



Exploring the Neuropsychological Correlates of Swallowing Disorders in People with Parkinson's Disease: a Cross-Sectional Study

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Abstract

Around 80% of persons with Parkinson's disease (PD) present symptoms of dysphagia. Although cognitive impairment may contribute to dysphagia, few studies have investigated the association between the PD neuropsychological profile and objective measures of swallowing dysfunction. Since the swallowing function comprises involuntary but also voluntary actions, we hypothesize that specific measures of attention and executive functions can be underlined in PD-related dysphagia. Therefore, the aim of this study was to extensively investigate the correlation and the relationship between attentive and executive functions and safety/efficiency of pharyngeal phase of swallowing in people with PD. All participants received a fiberoptic endoscopic evaluation of swallowing and were evaluated using the Penetration Aspiration Scale (PAS); the Yale Pharyngeal Residue Severity Rating Scale (IT-YPRSRS), and the Functional Oral Intake Scale (FOIS-IT). Participants also underwent a neuropsychological assessment covering global cognitive status, attention, and frontal executive functions. Correlations and associations between neuropsychological measures and swallowing components were calculated. Twenty-one participants with PD (mean age 69.38 ± 6.58 years, mean disease duration 8.38 ± 5.31 years; mean MDS-UPDRS III 43.95 ± 24.18) completed all evaluations. The most significant correlations were found between attentive functions (i.e., Stroop Time), and executive functions (i.e., Raven's Progressive Matrices, Digit Backward and Semantic Fluency), and FOIS-IT, PAS, and IT-YPRSRS sinuses and valleculae. These associations were not influenced by disease duration. These results suggest that a dysfunction to attentional processes and/or to executive functions can contribute to penetration and the presence of pharyngeal residue in participants with middle-stage PD.

Keywords Dysphagia · Neuropsychological assessment · Attention · Executive functions · PD · Rehabilitation

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Introduction

Dysphagia is a frequent and fatal symptom in people with Parkinson's disease (PD). Swallowing impairments have been reported for all phases, from the oral preparatory to the esophageal phases of swallowing, in this population. The oral deficit includes hypotonia of the facial and tongue muscles, bradykinesia, tremor, and freezing, resulting in delayed initiation of swallowing [1–4]. Weakness and incoordination of oropharyngeal muscles lead to an increase in bolus residue and saliva pooling in the pharynx, which exposes people with PD to the risk of aspiration [5–7]. Bolus aspirations (i.e., foods and liquids) and a deficit of airway protection are determining factors for the onset of pulmonary infections that are recognized as one of the main causes of death in PD [8, 9]. In addition, dysphagia negatively impacts nutrition

status, length of hospitalization and reduces the quality of life of the patients and caregivers [10–13].

The clinical signs of dysphagia differ enormously in the PD population because swallowing impairments seem to be caused not only by the degeneration of subcortical regions and basal ganglia but also by the cortical areas [14, 15]. The degeneration of the dopamine circuit and the correlated cognitive impairments play a key role in reducing swallowing proprioception and awareness, which leads to underestimations of dysphagia signs in this population. For these reasons, questionnaires and self-reported assessments, when they are not accompanied by other objective tests, are not sufficiently valid for detecting swallowing deficits in this population [16, 17]. On the other hand, instrumental swallowing assessments such as fiberoptic endoscopic evaluation of swallowing (FEES) or video-fluoroscopy swallowing study (VFSS) are recognized as the gold standards for detecting dysphagia signs in PD [1, 2, 18]. Accordingly, the prevalence of dysphagia reached about 82% when assessed using instrumental examinations and about 25% using questionnaires or semi-structured interviews [16, 18].

Previous studies reported that dysphagia does not show a clear association with other clinical variables such as disease duration or motor symptom severity, but cognitive impairment may contribute to dysphagia severity in this population [19–21]. In the last decade, there has been an increasing interest in investigating the impact of cognitive deficits on swallowing functions in people with PD [22–26]. Swallowing food and eating requires an increased cognitive demand to recognize the food and to coordinate voluntary and involuntary functions that allow ingestion. Given that eating often occurs simultaneously with other activities such as speaking or watching television, most studies focused on executive functions and divided attention in people with dysphagia and PD. The simultaneous execution of two tasks (dual-task paradigm) often results in delayed reaction time or deteriorated performance in one or both tasks. During dual-task trials, people with PD increase the risk of dysphagia characterized by incoordination of the pharyngeal phase, premature bolus spillage, and pharyngeal residue [22–26]. Although these studies provide the first evidence of swallowing difficulties in the dual-tasks/executive process, there are few studies of the specific attentive and executive functions correlated to dysphagia in the PD population. A recent meta-analysis found that cognitive function is not related to dysphagia in PD [27], notably, the authors restricted their analysis to screening measures such as the MoCA and Mini-Mental State Examination (MMSE), without considering the classification of cognitive impairment throughout a more extensive neuropsychological examination. On the contrary, Kim and colleagues [28] found a correlation between executive functions and the dysfunction of the oral

phase of swallowing by administering a brief neuropsychological battery encompassing several cognitive domains and subtests. Participants included in their study clustered around the early stages of the disease. These results might be explained by the fact that the oral phase requires a number of abilities involved in mastication and lingual motion (i.e., coordinate, plan, and organize movements), that are driven by cognitive processes, while the pharyngo-esophageal phases are less affected by cognitive effort due to their involuntary nature [29].

Cognitive functions more often impaired in people with PD are attention and executive functions [i.e., 30]. Attentional deficits can manifest in several ways in patients with PD ranging from bradyphrenia, with loss of concentration and generalized cognitive slowing, to impairments in sustained or divided attention. Executive dysfunction (deficits in set-shifting, problem-solving, and goal maintenance) may be one of the most prominent neuropsychological deficits in PD, and neuropsychological testing often reveals difficulty with category fluency, motor sequencing, problem solving, rule detection, set sifting, and inability to integrate different sensory elements into a coherent whole [31, 32]. Decreased dopaminergic striatal stimulation in PD can interfere with the normal functioning of frontostriatal circuits. This disruption can lead to changes in attentional processes and executive functions. In various clinical stages of PD, the most significant dopamine depletion occurs in the foremost dorsolateral region of the caudate nucleus, which plays a crucial role in the dorsolateral circuit. The dorsolateral prefrontal cortex is associated with a range of attentional abilities and executive functions, including attentional control such as working memory, set-switching, planning, response inhibition, organizational skills, reasoning, problem-solving, and abstract thinking. The optimal functioning of the frontostriatal system is essential for performing these intricate tasks, facilitating behavioral adjustments and managing daily social interactions [33].

Despite swallowing function underlines involuntary and voluntary processes involving brainstem swallowing centers and the integration of multiple cerebral cognitive functions, respectively [34], the involvement of cognitive functions required especially for the voluntary process in PD-related dysphagia remains unclear.

We specifically hypothesize that the presence of oropharyngeal dysphagia would be related to attentive and executive dysfunction, as swallowing also requires action planning, and attentive/executive functions are required for a complex planning process. Therefore, the aim of this pilot cross-sectional study was to extensively investigate the correlation and the relationship between attentive and executive functions (through a neuropsychological assessment) and safety and efficiency of pharyngeal phase of swallowing

(through the instrumental assessment, i.e., FEES) in people with PD.

Materials and Methods

Participants

This pilot cross-sectional study was conducted between March and October 2023 including participants consecutively admitted to the Neurorehabilitation Unit of the IRCCS Istituti Clinici Maugeri of Bari Hospital. Participants with PD diagnosed according to the current clinical criteria of the UK Parkinson's Disease Society Brain Bank [35] were consecutively recruited in this study. In addition, this study report followed the STROBE (Strengthening the Reporting of Observational Studies in Epidemiology) reporting guidelines (<https://www.strobe-statement.org/>).

Exclusion criteria were severe comprehension deficit, psychotic disorders, history of alcohol or drug abuse, and history of dysphagia prior to PD symptom onset, based on neurological examination. All subjects were inpatients and provided their informed written consent to participate in the study and to perform the swallowing evaluation and the comprehensive neuropsychological tests. The study protocol was approved by the Institutional Review Board of the IRCCS Giovanni Paolo II Hospital (Prot. n. 1195/CE Maugeri).

