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ORIGINAL ARTICLE

Variability of Voluntary Cough Airflow in Healthy Adults and Parkinson's Disease

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Abstract

Cough is an important airway protective behavior responsible for ejecting material from the airway to prevent pneumonia, a leading cause of death in older adults and individuals with Parkinson's disease (PD). Variability of motor performance for both spinal and bulbar functions has been documented; however, there are no studies examining variability of cough motor control in PD and healthy controls. The present study examined the effects of age and PD on variability of voluntary cough performance. Twenty-five healthy younger adults (HYA), 26 healthy older adults (HOA), and 16 participants with PD completed three trials of sequential voluntary cough with spirometry. Coefficients of variation were used to examine variability between groups. Increased variability of cough expired volume ($p = 0.012$) and inspiratory volume ($p = 0.006$) was appreciated in HOAs compared to HYAs. Participants with PD demonstrated increased variability of cough expired volume ($p = 0.029$), peak expiratory flow rise time ($p = 0.016$), and cough volume acceleration ($p = 0.034$) compared to HOAs. Though participants with PD descriptively demonstrated increased peak expiratory flow rate compared to HOAs, this finding was statistically nonsignificant after adjusting for multiple comparisons ($p = 0.072$). This study identified that variability in cough airflow increases in healthy aging and Parkinson's disease. These motor control impairments may be attributed to age and disease-related sensorimotor changes in the peripheral and central nervous system. Future research will be necessary to examine the relationship between inconsistent cough motor output, airway invasion, and aspiration pneumonia in PD.

Keywords Cough · Parkinson's disease · Aging · Motor control · Deglutition · Deglutition disorders

Introduction

Cough is a complex sensorimotor airway protective behavior requiring precise coordination of respiratory and laryngeal musculature. Cough is responsible for ejecting material from the upper and lower airways to facilitate pulmonary clearance and maintain respiratory health. Cough dysfunction is associated with adverse health outcomes, including aspiration [1, 2] and mortality [3]. Though research has primarily focused on the importance of cough effectiveness as measured by the strength and timing of cough airflow parameters, it would be expected that the consistent production of an effective cough also plays an important role in one's ability to repeatedly expel aspirate material to properly protect the airway. For example, in the presence of aspirate material it would disadvantageous to have subsequent cough epochs to vary from effective to ineffective. Instead, it would likely be more favorable to have several effective cough epochs to clear the airways. However, the consistency of cough airflow in healthy adults and individuals with Parkinson's disease has not been explicitly examined.

The neural substrates implicated in performing peripheral sensorimotor movements consistently have been well-studied. The basal ganglia, which receives input from the cerebral cortex and sends motor output to the brainstem via the thalamus, plays a major role in movement preparation and error correction [4, 5]. This neural structure is known to be affected in Parkinson's disease (PD) due to selective loss of dopaminergic neurons in the substantia nigra [6], and is also affected in normal aging resulting in biological alterations and reduced functional connectivity of the dopaminergic

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system [7]. Variability in performance of peripheral movements has been observed to increase during gait [8, 9], grip strength [10, 11], and finger-tapping [12] tasks in PD and healthy older adults (HOA). Relatedly, increased variability has been associated in some cases with worse functional outcomes. For example, gait variability has been associated with an increased risk of future falls [13]. However, current understanding of variability of brainstem-mediated airway protective functions like cough and swallowing are lacking.

Cough and swallowing are life-sustaining airway protective behaviors; therefore, when performed inconsistently there is potential for increased risk of aspiration and an inability to clear the airway, ultimately contributing to the development of medical morbidities, such as dehydration, malnutrition, and pneumonia [14–16]. Physiologic temporal and spatial kinematic variability has been observed during swallowing in healthy adults as a function of age [17, 18]. Additionally, increased variability of velopharyngeal pressures were identified as an early indicator of subtle swallowing changes in PD compared to healthy controls [19]. This emerging research suggests that variability during swallowing, a bulbar function with similar neuroanatomic substrates as cough, is common and can have important implications for clinical management and patient outcomes.

