	F	72	35	3	11	16
19	M	75	29	2	8	16
20	M	67	42	2.5	10	12
	16 (M) 4 (F)	71.4 (9.67)	33.05 (9.67)	13 (H&Y 2) 2 (H&Y 2.5) 5 (HY& 3)	6.85 (3.39)	16.85 (3.30)

2.2. Study design

All participants underwent two different phases of study which lasted a total of approximately an hour and a half. Participants with PD were tested within the window of optimized medication function (i.e., 1 h after taking anti-PD medications). Prior to completion of any tests, the participant provided informed consent (UF IRB# 518–2008).

2.2.1. Phase 1: cognitive testing procedures

The first half of the experimental visit included assessment of study eligibility and neuropsychological status. The neuropsychological testing included: 1) DRS-II, a valid mental screening test of cognitive functioning in patients with PD [18]; 2) digit span forward, backward, and ordering to assess working memory [19,20]; and 3) Trails A & B and Stroop color-word and color-word interference tasks for assessment of cognitive flexibility and attention [21].

2.2.1.1. Training on experimental procedures. Prior to the experimental VFSS, participants were trained on the experimental task. Participants were given small cups filled with water (instead of barium) to swallow. Participants were trained to 90% success prior to enrollment in the experimental paradigm (described in detail below).

2.2.2. Phase 2: experimental procedures

2.2.2.1. Videofluoroscopic (VFSS) procedures. The experimental dual task procedures took place in the Department of Radiology at the Malcom Randall VAMC, Gainesville, FL, using videofluoroscopy. Participants were seated upright and images of barium swallows were recorded in the lateral view. A properly collimated Phillips Radiographic/Fluoroscopic unit that provides a 63-kV, 1.2-m-A type output for full field of view mode was utilized. Fluoroscopic images were recorded to a Kay Elemetrics Swallowing Signals Lab (Kay Elemetrics, Lincoln Park, NJ) using a digital scan converter and electronically recorded at 30 frames per second. The field of view allowed for a complete visualization of the oral and pharyngeal structures involved in swallow.

2.2.2.2. Cognitive task. The cognitive task used in the experimental paradigm was a modified digit span forward with six digits. The participants were instructed to listen to the aurally presented span of digits and then recite the digits. Accuracy of responses was assessed by determining proportion of correctly recalled digits. Previous studies revealed that participants began to demonstrate greatest breakdown in digit span forward following presentation of five digits [22,23]. Therefore, six digits were chosen to challenge participants, while still allowing sufficient success to determine dual task effects. Responses were transcribed online and accuracy was assessed following the experimental paradigm.

2.2.2.3. Motor task. The motor task for the dual task paradigm was the swallowing of 10 cc of thin barium contrast by small cup (Liquid E-Z Paque Barium Sulfate Suspension; 60% w/v, 41% w/w; from E-Z-EM). The cup for self-feeding was selected to approximate everyday feeding conditions. In the single swallow task, participants were instructed to "empty the barium into [your] mouth and swallow when [you're] ready."

2.2.2.4. Dual task. The experimental paradigm consisted of single (cognitive and swallow) and dual task (cognitive plus swallow) conditions. Participants completed the cognitive task independently of the swallow task (single task cognitive condition) or the swallow task independently of the cognitive task (single task swallow condition). Under dual task conditions, the participants were given the cup of barium to hold and instructed, "I will now read you six numbers, please give me the numbers forward after you swallow." Then, the numbers were read aloud by the examiner, at a rate of approximately one per second. Following this, participants immediately brought the cup to their mouth, swallowed the liquid, and then recited the numbers. Each single task (digits forward and swallow) was completed five times, and the dual task (digits forward while swallowing) was completed five times. The total number of swallows was limited as not to create overexposure to radiation and excessive ingestion of barium for participants. The same cognitive stimuli were used for all participants, but all trials (both single and dual task) were randomized.

2.3. Data analysis and outcome measures

All swallowing measurements were completed by an examiner trained in the analysis of videofluoroscopic swallow studies blinded to participant identity and condition. Analysis was completed frame by frame to ensure accuracy and reliability of measurement.