Clinical Assessment

Clinical and demographic data, including age, sex, and years of education, along with information on disease duration and antiparkinsonian medication, were collected from participants. Participants were treated with levodopa and their medication state was kept stable throughout the study period. The levodopa (l-dopa) equivalent daily dosage (LEDD) was calculated using a previously published formula [36]. All participants underwent clinical interviews and neurological examinations by an experienced neurologist (B.M.) and were examined using the MDS-UPDRS III (MDS-Unified Parkinson's Disease Rating Scale) developed to assess non-motor and motor symptoms and their complications, in tandem with a semi-structured interview [37]. The disease stage was assessed by the Hoehn and Yahr Scale (H&Y), which was applied to gauge the course of the disease over time [38]. All investigations were performed at admission to the rehabilitation unit, during participants' "ON" state, within two hours following levodopa intake.

Neuropsychological Assessment

All participants underwent a neuropsychological assessment within two weeks before the swallowing examination. The neuropsychological assessment took around 1 h (each test takes approximately 3 to 5 min to be completed) and was carried out by one neuropsychologist (S.T.), while the other two neuropsychologists were employed in the correction and interpretation of the test's results (G.L., C.P.). The number of tests has been decided based on the level-2 criteria of the Movement Disorder Society Task Force, including the Montreal Cognitive Assessment (MoCA) and a full neuropsychological assessment, in order to identify the presence of Mild Cognitive Impairment in PD [39]. We specified to participants that if they wanted to rest, we could split the assessment into two sessions in order to avoid any bias related to fatigue. Notably, none of the participants wanted to rest during the assessment. Participants underwent the Montreal Cognitive Assessment (MoCA), a brief screening test assessing executive functioning, attention, language, memory, visuo-spatial abilities, and orientation domains [40]. Scores ≥ 15.5 indicate a normal cognitive profile, while lower scores indicate cognitive impairment.

We focused our study on executive functions and attention, therefore other cognitive measures were the Stroop Test - Brief version [41], Trail Making Test (TMT A-B; [42]), Clock Drawing Test [43], Phonemic fluency test [44] and Semantic fluency test [45], Raven's Progressive Matrices [46], Digit Span Forward and Backward [47].

Specifically, the Stroop Test brief version [41] is administered to assess processing speed and inhibition of cognitive interference. Three tables are shown for subjects. The first and the second tables contain "congruous stimuli", participants have to read the names of colors printed in black ink and name different color patches, respectively. In the third table, color words are printed in an inconsistent color ink. In this condition, participants are required to name the color of the ink instead of reading the word. The TMT comprises A and B forms [42]. Both parts A and B assess psychomotor processing speed and visual scanning. Also, part B provides a measure of attentional set-shifting. Participants have to connect an array of numbers (1 to 13) in sequential order (A form) or alternating numbers and letters (B form) as quickly as possible while maintaining accuracy. The Clock Drawing test [43] assesses various executive and visuo-spatial functions. Often, it has been used as a screening tool for constructional apraxia, common in certain dementias and other neurologic disorders [48]. However, other functions including planning, organization, simultaneous processing, and aspects of attention, semantic memory, and graphomotor functions play an important role in the test execution. To help discriminate executive function from constructional

praxis; the patient observes the examiner drawing a clock and is then asked to copy the clock separately and to add all of its components, with hands set at a specific time. The Phonemic Fluency test [44] measures the number of words from initial letters (F, A, and S) generated under time constraints (60 seconds) per letter. The Semantic Fluency test [45] assesses the ability to verbally name as many words from three categories (fruits, animals, and car brands) as fast as possible in 60 seconds. The Raven's Progressive Matrices [46] requires the ability to solve visual analogies, with abstract stimuli, given a number of alternatives, the subject has to identify the missing pattern to complete a configuration. The sets in turn become progressively more difficult. It

is considered an excellent measure of fluid reasoning (i.e., the ability to be flexible when encountering novel problem-solving situations). Digit Span Forward and Backward [47] evaluate sustained attention and working memory, respectively. The examiner reads a number of sequences of increasing length and asks participants to repeat them in the same (Forward) or reserved (Backward) order. Table 1 summarizes all tests, provides a detailed description of each test and outcome measures that have been used in this study.

Table 1 Outcome measures

Neuropsychological test	Description	Main outcomes
Montreal Cognitive Assessment (MoCA)	MoCA is a screening test consisting of 12 subtasks exploring (1) memory (delayed recall of five nouns); (2) visuospatial abilities (a clock-drawing task and copy of a cube); (3) executive functions (a brief version of the Trail Making B, a phonemic fluency task, and a two-item verbal abstraction task); (4) attention, concentration and working memory (target detection using tapping; a serial subtraction task, and forward and backward digit span); (5) language (a naming task with low-familiarity animals, repetition of two syntactically complex sentences); (6) temporal and spatial orientation (a structured queries about the current year, month, exact date, and day of the week; name of this place, and which city it is in).	Number of correct trials.
Stroop Test - Brief version	Stroop is a measure of cognitive flexibility and attention performed in 3 conditions. Condition (1) black words appear; Condition (2) different colored circles appear (blue, green, red); Condition (3) colored words appear (blue, green, red). In the first two conditions, the participant is instructed to read as quickly as possible on the correct black words and the correct colored circles. In condition 3 (Inhibition), the colour words are written in a different colour with respect to their real colour (i.e., blue is printed in red). The participant is instructed to name the color of the ink in which the word is printed, rather than reading the name of the color.	Time (seconds) to completion of each trial, the difference in color-naming speed and the number of errors in the color-word interference effect.
Trail Making Test (TMT A-B)	A brief, 2-part test (A-B) of basic attention and working memory. First part (A) tests psychomotor processing speed and visual scanning. An array of numbers on a page are presented to the subjects and they are instructed to draw lines connecting the numbers in sequential order within the allowed time. The second part (B) provides cognitive flexibility measures: psychomotor processing speed, visual scanning, and attentional set shifting. An array of numbers and letters are presented to the subjects and they are asked to draw connecting lines while alternating between numbers and letters in sequential order.	Time (seconds) to completion of each trial.
Clock Drawing Test	The participant is shown a blank circle and asked to fill in the numbers of a clock-face and set hands on a specific time (e.g., 6:05).	Number of errors in the sequence and presence of the numbers within the clock, and the presence and placement of the clock's hands.
Phonemic and Semantic Fluency	Two tests of verbal production and executive functions, the participant is instructed to say as many words as possible during 1 min, starting with a specific letter (Phonemic Fluency) or belonging to a specific category (Semantic Fluency).	Number of words produced over all trials.
Raven's Progressive Matrices	It's a test of abstract reasoning. $N=36$ abstract stimuli are presented each with a number of alternatives. The participant has to identify the missing pattern to complete a configuration. The sets in turn become progressively more difficult.	Number of correct trials.
Digit Span	Digit Span is a test of short- term and working memory. The examiner presents orally a series of random digits (e.g., 3-6-5) usually at a rate of one digit per second (some tests vary the rate of presentation). After each sequence has finished, in the Forwards Condition, the participant is required to repeat same digits exactly as presented, while in the Backwards Condition the participant is required to repeat the same digits in the reverse order.	Digit Span Forwards— Number of correct trials in the forward condition; Digit Span Backwards—Number of correct trials in the Backward condition.

Swallowing Assessment via FEES Study

The assessment of dysphagia included functional and instrumental examinations, via FEES using the following swallowing outcome measures. The FEES was performed by an otorhinolaryngologist using a flexible transnasal endoscope Olympus XION EF-N flexible fiberscope (XION GmbH, Berlin, Germany) attached to an EndoSTROBE camera (XION GmbH, Berlin, Germany) and recorded as an AVI format anonymously. The evaluations were carried out with thin liquids (IDSSI 0) (5–10–20 mL of milk room-temperature $\times$ 3 trials for each volume), pureed food (IDSSI = 3) (5–10–20 mL of Frullà Polpa di Frutta, Natura Nuova, Bagnacavallo (RA), Italy—pudding $\times$ 3 trials for each volume), and regular food (IDSSI = 7) (half 8 g of Gran Pavesi cracker, Parma, Italy—biscuit $\times$ 2 trials). Liquids were administered using a feeding syringe and were mixed with one drop of blue dye in each milliliter, to improve visualization during endoscopy and avoid confounding food with salivary secretion. The amount of liquid was increased to 10 mL and 20 mL if the participants did not cough or present a wet voice after swallowing. Pureed food was given at fridge temperature (at 3–5 °C) to minimize the risk of aspiration [49–51]. We avoided testing liquids in participants who had a compromised ability to swallow the saliva or present aspiration during pureed, nor solid if the masticatory system was significantly impaired, to minimize the possibility of aspiration. The entire clinical procedure was recorded on video, which was later analyzed by the two senior speech and language pathologists (D.M., and R.F.). The Penetration Aspiration Scale (PAS) [52] was used to measure the presence of swallowing safety. PAS is an 8-point scale used to quantify the increasing severity of inhalation of bolus (1 = Material does not enter the airway; 2–5 = Penetration; 5–8 = Aspiration). The Yale Pharyngeal Residue Severity Rating Scale (IT-YPRSRS) was used to assess the swallowing efficacy, reporting the stagnation at the level of the glossoepiglottic valleculae and pyriform sinuses by assigning a score from 1 (absence of stagnation) to 5 (severe stagnation) [53, 54]. To document the method of oral intake, we employed the Italian version of the Functional Oral Intake Scale (FOIS-IT [55, 56]), a 7-level scale that classifies the participants according to the ability to feed himself by mouth where level 1 corresponds to complete parenteral/enteral feeding and 7 corresponds to complete oral feeding without restrictions. A cut-off < 7 identifies dysphagic participants.