To date there has not been a systematic investigation of cough variability. However, we know that voluntary coughing involves many degrees of freedom to produce the desired motor output of an effective cough. For example, to increase peak expiratory flow rate you can increase the volume of inspired air or change the duration of glottic closure. Given cough's protective role in expelling aspirate material, particularly for individuals with swallowing dysfunction and chronic aspiration, variability in cough expiratory airflow might be considered disadvantageous since a consistent and robust motor output is necessary to facilitate pulmonary clearance. An examination of variability would not only inform our understanding of cough motor control in healthy and disease states, but also inform clinical management, including the development of reference values for normative behavior and clinical protocols for the number of trials necessary to comprehensively capture one's cough presentation. An understanding of cough variability would also provide clinical perspective when monitoring for improvements or deterioration in cough function, as well as assessing treatment generalization. Functionally, cough variability might help to explain adverse health outcomes in neurodegenerative populations, specifically high rates of aspiration pneumonia [20], and serve as a therapeutic target for cough rehabilitation paradigms.

Therefore, the primary aim of this study was to examine the effects of aging and Parkinson's disease on the variability of cough motor performance as measured by cough airflow parameters. Secondarily, we aimed to explore potential demographic and disease-specific factors associated with variability in PD. Given existing literature documenting variability in PD during peripheral movements and swallowing, we hypothesized that individuals with PD would demonstrate increased variability compared to healthy adults, whereas HOAs would demonstrate similar variability compared to healthy younger adults (HYA) across cough airflow outcomes.

Methods

Study Design

This study was a secondary analysis of a subset of previously published data examining voluntary cough airflow across healthy adults and individuals with PD [21, 22]. Inclusion criteria included normal forced vital capacity defined as > 80% of expected values based on age, sex, height, and weight. Exclusion criteria included history of neurological disease other than PD, head and neck cancer, respiratory disease, smoking, or recent chest infection. The Unified Parkinson's disease rating scale (UPDRS) and Hoehn and Yahr stage were used as measures of disease severity. Disease duration was calculated as years since PD diagnosis. Cough testing was performed when all PD participants were on dopaminergic medication. All diagnoses of PD were made by a fellowship-trained movement disorders neurologist using UK Brain Bank criteria [23].

Cough Testing Protocol

Cough airflow was assessed during sequential voluntary cough. A facemask coupled to a pneumotachograph and digital spirometer (MLT 1000, ADInstruments, Inc.) was held over the participant's nose and mouth. Participants were provided the following instructions: "When you are ready, cough as if something has gone down the wrong pipe." Airflow data were inputted to a Power Lab Data Acquisition System (ML870/P ADInstruments), digitized at 2000 Hz, and recorded to a computer through LabChart software. Each sample was low pass filtered at 50 Hz within LabChart.

Data Analysis

Participants with three trials of voluntary cough were included in analyses. Cough airflow outcomes included peak expiratory flow rate (PEFR; L/s), cough expiratory volume (CEV; Liters), inspiratory volume (IV; Liters), compression phase duration (CPD; seconds), peak expiratory flow rise time (PEFRT; seconds), cough volume acceleration (CVA; L/s/s), and number of coughs per trial (Fig. 1). CVA was calculated by dividing PEFR by PEFRT. Among all participants, cough airflow measurements (CPD, CEV, PEFRT, PEFR, CVA) were obtained from the first cough (Cr1) in each cough epoch across