2.3.1. Primary outcome: swallowing safety

Swallowing safety for each swallow was quantified using the Penetration–Aspiration (PA) scale [24]. The PA scale is a validated, ordinal scale used to measure whether or not material entered the airway and if it did, whether the residue remained or was expelled.

2.3.2. Secondary outcomes: swallow timing

Measures of swallow timing included oral transit time, pharyngeal transit time, and total swallow duration [25,26]. Oral transit time (OTT) was defined as the duration of time it took a participant to clear the bolus from the oral cavity. Pharyngeal transit time (PTT) was defined as the time it took the bolus to clear the pharyngeal cavity. Total swallow duration (TSD) was defined as the amount of time required for the bolus to move through the oral cavity and clear the pharyngeal cavity.

2.3.3. Dual task response

Comparisons between single and dual task performance within cognitive and swallow measures was completed to assess whether participants were "responders" to the dual task condition. Difference scores (single task performance minus dual task performance) were calculated for each trial completed by each participant. These scores were then averaged by participant within condition. To assess *dual task cognitive response*, correct number of digits recited in the dual task condition were subtracted from correct number of digits recited in the single task condition. Therefore, positive differences scores represented better cognitive performance in the single task condition. Whereas, negative difference scores represented worse cognitive performance in the single task. Additionally, to assess *dual task (swallow) motor response* PA score in the dual task condition was subtracted from PA score in the single task condition. A score of zero placed participants in the *no change group*. Participants who *worsened* in swallowing safety in the dual vs. single task condition were identified as those with negative difference scores. Those with positive difference scores were identified as participants who had *improved* in swallowing safety in the dual vs. single task condition. Based on these difference scores participants were divided into dual task motor (swallow) response groups.

2.3.4. Reliability

Inter and intra-rater reliability for the primary outcome measure, PA score, was completed on 25% of the obtained swallowing data. The primary rater was the principal investigator and the secondary rater was a trained graduate student in speech-language pathology.

2.4. Statistical analyses

Statistical analysis of the data was completed using the Statistical Package for the Social Sciences (SPSS) software version 17.0. Given the ordinal nature of the primary outcome of PA score, a Wilcoxon signed rank test for two related samples was utilized to test differences in the single vs. dual task conditions. Analysis of cognitive measures and swallow timing by dual task response group was completed using nonparametric Kruskal–Wallis testing. Paired samples *t*-tests were utilized to test any difference in the single and dual tasks for transit time measures. Both inter and intra-rater reliability was assessed statistically using intraclass correlational analyses providing a Cronbach's alpha. Statistical significance was set at $p \leq .05$.

3. Results

Four females (ages 72–77 years, mean = 75) and 16 males (ages 65–80 years, mean = 70.5) completed the study. PA scores were not significantly different between the single versus dual task conditions across the entire sample ($Z = -1.259$, $p = .208$). Eight of 20 participants worsened in swallowing safety in the dual task versus single task conditions, five of 20 participants demonstrated no change in swallowing safety in the two conditions, and seven of 20 participants demonstrated an improvement in swallowing safety in the dual task condition. Inspection of groups by dual task motor response revealed significant differences in performance on Stroop color-word task (Chi-square = 9.430, $p = .009$) and Trails A (Chi-square = 12.20, $p = .002$) by response group (Table 2). In both cases, the least impaired scores were found for the group which demonstrated no change in swallowing function in the dual vs. single task conditions and the most impaired scores were found for the group which improved in swallowing safety in the dual vs. single task conditions (Table 2).

Additionally, a significant shortening occurred in all swallowing timing measures in the dual task swallows, compared to the single task swallows (Table 3). OTT decreased from 0.50 s to 0.45 s ($t = 2.524$, $df = 17$, $p = .022$), PTT decreased from 0.84 s to 0.78 s ($t = 2.141$, $df = 17$, $p = .047$), and TSD decreased from 1.02 s to 0.94 s ($t = 2.731$, $df = 17$, $p = .014$). Post-hoc analysis did not reveal any differences in swallowing transit times by dual task motor response group (Table 4).

3.1. Reliability

Intraclass correlation analyses revealed that interrater reliability was excellent with a Cronbach's alpha of 0.968. Intrarater reliability was excellent with a Cronbach's alpha of 0.966.