Statistical Analysis

The sociodemographic characteristics of participants are presented using descriptive summary statistics. Continuous variables were expressed as mean $\pm$ standard deviation

(SD), ordinal variables as median (min to max), and categorical variables as proportion (%). The characteristics of the population in terms of distributions and frequencies, means with SD, and medians with ranges were calculated. To look for any correlations between cognitive deficits and degrees of dysphagia, the non-parametric Spearman partial correlation coefficients were calculated between clinical measures of dysphagia and the results of neuropsychological variables, controlled by disease duration. Forward-backward stepwise multiple linear regression analyses were performed to clarify further the relationship between cognitive outcomes (MoCA, Raven's Progressive Matrices, Stroop Time, Stroop Errors, TMT-A, TMT-B, Digit Span Forward and Backward, Semantic and Phonemic Fluency were defined as independent variables) and dysphagia outcomes (FOIS-IT, PAS, IT-YPRSRS valleculae and pyriform sinuses were defined as dependent variables). In order to optimize the number of dysphagia-dependent variables, we took into consideration the fact that the IT-YPRSRS valleculae, IT-YPRSRS sinuses, and PAS scores were assigned to three different consistencies (liquid, semisolid, and solid, respectively). As a result, we calculated an index (PAS Index, IT-YPRSRS valleculae Index, and IT-YPRSRS sinuses Index) that considered the worst score for each trial, i.e., the maximum value of the three aforementioned food consistencies. Finally, we applied an unadjusted model and an adjusted model adjusted for potential confounders (i.e., disease duration). The significance level adopted was 5% ($p < 0.05$), with 95% confidence intervals (CI). Data were analyzed using R studio program version 2021.09.1.

Results

From March to October 2023, we visited $n = 31$ participants with PD, diagnosed according to the current clinical criteria of the UK Parkinson's Disease Society Brain Bank, consecutively admitted to the Neurorehabilitation Unit. Ten subjects were excluded due to one of the following reasons: (1) refusal to participate in the FEES evaluation ($n = 6$), (2) participants presenting with a history of other neurological diseases and/or psychiatric conditions ($n = 3$); and (3) a history of dysphagia prior to PD symptom onset ($n = 1$).

Descriptive statistics of socio-demographic, clinical characteristics, neuropsychological scores, and measures of dysphagia collected with different clinical scales are outlined in Table 2. Furthermore, individual dysphagia measures are shown in detail in Table S1 of the Supplementary Material.

Twenty-one participants with PD met the inclusion criteria and were included in these analyses. Participants included 12 males and 9 females with idiopathic PD. They

Table 2 Socio-demographic and clinical, neuropsychological, and swallowing measures of patients

	Mean $\pm$ SD	Median (min to max)
<i>Socio-demographic and Clinical data</i>		
Age	69.38 $\pm$ 6.58	70 (50 to 79)
Gender		
Male	12 (57.2)	
Female	9 (42.8)	
Educational Level (yrs)	10.86 $\pm$ 4.84	11 (5 to 22)
Disease Duration (yrs)	8.38 $\pm$ 5.31	7 (10 to 20)
LEDD	878.81 $\pm$ 469.57	800 (150 to 2320)
H&Y		4 (1.5 to 5)
MDS-UPDRS III	43.95 $\pm$ 24.18	40 (4 to 96)
<i>Neuropsychological data</i>		
MoCA	18.24 $\pm$ 5.03	20 (11 to 26)
Clock Drawing Test	8.33 $\pm$ 3.57	9 (3 to 15)
Stroop Time	53.01 $\pm$ 35.22	50 (6.5 to 113)
Stroop Errors	6.64 $\pm$ 8.38	4 (0 to 29)
TMT-A	147.62 $\pm$ 114.10	100 (30 to 400)
TMT-B	358.62 $\pm$ 148.89	340 (115 to 500)
Phonemic Fluency	25.29 $\pm$ 13.92	24 (0 to 45)
Semantic Fluency	24.62 $\pm$ 11.38	26 (0 to 40)
Digit Forward	4.86 $\pm$ 1.06	5 (3 to 7)
Digit Backward	3.19 $\pm$ 0.93	3 (5 to 20)
Raven's Progressive Matrices	23.5 $\pm$ 7.07	22 (10 to 36)
<i>Dysphagia measures</i>		
FOIS-IT		6 (1 to 7)
PAS liquids		2 (1 to 8)
PAS semisolids		1 (1 to 1)
PAS solids		1 (1 to 8)
PAS Index		2 (1 to 8)
IT-YPRSRS valleculae liquids		2 (1 to 5)
IT-YPRSRS valleculae semisolids		1 (1 to 5)
IT-YPRSRS valleculae solids		1 (1 to 5)
IT-YPRSRS valleculae Index		3 (1 to 5)
IT-YPRSRS sinuses liquids		2 (1 to 5)
IT-YPRSRS sinuses semisolids		1 (1 to 5)
IT-YPRSRS sinuses solids		1 (1 to 5)
IT-YPRSRS sinuses Index		2 (1 to 5)

LEDD: levodopa (l-dopa) equivalent daily dosage, H&Y: Hoehn and Yahr Scale MDS-UPDRS III: MDS-Unified Parkinson's Disease Rating Scale, MoCA: Montreal Cognitive Assessment, TMT: Trial Making Test, Swal QoL: Swallowing Quality of Life Questionnaire; PAS: Penetration Aspiration Scale; IT-YPRSRS: Italian Yale Pharyngeal Residue Severity Rating Scale; FOIS-IT: Functional Oral Intake Scale

had an average age of 69.38 years ($\pm$ 6.58 years), an average education of 10.86 years ($\pm$ 4.84 years) an average disease duration of 8.38 years ($\pm$ 5.31 years), a median motor disease stage measured by H&Y of 4 (1.5 to 5), and an average MDS-UPDRS III disease severity score of 43.95 ($\pm$ 24.18).

The mean global level of cognitive efficiency measured by MoCA among the included participants was 18.24 ($\pm$ 5.03), indicating that, on average, participants performed above the cut-off. Concerning the executive functions tests, participants' mean performance was below the cut-off for the Stroop Time, Stroop Errors, TMT-A, TMT-B, according to the Italian normative data (see Table 2).

Results of the clinical and instrumental evaluation of dysphagia revealed that the worst score indicating dysphagia symptoms was reported for liquids with the PAS liquid median score of 2 (1 to 8) and the PAS solid median score of 1 (1 to 8). FOIS-IT score ranged from 1 (complete parenteral/enteral feeding) to 7 (complete oral feeding without restrictions) with a median score of 6 (1 to 7).

Correlation Between Dysphagia Measures and Cognitive Tests

Spearman partial correlation coefficients, adjusted for disease duration, have been calculated between clinical measures of dysphagia and cognitive tests (Table 3).

As to the dysphagia-cognitive correlation in PD, Spearman's analysis showed that the FOIS-IT was significantly directly related to the MoCA ($P < 0.030$ and $\rho = 0.4861$), the Phonemic Fluency ($P < 0.032$ and $\rho = 0.4796$), the Semantic Fluency ($P < 0.001$ and $\rho = 0.6698$), the Digit Backward ($P < 0.022$ and $\rho = 0.5085$), and the Raven's Progressive Matrices ($P < 0.000$ and $\rho = 0.7904$), while it was significantly inversely related to the Stroop Time ($P = 0.019$ and $\rho = -0.5201$), TMT-A ($P = 0.002$ and $\rho = -0.6457$), and the TMT-B ($P = 0.023$ and $\rho = -0.5044$).

The PAS liquid was significantly directly related to the Stroop Time ($P = 0.025$ and $\rho = 0.5006$), the TMT-A ($P = 0.033$ and $\rho = 0.4771$); while it was significantly inversely related to the Semantic Fluency ($P < 0.024$ and $\rho = -0.5029$), the Digit Backward ($P < 0.021$ and $\rho = -0.5121$), and the Raven's Progressive Matrices ($P < 0.001$ and $\rho = -0.6752$).

The PAS solid was significantly directly related to the Stroop Time ($P = 0.040$ and $\rho = 0.4624$), the TMT-A ($P = 0.049$ and $\rho = 0.4463$); while it was significantly inversely related to the MoCA ($P < 0.002$ and $\rho = -0.6559$), the Clock drawing test ($P < 0.014$ and $\rho = -0.5383$), the Digit Backward ($P < 0.003$ and $\rho = -0.6343$), and the Raven's Progressive Matrices ($P < 0.012$ and $\rho = -0.5519$).

The PAS semisolid did not report results because all participants scored 1, thus it was not possible to calculate any correlation (see Table 2).

Table 3 Correlation matrix for study variables (Spearman's rho)

Variable	MoCA	Stroop time	Stroop errors	Clock	TMT-A	TMT-B	Phonemic fluency	Semantic fluency	Digit forward	Digit backward	Raven
FOIS-IT	0.4861 0.030	-0.5201 0.019	-0.3015 0.196	0.4051 0.076	-0.6457 0.002	-0.5044 0.023	0.4796 0.032	0.6698 0.001	0.3058 0.190	0.5085 0.022	0.7904 0.000
PAS liquids	-0.3448 0.136	0.5006 0.025	0.3244 0.163	-0.1741 0.463	0.4771 0.033	0.3303 0.155	-0.2234 0.344	-0.5029 0.024	-0.1209 0.612	-0.5121 0.021	-0.6752 0.001
PAS solids	-0.6559 0.002	0.4624 0.040	0.1172 0.623	-0.5383 0.014	0.4463 0.049	0.3175 0.173	-0.2135 0.366	-0.3956 0.084	-0.3532 0.127	-0.6343 0.003	-0.5519 0.012
IT-YPRSRS sinouses liquids	-0.5548 0.011	0.3533 0.127	0.2377 0.313	-0.2327 0.324	0.5668 0.009	0.6152 0.004	-0.1481 0.533	-0.4608 0.041	-0.3080 0.186	-0.5950 0.006	-0.5483 0.012
IT-YPRSRS sinouses semisolids	-0.6003 0.005	0.5020 0.024	0.2525 0.283	-0.1264 0.595	0.6351 0.003	0.5896 0.006	-0.5136 0.021	-0.7346 0.000	-0.3373 0.146	-0.5163 0.020	-0.6510 0.002
IT-YPRSRS sinouses solids	-0.6539 0.002	0.4635 0.040	0.1054 0.658	-0.5472 0.013	0.4378 0.054	0.3197 0.169	-0.1723 0.468	-0.3682 0.110	-0.2878 0.218	-0.6307 0.003	-0.5572 0.011
IT-YPRSRS valleculeae liquids	-0.5501 0.012	0.4030 0.078	0.3091 0.185	-0.2313 0.327	0.5149 0.020	0.5157 0.020	-0.1985 0.402	-0.4428 0.051	-0.3117 0.181	-0.5641 0.010	-0.4518 0.046
IT-YPRSRS valleculeae semisolids	-0.4841 0.031	0.3635 0.115	0.3279 0.158	0.0362 0.880	0.5223 0.018	0.4745 0.035	-0.4093 0.073	-0.5894 0.006	-0.2156 0.361	-0.4209 0.065	-0.4937 0.027
IT-YPRSRS valleculeae solid	-0.6103 0.004	0.5363 0.015	0.2580 0.272	-0.6417 0.002	0.5917 0.006	0.3853 0.093	-0.3157 0.175	-0.4320 0.057	-0.2149 0.363	-0.5717 0.008	-0.5722 0.008

The values presented in the first row represent Spearman partial correlation coefficients that have been adjusted for disease duration. The values in the second row correspond to the *p*-values, wherein values are highlighted in bold if they are below the significance threshold ($p < 0.05$). FOIS-IT: Functional Oral Intake Scale; PAS: Penetration Aspiration Scale; IT-YPRSRS: Italian Yale Pharyngeal Residue Severity Rating Scale

The IT-YPRSRS sinuses liquid was significantly directly related to the TMT-A ($P = 0.009$ and $\rho = 0.5668$), and the TMT-B ($P = 0.004$ and $\rho = 0.6152$); while it was significantly inversely related to the MoCA ($P < 0.011$ and $\rho = -0.5548$), the Semantic Fluency test ($P < 0.041$ and $\rho = -0.4608$), the Digit Backward ($P < 0.006$ and $\rho = -0.5950$), and the Raven's Progressive Matrices ($P < 0.012$ and $\rho = -0.5483$).

The IT-YPRSRS sinuses semisolid was significantly directly related to the Stroop Time ($P = 0.024$ and $\rho = 0.5020$), TMT-A ($P = 0.003$ and $\rho = 0.6351$), and the TMT-B ($P = 0.006$ and $\rho = 0.5896$); while it was significantly inversely related to the MoCA ($P < 0.005$ and $\rho = -0.6003$), the Phonemic Fluency test ($P < 0.021$ and $\rho = -0.5136$), the Semantic Fluency test ($P < 0.000$ and $\rho = -0.7346$), the Digit Backward ($P < 0.020$ and $\rho = -0.5163$), and the Raven's Progressive Matrices ($P < 0.002$ and $\rho = -0.6510$).

The IT-YPRSRS sinuses solid was significantly directly related to the Stroop Time ($P = 0.040$ and $\rho = 0.4635$); while it was significantly inversely related to the MoCA ($P < 0.002$ and $\rho = -0.6539$), the Clock drawing test ($P < 0.013$ and $\rho = -0.5472$), the Digit Backward ($P < 0.003$ and $\rho = -0.6307$), and the Raven's Progressive Matrices ($P < 0.011$ and $\rho = -0.5572$).

The IT-YPRSRS valleculeae liquid was significantly directly related to the TMT-A ($P = 0.020$ and $\rho = 0.5149$), and the TMT-B ($P = 0.020$ and $\rho = 0.5157$); while it was

significantly inversely related to the MoCA ($P < 0.012$ and $\rho = -0.5501$), the Digit Backward ($P < 0.010$ and $\rho = -0.5641$), and the Raven's Progressive Matrices ($P < 0.046$ and $\rho = -0.4518$).

The IT-YPRSRS valleculeae semisolid was significantly directly related to the TMT-A ($P = 0.018$ and $\rho = 0.5223$), and the TMT-B ($P = 0.035$ and $\rho = 0.4745$); while it was significantly inversely related to the MoCA ($P < 0.031$ and $\rho = -0.4841$), the Semantic Fluency Test ($P < 0.006$ and $\rho = -0.5894$), and the Raven's Progressive Matrices ($P < 0.027$ and $\rho = -0.4937$).

The IT-YPRSRS valleculeae solid was significantly directly related to the Stroop Time ($P = 0.015$ and $\rho = 0.5363$), and the TMT-A ($P = 0.006$ and $\rho = 0.5917$); while it was significantly inversely related to the MoCA ($P < 0.004$ and $\rho = -0.6103$), the Clock drawing test ($P < 0.002$ and $\rho = -0.6417$), Digit Backward ($P < 0.008$ and $\rho = -0.5717$), and the Raven's Progressive Matrices ($P < 0.008$ and $\rho = -0.5722$).

Other subtests failed to show significant correlations.