4. Discussion

This study revealed differential effects to swallowing safety that were significantly related to baseline scores of cognitive flexibility and attention. This finding is novel and supports the hypothesis that top-down, supramedullary drive can influence swallowing motor performance. No other available studies have tested dual task performance during swallowing under videofluoroscopy.

Participants who were mildly impaired in cognitive flexibility and attention demonstrated cognitive-motor interference with worsening of swallowing safety and cognitive performance. Results from this subgroup supported our prediction of higher PA scores (less safe swallow) in the dual task condition. These findings are consistent with the gait and balance dual task literature in PD reporting that there is a breakdown in postural stability and gait (i.e. less anticipatory postural adjustment and velocity) in the dual task versus single task conditions [27,28]. This subgroup of participants demonstrated cognitive-motor interference, supporting the theory that the modified digit span task and the swallowing task shared attentional resources, resulting in a breakdown to both swallowing safety, and digit span performance in the dual task condition.

Participants who demonstrated no change in swallowing safety in the dual vs. single task conditions (i.e. non-responders) also demonstrated no change in cognitive performance between the two conditions. Basically, these participants were non-responders to the cognitive and motor aspects of the dual task paradigm. These participants also showed the highest cognitive scores on measure of cognitive flexibility and attention. This suggests that a threshold level of motor and/or cognitive impairment must be reached before the swallowing motor plan, which is mainly controlled at the level of the brainstem swallowing central pattern generator, is disrupted by cognitive input. This threshold level may not have been achieved with the simple digit span forward task in the five participants who were non-responders.

Remarkably, participants who demonstrated most impaired scores in the domains of cognitive flexibility and attention demonstrated improvements in swallowing safety in the dual task condition. This unanticipated finding suggests that the dual task condition may have served as a method for improving swallowing in the participants with most impaired cognitive flexibility and attention. However, it is not clear why this effect was only evident in the most cognitively impaired group. One possibility is that this group, under normal single task conditions, has lower than average cognitive arousal. Thus, the simple fact that they were completing a more difficult combined task may have increased arousal during the dual task, thereby increasing available attentional resources for both swallowing and cognition. Another possibility is that this group was more concerned about being able to manage the dual task swallowing and thus prioritized the swallowing task resulting in improved swallowing safety.

Participants demonstrated shorter transit times in dual task conditions as compared to single task conditions. OTT for single task swallows was within the normal range identified for older adults [25] and remained within that range for dual task swallows. Interestingly, PTT was fast as compared to normal older adults [25] and only became faster in the dual task condition. This may reflect increased discoordination of the pharyngeal swallow during dual task conditions. Swallowing transit times were not found to explain

Table 2
Means, *standard deviations,* significance based on Kruskal Wallis non-parametric statistical analyses of scores on baseline cognitive scores by dual task response groups.

Dual task motor response	Dual task cognitive response	UPDRS	DRS	Stroop color-words	Stroop color interference	Digit span forward	Digit span backward	Digit ordering	Trails A	Trails B
No change	0.00	26.60	138.60	76.60	37.00	7.00	6.80	14.60	86.40	182.60
	0.08	*3.78*	*4.56*	*7.77*	*14.07*	*3.24*	*4.21*	*4.83*	*14.26*	*108.60*
Worsened	0.05	35.13	139.88	58.63	35.38	7.88	5.50	12.75	130.38	261.13
	0.09	*12.40*	*2.11*	*19.03*	*7.21*	*1.81*	*1.60*	*4.27*	*40.79*	*176.93*
Improved	0.12	34.40	137.33	47.33	26.17	7.33	6.17	12.67	185.17	317.00
	0.09	*8.82*	*4.412*	*11.48*	*6.31*	*1.03*	*1.33*	*1.21*	*24.74*	*112.98*
Chi-square	3.907	2.711	1.345	9.430	4.865	1.052	0.429	0.748	12.20	4.852
Asymp. sig	*0.142*	*0.258*	*0.510*	*0.009*	*0.088*	*0.591*	*0.807*	*0.688*	*0.002*	*0.088*

The italics were placed there in order to distinguish the means from the st deviations in the tables. All standard deviations in the tables are in italics.

the variations in PA scores identified by response group (Table 4). Brodsky and colleagues [12] reported that transit times were unchanged in dual task conditions, but the differences may be explained by variations in methodology. Despite these differences, both studies support the theory that swallowing is influenced by changes in attentional resource allocation and with varying cognitive load.