Association Between Dysphagia Measures and Cognitive Tests

We investigated neuropsychological factors associated with dysphagia. The results are summarized in Table 4. In the linear regression unadjusted model, Semantic Fluency

Table 4 Stepwise Linear regression model on IT-YPRSRS sinuses Index; IT-YPRSRS vallecule Index, PAS Index, and FOIS-IT as dependent variables and regressors

Dependent variable	Unadjusted Model				Adjusted Model*			
	Variables	Coefficients	P-value	CI 95%	Variables	Coefficients	P-value	CI 95%
FOIS-IT	(Intercept)	4.01	<0.001	2.41 to 5.61	(Intercept)	3.92	<0.001	2.32 to 5.52
	Semantic Fluency	0.10	<0.001	0.05 to 0.14	Semantic Fluency	0.09	<0.001	0.05 to 0.14
	Stroop Time	-0.02	0.04	-0.03 to -0.002	Stroop Time	-0.02	0.03	-0.04 to -0.00E-03
PAS Index	(Intercept)	11.08	<0.001	6.82 to 15.34	(Intercept)	13.07	<0.0001	8.29 to 17.85
	Digit Backward	-2.14	<0.01	-3.43 to -0.86	Digit Backward	-2.30	<0.01	-3.55 to -1.05
					Disease duration	0.07	0.29	-0.05 to 0.18
IT-YPRSRS sinuses Index	(Intercept)	7.62	<0.0001	5.24 to 10.01	(Intercept)	9.20	<0.0001	6.52 to 11.89
	Raven's Progressive Matrices	-0.12	0.04	-0.22 to -0.01	Raven's Progressive Matrices	-0.16	<0.01	-0.26 to -0.06
	Digit Backward	-0.57	0.17	-1.36 to 0.22	Digit Backward	-0.65	0.08	-1.34 to 0.04
IT-YPRSRS vallecule Index	(Intercept)	8.14	<0.0001	6.03 to 10.24	(Intercept)	8.98	<0.0001	5.98 to 11.99
	Raven	-0.14	<0.01	-0.22 to -0.04	Raven's Progressive Matrices	-0.15	0.02	-0.26 to -0.04
	Digit Backward	-0.71	0.06	-1.40 to -0.01	Digit Backward	-0.50	0.22	-1.27 to 0.27
					Disease duration	-0.09	0.18	-0.22 to 0.04

*Adjusted for Disease Duration. Values are highlighted in bold if they are below the significance threshold ($p < 0.05$)

MoCA: Montreal Cognitive Assessment, TMT: Trial Making Test, PAS: Penetration Aspiration Scale; IT-YPRSRS: Italian Yale Pharyngeal Residue Severity Rating Scale; FOIS-IT: Functional Oral Intake Scale

(beta=0.10 CI 95% 0.05 to 0.14) and Stroop Time (beta = -0.02, CI 95% -0.03 to -0.002) showed a direct and an inverse association, respectively, with FOIS-IT.

The Digit Backward (beta = -2.14, CI 95% -3.43 to -0.86) was inversely significantly associated with the PAS Index. The Raven's Progressive Matrices (beta= -0.12, CI 95% -0.22 to -0.01) were inversely significantly associated with the IT-YPRSRS sinuses Index. The Raven's Progressive Matrices (beta= -0.14, CI 95% -0.22 to -0.04) were also inversely associated with the IT-YPRSRS vallecule Index.

In the adjusted model, the association remained significant for all variables investigated with the unadjusted model.

Discussion

In this pilot cross-sectional study, we performed an in-depth investigation of the relationship between attentive and executive impairment assessed by an extensive neuropsychological battery and swallow efficiency and safety tested on FEES recordings in participants with PD.

We found that global cognitive efficiency (e.g., MoCA) and the majority of executive function measures were directly correlated to the method of oral intake using the FOIS-IT, revealing that people with cognitive deficits modified food consistencies. Furthermore, we found that the Stroop reaction times showed a positive correlation with the

PAS scores for solids and liquids, as well as the IT-YPRSRS scores for solids in the sinuses and in the vallecule, and the IT-YPRSRS scores for semisolids in the sinuses. Conversely, the Stroop reaction time exhibited an inverse correlation with the FOIS-IT score. These data suggest that longer Stroop reaction times may be indicative of a higher likelihood of penetration for solids and liquids, as well as the pooling of solids and semisolids in the sinuses, and solely solids in the vallecule. Similarly, the TMT-A reaction times were strongly correlated with penetration of liquids and solids as measured by PAS and with possible difficulties in pharyngeal clearance and the presence of pharyngeal residue as measured by the IT-YPRSRS. The ability to switch attention between two tasks assessed by the TMT-B exhibited a positive correlation with the IT-YPRSRS sinuses scores for liquids and semisolids, as well as the IT-YPRSRS scores for both liquids and semisolids consistencies in the vallecule. Conversely, it showed an inverse correlation with the FOIS-IT. Overall, swallowing efficiency and safety were significantly correlated with all measures of visual attention (e.g., Stroop, TMT-A, TMT-B reaction times) rather than measures of auditory attention (e.g., Digit Span Forward). A similar result has been also reported in a previous study conducted on a post-stroke dysphagia population, where the oral phase of swallowing (i.e., premature loss) was more correlated to participants' performances on attention and

visual cues tests (such as the TMT-A and TMT-B) rather than auditory and memory tasks [57].

Concerning executive function tests, Phonemic Fluency, Semantic Fluency, Digit Span Backward, Clock Drawing Test, and Raven's Progressive Matrices show associations with swallowing functions in PD. The results showed that good performance at these executive functions correlated with better methods of oral intake (FOIS-IT) and fewer episodes of penetration and/or aspiration (PAS) and pharyngeal residues (IT-YPRSRs). This could suggest that cognitive organization, initiation, maintenance of effort, and the ability to conduct a non-routine search for words, working memory, problem-solving, and logical reasoning are strongly related to fewer dysphagia symptoms as measured by the FEES examination. The performed regression analyses also showed significant associations between frontal attentive and executive functions assessed by Stroop Time, Raven's Progressive Matrices, Digit Backward, and Semantic fluency and several scores of dysphagia (i.e., FOIS-IT, PAS, and IT-YPRSRs sinuses and valleculae). Our results confirm the initial hypothesis that the presence of swallowing disorders is correlated to attention and executive dysfunctions, suggesting that the swallowing process is a complex planning process that also requires sustained attention and executive functions such as volitional effort for planning, coordination, and sequential and organized movements to be realized.

The influence of executive function and attention on the swallowing function has been demonstrated already in other neurological populations [58, 59]. Although certain studies have reported the absence of a correlation between dysphagia and cognition, the lack of an association was probably due to methodological aspects such as the use of qualitative measures instead of administering standardized tests to assess cognitive functions [60–62]. Looking at major neurocognitive disorders, a cross-section pilot study on participants diagnosed with Amyotrophic Lateral Sclerosis identified a correlation between executive functions assessed by the Frontal Assessment Battery and TMT-A and dysphagia [63]. Moreover, dysphagia in Alzheimer's disease has been associated with a deficit in attention domain and executive functions [64, 65]. Even though cognitive-dysphagia relationships have been previously reported in the literature, very few studies extensively investigate which attentive/executive function measures are associated with dysphagia in PD. Interestingly, a previous study found that higher scores on the Stroop test were correlated with the dysfunction of the oral phase of swallowing in a sample of people with PD at the early stage of their disease [28], while our sample consisted of participants undergoing rehabilitation, all of whom were admitted at an intermediate stage of the disease as measured by the H&Y scale. Compared to

previous studies, our study investigated the cognitive profile of PD by administering a full attention and executive functions battery together with an objective instrumental examination of dysphagia (e.g., the FEES study).

Overall, these results pointed out the crucial role of executive function and attention in selecting the best strategies to plan a complex action like swallowing. Indeed, the swallowing function involves the activation of different brain regions associated with attention-demanding and executive processes [66]. In fact, the control of swallowing behavior is not solely governed by the brainstem swallowing centers (whose dysfunction is typically linked to PD-dysphagia), instead, the initiation of swallowing involves the integration of complex cognitive functions within the frontal cerebral regions beyond the just reflexive brain networks [67, 68]. Specifically, the lateral precentral gyrus, lateral postcentral gyrus, right insula, as well as middle and inferior frontal gyri, and frontal operculum show activation across automatic and volitional swallowing [67]. There are several neuroimaging studies on dysphagia in PD showing the involvement of different brain areas affected during the alteration of swallowing. As compared to non-PD subjects, the glucose metabolism in the supplementary motor areas and the anterior cingulate cortex decreased in participants with PD and swallowing disorders [69]. Conversely, participants with PD without dysphagia benefit from a compensatory activation of the premotor, motor, and inferolateral parietal cortex, as highlighted by using magnetoencephalography [15]. Moreover, an increase in functional connectivity of the cerebellum, left premotor cortex, supplementary motor area, primary motor cortex, right temporal pole of superior temporal gyrus, inferior frontal gyrus, anterior cingulate cortex, and insula seem to be a pathophysiological mechanism of dysphagia in participants with PD [70]. A recent retrospective cross-sectional study investigated brain glucose metabolism in PD with dysphagia [71] and found that the oral phase is characterized by hypermetabolism in the right inferior temporal gyrus, bilateral cerebellum, superior frontal gyrus, and anterior cingulate cortices. Also, they appreciated a correlation between the oral phase of swallowing and hypometabolism of the bilateral orbital and triangular parts of the inferior to middle frontal gyrus. Posterior parts of parieto-occipital lobe and cerebellum hypermetabolism were found for the pharyngeal phase, while hypometabolism of the anterior parts of the frontotemporal lobe was related to the dysphagia in PD. Overall, neuroimaging studies suggested that reduced cortical plasticity contributes to dysphagia in the PD population [15].

Finally, we found that disease duration did not influence the relationship between efficiency and safety of swallowing and cognitive impairment. Previous studies also reported a lack of correlation between disease duration and measures

of dysphagia [72, 73]. Therefore, attentive and executive dysfunction plays a crucial role in PD and the severity of dysphagia needs to be related also to non-motor (e.g., cognitive) aspects. Although this is a pilot study, the results could have important implications in clinical practice. The presence of cognitive symptoms in people with PD could be associated with unreported swallowing deficit, that should be assessed. Clinicians should take into account the inter-correlation between these functions during rehabilitation in people with PD in order to detect swallowing deficits at early stages as well as to design patient-centered treatment in order to prevent fatal risks.

Limitation

This pilot study is not without its limitations. Firstly, the assessment of dysphagia focused mainly on the pharyngeal phase using FEES, we did not assess specifically the oral phase using validated tests. Future studies should evaluate if there are any correlations between the impairments of cognitive functions and the bolus oral process using different types of bolus (solid/semisolid) and temperature. Specifically, cooler temperatures have been shown to influence the initiation of pharyngeal swallow [49–51], since we administered puree at fridge temperature, this could not reflect the natural eating habits of our participants. Thus, in the future, it will be necessary to control food temperature to draw ecological conclusions. Several studies reported that people with PD have more difficulties in solid food than liquids [74], hence it would be interesting to verify if cognitive deficit has an impact on it. In addition, this study did not assess the pathophysiology underlying the dysphagia symptom in the sample. Hence, it would be interesting to investigate the neuronal correlates and cranial nerve lesions that cause swallowing deficits in people with PD. Moreover, we acknowledge that this pilot study included a small sample of people with PD, future studies could evaluate if this association between cognition and swallowing is also confirmed in a larger sample to confirm the significant correlations that we found in the present study.

Conclusion

In conclusion, the present pilot cross-sectional study showed that attention/executive functions are mainly associated with dysphagia measures including penetration and presence of pharyngeal residue in sinuses and valleculae in participants with middle-stage of PD. These findings have some clinical implications on the rehabilitation and management of participants with PD suggesting that early identification of cognitive deficits could help to strengthen the results of a

specific training for dysphagia. In particular, neuropsychologists and speech and language therapists should explore the effect of combined training to successfully improve their cognitive abilities and reduce their swallowing difficulties in PD.

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Author Contributions All authors contributed to the study's conception and design. Statistical analysis was performed by: Simona Aresta and Federico Merlo. Material preparation and data collection were performed by Serena Tagliente, Davide Mongelli, Gianvito Lagravinese, Rosanna Falcone, Cinzia Palmirotta, Gilda Turi, Micol Castellari, Alessandra Zonno, Christian Gelao, and Emilia Picciola. The first draft of the manuscript was written by Petronilla Battista, Serena Tagliente, and Irene Battel. Resources: Pietro Fiore, Brigida Minafra. All authors read and approved the final manuscript.

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Data Availability Data will be made available on request to the corresponding author.

Declarations

Ethical Approval The study was approved by the Ethics Committee of the Institutional Review Board of the Giovanni Paolo II Hospital IRCCS of Bari (No. Prot. 1230 CE/Maugeri) and carried out in accordance with the Declaration of Helsinki. All participants signed an informed consent for their inclusion.

Conflict of Interest The authors have no conflicts of interest to declare that are relevant to the content of this article.

References

1. Warnecke T, Hamacher C, Oelenberg S, Dziewas R. Off and on state assessment of swallowing function in Parkinson's disease. *Parkinsonism Relat Disord.* 2014;20:1033–4. <https://doi.org/10.1016/j.parkreldis.2014.06.016>.
2. Warnecke T, Suttrup I, Schröder JB, Osada N, Oelenberg S, Hamacher C, et al. Levodopa responsiveness of dysphagia in advanced Parkinson's disease and reliability testing of the FEES-Levodopa-test. *Parkinsonism Relat Disord.* 2016;28:100–6. <https://doi.org/10.1016/j.parkreldis.2016.04.034>.
3. Miller N. Swallowing in Parkinson's disease: clinical issues and management. *Neurodegener Dis Manag.* 2017;7:205–17. <https://doi.org/10.2217/nmt-2017-0006>.