The current study is novel, but has limitations. First, the small sample size of 20 persons with PD may have limited the degree to which subtle changes could be statistically assessed secondary to reduced power. The sample was however carefully characterized and of similar disease severity. Secondly, more bolus types and sizes will need to be tested in future experimental designs. The bolus type/size selected was 10 cc of thin liquid barium. This relatively small bolus size is not comparable to the bolus sizes present in everyday eating conditions. Nevertheless, the smaller bolus size allowed for the relative control of bolus residue in these participants all of whom had oropharyngeal dysphagia. Too much residue could have obscured measurement. This bolus size was also selected to diminish the possibility of a floor effect by restricting the incidence of aspiration and control the ceiling effect, by allowing for enough swallowing deterioration.

Another limitation of the study was that each participant's cognitive system was taxed to a different degree with the digit span forward task depending on their baseline. For instance, a person whose baseline function only allowed for 6 digit forward recall was taxed maximally by our experimental task, however a person with 11 digit recall was stressed less. The limitation however was mitigated by the results showing cognitive-motor interference in a subgroup of the tested sample. Additionally, the effects of PD-type and dyskinesias on swallowing-specific results should be considered in future studies. Despite the limitations, we believe that the current design was the most appropriate for this initial study using a dual task paradigm to test swallowing safety under videofluoroscopy.

Table 3
Means, *standard deviations*, and *p*-values for all swallowing-related outcomes.

	Single task	Dual task	*p*-values
Primary swallowing outcome			
Penetration-Aspiration scores	2.09	2.26	*0.208*
	1.17	*1.44*	
Swallow timing measures			
Oral transit time	0.4982	0.449	*0.022*
	0.1610	*0.1337*	
Pharyngeal transit time	0.8443	0.7771	*0.047*
	0.1944	*0.1550*	
Total swallow duration	1.0213	0.9381	*0.014*
	0.2125	*0.1997*	

4.1. Implications for evaluation and treatment of dysphagia

The act of swallowing does not occur in isolation. Swallowing usually occurs during a social event that may be conducted in the context of multiple cognitive and motor distractions. Current evaluation methods for dysphagia do not consider the cognitive complexity surrounding eating and swallowing. Instead, patients are typically evaluated in an isolated, usually quiet environment. During the time of evaluation patients are completely focused on the task of swallowing. They are presented with a controlled set of boluses, the type and size of which are usually selected by the clinician. Therefore, the evaluation loses ecological validity as it no longer represents the reality of the swallowing and eating experience. Although more studies are needed to understand the cognitive-motor interactions associated with swallowing, this study highlights the potential benefits of increasing cognitive load during swallowing evaluations in order to elucidate changes which may be more representative of the mealtime experience.

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Dr. Troche has no disclosures related to this study.

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Table 4
Means, *standard deviations,* significance based on Kruskal Wallis non-parametric statistical analyses of oral transit times (OTT), pharyngeal transit times (PTT) and total swallow duration (TSD) by dual task response groups.

Dual task motor response	OTT single task	OTT dual task	PTT single task	PTT dual task	TSD single task	TSD dual task
No change	0.50	0.43	0.84	0.73	1.03	0.89
	0.20	*0.14*	*0.18*	*0.17*	*0.34*	*0.25*
Worsened	0.49	0.43	0.86	0.77	1.00	0.90
	0.17	*0.15*	*0.25*	*0.12*	*0.18*	*0.14*
Improved	0.51	0.49	0.83	0.82	1.04	1.02
	0.15	*0.11*	*0.15*	*0.20*	*0.19*	*0.24*
Chi-square	0.041	1.263	0.045	0.633	0.197	1.629
Asymp. sig	*0.980*	*0.532*	*0.978*	*0.729*	*0.906*	*0.443*

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