4. Hirschwald J, Hofacker J, Duncan S, Walshe M. Swallowing outcomes in dysphagia interventions in Parkinson's disease: a scoping review. *BMJ Evidence-Based Med.* 2023;28:93–100. <https://doi.org/10.1136/bmjebm-2022-112082>.
5. Curtis JA, Molfenter SM, Troche MS. Pharyngeal area changes in Parkinson's Disease and its Effect on Swallowing Safety, Efficiency, and Kinematics. *Dysphagia.* 2020;35:389–98. <https://doi.org/10.1007/s00455-019-10052-7>.
6. Molfenter SM, Amin MR, Branski RC, Brumm JD, Hagiwara M, Roof SA, et al. Age-related changes in pharyngeal lumen size: a retrospective MRI analysis. *Dysphagia.* 2015;30:321–7. <https://doi.org/10.1007/s00455-015-9602-9>.
7. Castell JA, Johnston BT, Colcher A, Li Q, Gideon RM, Castell DO. Manometric abnormalities of the oesophagus in patients with Parkinson's disease. *Neurogastroenterol Motil.* 2001;13:361–4. <https://doi.org/10.1046/j.1365-2982.2001.00275.x>.
8. Pitts T, Troche M, Mann G, Rosenbek J, Okun MS, Sapienza C. Using Voluntary Cough to detect penetration and aspiration during Oropharyngeal swallowing in patients with Parkinson Disease. *Chest.* 2010;138:1426–31. <https://doi.org/10.1378/chest.10-0342>.
9. Akbar U, Dham B, He Y, Hack N, Wu S, Troche M, et al. Incidence and mortality trends of aspiration pneumonia in Parkinson's disease in the United States, 1979–2010. *Parkinsonism Relat Disord.* 2015;21:1082–6. <https://doi.org/10.1016/j.parkreldis.2015.06.020>.
10. Carneiro D, das Graças Wanderley de Sales, Corio M, Belo LR, de Marcos Rabelo AR, Asano AG, Lins OG. Quality of Life Related to Swallowing in Parkinson's Disease. *Dysphagia.* 2014;29:578–82. <https://doi.org/10.1007/s00455-014-9548-3>.
11. Jones E, Speyer R, Kertscher B, Denman D, Swan K, Cordier R. Health-Related Quality of Life and Oropharyngeal Dysphagia: a systematic review. *Dysphagia.* 2018;33:141–72. <https://doi.org/10.1007/s00455-017-9844-9>.
12. Perry SE, Borders JC, Dakin AE, Troche MS. Characterizing quality of life in caregivers of people with Parkinson's Disease and Dysphagia. *Dysphagia.* 2022;37:523–32. <https://doi.org/10.1007/s00455-021-10299-z>.
13. Zimmerman AS, Shune S, Smith KG, Estis JM, Garand KL. Comparison of patient-reported and caregiver-reported swallowing-related quality of life in Parkinson's Disease. *Dysphagia.* 2022;37:436–45. <https://doi.org/10.1007/s00455-021-10301-8>.
14. Chaudhuri KR, Healy DG, Schapira AHV. Non-motor symptoms of Parkinson's disease: diagnosis and management. *Lancet Neurol.* 2006;5:235–45. [https://doi.org/10.1016/S1474-4422\(06\)70373-8](https://doi.org/10.1016/S1474-4422(06)70373-8).
15. Suntrup S, Teismann I, Bejer J, Suttrup I, Winkels M, Mehler D, et al. Evidence for adaptive cortical changes in swallowing in Parkinson's disease. *Brain.* 2013;136:726–38. <https://doi.org/10.1093/brain/awt004>.
16. Buhmann C, Flügel T, Bihler M, Gerloff C, Niessen A, Hidding U, et al. Is the Munich dysphagia test–Parkinson's disease (MDT-PD) a valid screening tool for patients at risk for aspiration? *Parkinsonism Relat Disord.* 2019;61:138–43. <https://doi.org/10.1016/j.parkreldis.2018.10.031>.
17. Nienstedt JC, Bihler M, Niessen A, Plaetke R, Pötter-Nerger M, Gerloff C, et al. Predictive clinical factors for penetration and aspiration in Parkinson's disease. *Neurogastroenterology Motil.* 2019;31. <https://doi.org/10.1111/nmo.13524>.
18. Kalf JG, de Swart BJM, Bloem BR, Munneke M. Prevalence of oropharyngeal dysphagia in Parkinson's disease: a meta-analysis. *Parkinsonism Relat Disord.* 2012;18:311–5. <https://doi.org/10.1016/j.parkreldis.2011.11.006>.
19. Monte FS, da Silva-Júnior FP, Braga-Neto P, Nobre e Souza MÂ, Sales, de Bruin VM. Swallowing abnormalities and dyskinesia in Parkinson's disease. *Mov Disord.* 2005;20:457–62. <https://doi.org/10.1002/mds.20342>.
20. Lam K, Kwai Yi Lam F, Kwong Lau K, Kay Chan Y, Yee Ling Kan E, Woo J, et al. Simple clinical tests may predict severe oropharyngeal dysphagia in Parkinson's disease. *Mov Disord.* 2007;22:640–4. <https://doi.org/10.1002/mds.21362>.
21. Cereda E, Cilia R, Klersy C, Canesi M, Zecchinelli AL, Mariani CB, et al. Swallowing disturbances in Parkinson's disease: a multivariate analysis of contributing factors. *Parkinsonism Relat Disord.* 2014;20:1382–7. <https://doi.org/10.1016/j.parkreldis.2014.09.031>.
22. Brodsky MB, Abbott KV, McNeil MR, Palmer CV, Grayhack JP, Martin-Harris B. Effects of divided attention on swallowing in persons with idiopathic Parkinson's Disease. *Dysphagia.* 2012;27:390–400. <https://doi.org/10.1007/s00455-011-9381-x>.
23. Troche MS, Okun MS, Rosenbek JC, Altmann LJ, Sapienza CM. Attentional resource allocation and swallowing safety in Parkinson's disease: a dual task study. *Parkinsonism Relat Disord.* 2014;20:439–43. <https://doi.org/10.1016/j.parkreldis.2013.12.011>.
24. Reynolds H, Miller N, Walker R. Drooling in Parkinson's Disease: evidence of a role for divided attention. *Dysphagia.* 2018;33:809–17. <https://doi.org/10.1007/s00455-018-9906-7>.
25. Signorini AV, Dornelles S, Ardenghi LG, Maahs GS, de Rieder CR. M. Does dual-tasking, swallow performance and attention, influence dysphagia in Parkinson disease? *Revista brasileira de neurologia Rio de Janeiro vol 54, no 3 (jul / set 2018), p 9–15.*
26. Labeit B, Claus I, Muhle P, Regner L, Suntrup-Krueger S, Dziewas R, et al. Effect of cognitive and motor dual-task on oropharyngeal swallowing in Parkinson's disease. *Eur J Neurol.* 2021;28:754–62. <https://doi.org/10.1111/ene.14603>.
27. Gong S, Gao Y, Liu J, Li J, Tang X, Ran Q, et al. The prevalence and associated factors of dysphagia in Parkinson's disease: a systematic review and meta-analysis. *Front Neurol.* 2022;13:1000527. <https://doi.org/10.3389/fneur.2022.1000527>.
28. Kim JS, Youn J, Suh MK, Kim T-E, Chin J, Park S, et al. Cognitive and motor aspects of Parkinson's Disease Associated with Dysphagia. *Can J Neurol Sci.* 2015;42:395–400. <https://doi.org/10.1017/cjn.2015.304>.
29. Steele CM, Miller AJ. Sensory input pathways and mechanisms in swallowing: a review. *Dysphagia.* 2010;25:323–33. <https://doi.org/10.1007/s00455-010-9301-5>.
30. Rodriguez-Oroz MC, Jahanshahi M, Krack P, Litvan I, Macias R, Bezard E, et al. Initial clinical manifestations of Parkinson's disease: features and pathophysiological mechanisms. *Lancet Neurol.* 2009;8:1128–39. [https://doi.org/10.1016/S1474-4422\(09\)70293-5](https://doi.org/10.1016/S1474-4422(09)70293-5).
31. Miyake A, Friedman NP. The Nature and Organization of Individual Differences in Executive Functions: four general conclusions. *Curr Dir Psychol Sci.* 2012;21:8–14. <https://doi.org/10.1177/0963721411429458>.
32. Poletti M, De Rosa A, Bonuccelli U. Affective symptoms and cognitive functions in Parkinson's disease. *J Neurol Sci.* 2012;317:97–102. <https://doi.org/10.1016/j.jns.2012.02.022>.
33. Sawamoto N, Piccini P, Hotton G, Pavese N, Thielemans K, Brooks DJ. Cognitive deficits and striato-frontal dopamine release in Parkinson's disease. *Brain.* 2008;131:1294–302. <https://doi.org/10.1093/brain/awn054>.
34. Grinberg LT, Rueb U, Alho AT, di Heinsen L. Brainstem pathology and non-motor symptoms in PD. *J Neurol Sci.* 2010;289:81–8. <https://doi.org/10.1016/j.jns.2009.08.021>.
35. Hughes AJ, Daniel SE, Kilford L, Lees AJ. Accuracy of clinical diagnosis of idiopathic Parkinson's disease: a clinico-pathological study of 100 cases. *J Neurol Neurosurg Psychiatry.* 1992;55:181–4. <https://doi.org/10.1136/jnnp.55.3.181>.

36. Tomlinson CL, Stowe R, Patel S, Rick C, Gray R, Clarke CE. Systematic review of levodopa dose equivalency reporting in Parkinson's disease. *Mov Disord.* 2010;25:2649–53. <https://doi.org/10.1002/mds.23429>.
37. Goetz CG, Tilley BC, Shaftman SR, Stebbins GT, Fahn S, Martinez-Martin P, et al. Movement Disorder Society-sponsored revision of the Unified Parkinson's Disease Rating Scale (MDS-UPDRS): Scale presentation and clinimetric testing results. *Mov Disord.* 2008;23:2129–70. <https://doi.org/10.1002/mds.22340>.
38. Hoehn MM, Yahr MD. Parkinsonism: onset, progression, and mortality. *Neurology.* 1967;17:427–427. <https://doi.org/10.1212/WNL.17.5.427>.
39. Litvan I, Goldman JG, Tröster AI, Schmand BA, Weintraub D, Petersen RC, et al. Diagnostic criteria for mild cognitive impairment in Parkinson's disease: Movement Disorder Society Task Force guidelines. *Mov Disord.* 2012;27:349–56. <https://doi.org/10.1002/mds.24893>.
40. Santangelo G, Siciliano M, Pedone R, Vitale C, Falco F, Bisogno R, et al. Normative data for the Montreal Cognitive Assessment in an Italian population sample. *Neurol Sci.* 2015;36:585–91. <https://doi.org/10.1007/s10072-014-1995-y>.
41. Caffarra P, Vezzadini G, Dieci F, Zonato F, Venneri A. Una versione abbreviata del test di Stroop: dati normativi nella popolazione italiana. *Riv Neurol.* 2002;12:111–5. <https://api.semanticscholar.org/CorpusID:141215044>.
42. Giovagnoli AR, Del Pesce M, Mascheroni S, Simoncelli M, Laiacina M, Capitani E. Trail making test: normative values from 287 normal adult controls. *Ital J Neurol Sci.* 1996;17:305–9. <https://doi.org/10.1007/BF01997792>.
43. Caffarra P, Gardini S, Zonato F, Concarì L, Dieci F, Copelli S, et al. Italian norms for the Freedman version of the clock drawing test. *J Clin Exp Neuropsychol.* 2011;33:982–8. <https://doi.org/10.1080/13803395.2011.589373>.
44. Carlesimo GA, Caltagirone C, Gainotti G, Fadda L, Gallassi R, Lorusso S, et al. The mental deterioration battery: normative data, diagnostic reliability and qualitative analyses of cognitive impairment. *Eur Neurol.* 1996;36:378–84. <https://karger.com/Article/Abstract/117297>.
45. Novelli G, Papagno C, Capitani E, Laiacina M, Al E. Tre test clinici di ricerca e produzione lessicale. Taratura su soggetti normali. [Three clinical tests to research and rate the lexical performance of normal subjects]. *Arch Psicol Neurol Psichiatr.* 1986;47:477–506.
46. RAVEN JC, Organizzazioni Speciali OS. <https://doi.org/10.1007/s00455-021-10299-z>.
47. Monaco M, Costa A, Caltagirone C, Carlesimo GA. *Neurol Sci.* 2015;36:345–7. <https://doi.org/10.1007/s10072-014-2019-7>. Erratum to: Forward and backward span for verbal and visuo-spatial data: standardization and normative data from an Italian adult population.
48. Lezak MD. *Neuropsychological Assessment.* Oxford University Press; 2004. <https://play.google.com/store/books/details?id=FroDVkVKA2EC>.
49. Gillman A, Winkler R, Taylor NF. Implementing the Free Water Protocol does not result in aspiration pneumonia in carefully selected patients with Dysphagia: a systematic review. *Dysphagia.* 2017;32:345–61. <https://doi.org/10.1007/s00455-016-9761-3>.
50. Peña-Chávez RE, Schaen-Heacock NE, Hitchcock ME, Kurosu A, Suzuki R, Hartel RW, et al. Effects of Food and Liquid Properties on swallowing physiology and function in adults. *Dysphagia.* 2023;38:785–817. <https://doi.org/10.1007/s00455-022-10525-2>.
51. Watando A, Ebihara S, Ebihara T, Okazaki T, Takahashi H, Asada M, et al. Effect of temperature on swallowing reflex in elderly patients with aspiration pneumonia. *J Am Geriatr Soc.* 2004;52:2143–4. https://doi.org/10.1111/j.1532-5415.2004.52579_3.x.
52. Rosenbek JC, Robbins JA, Roecker EB, Coyle JL, Wood JL. A penetration-aspiration scale. *Dysphagia.* 1996;11:93–8. <https://doi.org/10.1007/BF00417897>.
53. Neubauer PD, Rademaker AW, Leder SB. The Yale Pharyngeal Residue Severity rating scale: an anatomically defined and image-based Tool. *Dysphagia.* 2015;30:521–8. <https://doi.org/10.1007/s00455-015-9631-4>.
54. Nordio S, Maistrello L, D'Imperio D, Favaretto N, Del-lai A, Montino S, et al. Validity and reliability of the Italian translation of the Yale Pharyngeal Residue Severity rating scale. *Acta Otorhinolaryngol Ital.* 2023;43:12–9. <https://doi.org/10.14639/0392-100X-N2289>.
55. Battel I, Calvo I, Walshe M. Cross-cultural validation of the Italian version of the functional oral intake scale. *Folia Phoniatr Logop.* 2018;70:117–23. <https://doi.org/10.1159/000490792>.
56. Ninfa A, Pizzorni N, Eplite A, Moltisanti C, Schindler A. Validation of the Italian version of the functional oral intake scale (FOIS-IT-It) against fiberoptic endoscopic evaluation of Swallowing and Nutritional Status. *Dysphagia.* 2022;37:137–47. <https://doi.org/10.1007/s00455-021-10257-9>.
57. Jo SY, Hwang J-W, Pyun S-B. Relationship between cognitive function and Dysphagia after Stroke. *Ann Rehabil Med.* 2017;41:564–72. <https://doi.org/10.5535/arm.2017.41.4.564>.
58. Suh MK, Kim H, Na DL. Dysphagia in patients with dementia: Alzheimer versus vascular. *Alzheimer Dis Assoc Disord.* 2009;23:178–84. <https://doi.org/10.1097/WAD.0b013e318192a539>.
59. Moon HI, Pyun SB, Kwon HK. Correlation between location of brain lesion and cognitive function and findings of videofluoroscopic swallowing study. *Ann Rehabil Med.* 2012;36:347–55. <https://doi.org/10.5535/arm.2012.36.3.347>.
60. Holland G, Jayasekaran V, Pendleton N, Horan M, Jones M, Hamdy S. Prevalence and symptom profiling of oropharyngeal dysphagia in a community dwelling of an elderly population: a self-reporting questionnaire survey. *Dis Esophagus.* 2011;24:476–80. <https://doi.org/10.1111/j.1442-2050.2011.01182.x>.
61. Jeon WH, Park GW, Lee JH, Jeong HJ, Sim YJ. Association between location of brain lesion and clinical factors and findings of videofluoroscopic swallowing study in subacute stroke patients. *Brain Neurorehabil.* 2014;7:54. <https://synapse.koreamed.org/articles/1054738>.
62. Michel A, Verin E, Gbaguidi X, Druessne L, Roca F, Chassagne P. Oropharyngeal Dysphagia in Community-Dwelling older patients with dementia: prevalence and relationship with geriatric parameters. *J Am Med Dir Assoc.* 2018;19:770–4. <https://doi.org/10.1016/j.jamda.2018.04.011>.
63. Olchik MR, Ghisi M, Winckler PB, Ayres A. Correlation between cognitive aspects and dysphagia in patients with amyotrophic lateral sclerosis: preliminary report. *Int J Clin Med.* 2017;8:680–91. <https://www.scirp.org/journal/paperinformation.aspx?paperid=81504>.
64. Seçil Y, Arıcı Ş, İncesu TK, Gürgör N, Beckmann Y, Ertekin C. Dysphagia in Alzheimer's disease. *Neurophysiol Clin.* 2016;46:171–8. <https://doi.org/10.1016/j.neucli.2015.12.007>.
65. Hsieh S-W, Chuang H-Y, Hung C-H, Chen C-H. Cognitive deficits Associated with Dysphagia in patients with dementia. *J Neurogastroenterol Motil.* 2021;27:650–2. <https://doi.org/10.5056/jnm21027>.
66. Babaei A, Ward BD, Ahmad S, Patel A, Nencka A, Li S-J, et al. Reproducibility of swallow-induced cortical BOLD positive and negative fMRI activity. *Am J Physiol Gastrointest Liver Physiol.* 2012;303:G600–9. <https://doi.org/10.1152/ajpgi.00167.2012>.
67. Martin RE, Goodyear BG, Gati JS, Menon RS. Cerebral cortical representation of automatic and volitional swallowing in humans. *J Neurophysiol.* 2001;85:938–50. <https://doi.org/10.1152/jn.2001.85.2.938>.

68. Wei K-C, Wang T-G, Hsiao M-Y. The cortical and subcortical neural control of swallowing: a narrative review. *Dysphagia*. 2023. <https://doi.org/10.1007/s00455-023-10613-x>.
69. Kikuchi A, Baba T, Hasegawa T, Kobayashi M, Sugeno N, Konno M, et al. Hypometabolism in the supplementary and anterior cingulate cortices is related to dysphagia in Parkinson's disease: a cross-sectional and 3-year longitudinal cohort study. *BMJ Open*. 2013;3. <https://doi.org/10.1136/bmjopen-2012-002249>.
70. Gao J, Guan X, Cen Z, Chen Y, Ding X, Lou Y, et al. Alteration of Brain Functional Connectivity in Parkinson's Disease patients with Dysphagia. *Dysphagia*. 2019;34:600–7. <https://doi.org/10.1007/s00455-019-10015-y>.
71. Oh JY, An EJ, Lee Y, Kim SM, Cheon M, Kim JY. Association of dysphagia with altered brain glucose metabolism in Parkinson's disease. *CNS Neurosci Ther*. 2023;29:2498–507. <https://doi.org/10.1111/cns.14214>.
72. Clarke CE, Gullaksen E, Macdonald S, Lowe F. Referral criteria for speech and language therapy assessment of dysphagia caused by idiopathic Parkinson's disease. *Acta Neurol Scand*. 1998;97:27–35. <https://doi.org/10.1111/j.1600-0404.1998.tb00605.x>.
73. Ali GN, Wallace KL, Schwartz R, DeCarle DJ, Zagami AS, Cook IJ. Mechanisms of oral-pharyngeal dysphagia in patients with Parkinson's disease. *Gastroenterology*. 1996;110:383–92. <https://doi.org/10.1053/gast.1996.v110.pm8566584>.
74. Troche MS, Sapienza CM, Rosenbek JC. Effects of bolus consistency on timing and safety of swallow in patients with Parkinson's disease. *Dysphagia*. 2008;23:26–32. <https://doi.org/10.1007/s00455-007-9090-7>.

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