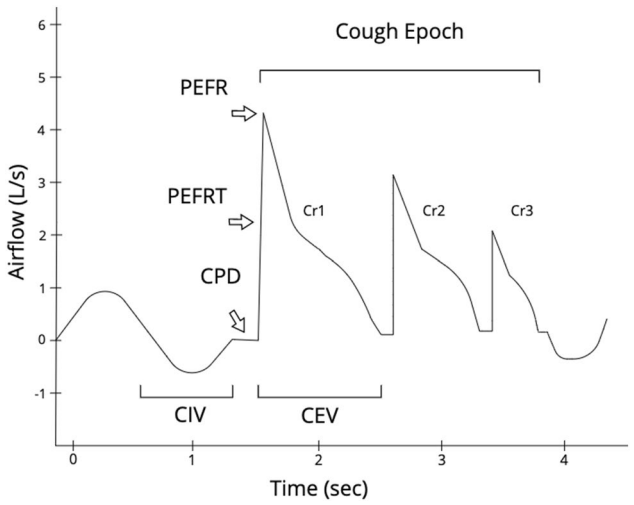

Fig. 1 Schematic representation of a sequential cough airflow waveform. *CIV* cough inspiratory volume; *CPD* compression phase duration; *PEFRT* peak expiratory flow rise time; *PEFR* peak expiratory flow rate; *CEV* cough expired volume; *Cr* cough re-acceleration

trials [24]. A coefficient of variation (CoV) was calculated for each participant across cough airflow outcomes (e.g., a CoV value for three trials of PEFR). CoV was calculated by dividing the standard deviation by the mean of three trials for each participant.

Statistical Analysis

A Student's *t*-test was performed with log-transformed PEFR CoVs to examine variability between HOAs and HYAs, and HOAs and PD. Welch's *t*-tests were performed on all other cough airflow CoVs to examine differences in variability between groups. A Chi-square test was used to examine differences in the total number of coughs between groups. As an exploratory aim, multiple linear regressions were performed to examine the relationship between UPDRS, Hoehn and Yahr stage, and disease duration on variability of cough airflow outcomes in PD. A Holm–Bonferroni adjustment corrected for multiple group comparisons within each outcome. Alpha was set a priori to $p < 0.05$ and adjusted p values are reported. Cohen's d was calculated as a metric of effect size and interpreted as < 0.2 'negligible', < 0.5 'small', < 0.8 'medium', and > 0.8 'large' [25]. Analyses were conducted in R v3.6 [26].

Results

Voluntary coughs from 25 HYAs, 26 HOAs, and 16 participants with PD were included in analyses. Demographic characteristics are provided in Table 1. There was no statistically significant difference in age between HOAs and PD ($p = 0.108$), whereas HOAs were significantly older than HYAs ($p < 0.001$). There were no significant differences in the total number of coughs across all three trials between HOAs and PD ($\chi^2 = 85.33$, $p = 0.559$) and HYAs and HOAs ($\chi^2 = 104.17$, $p = 0.848$). However, HOAs demonstrated significantly increased variability in the number of coughs across trials compared to HYAs (M difference $= 0.12$, $p = 0.022$, $d = 0.66$), whereas there was no significant difference between HOAs and PD (M difference $= 0.04$, $p = 0.559$).

After adjusting for multiple comparisons, HOAs demonstrated significantly increased variability of CEV ($p = 0.012$, $d = 0.80$) and IV ($p = 0.006$, $d = 0.89$) compared to HYAs (Fig. 2). No statistically significant differences were appreciated for PEFR ($p = 0.529$), CVA ($p = 0.105$), or CPD ($p = 0.162$) variability between these groups. Participants with PD demonstrated significantly increased variability of CEV ($p = 0.029$, $d = 0.84$), CVA ($p = 0.034$, $d = 1.06$), and PEFRT ($p = 0.016$, $d = 1.12$) compared to HOAs. Though increased PEFR variability was appreciated in participants with PD compared to HOAs, this finding was nonsignificant after adjusting for multiple comparisons ($p = 0.072$, $d = 0.70$; Table 2). Furthermore, there were no statistically significant differences in CPD ($p = 0.929$) or IV ($p = 0.891$) variability between groups. In participants with PD, multiple linear regressions showed no statistically significant relationships of cough airflow variability with age, disease duration, UPDRS, and Hoehn and Yahr stage ($p > 0.05$).

Discussion

Cough is an important airway protective behavior, responsible for ejecting material from the airway to prevent respiratory infections like pneumonia, a leading cause of death in older adults and individuals with Parkinson's disease (PD) commonly caused by aspiration [20, 27–29]. Though research has primarily focused on the importance of cough effectiveness as measured by the strength and timing of cough airflow parameters, it would be expected that the consistent production of an effective cough also plays an important role in one's ability to repeatedly expel aspirate material to properly protect the airway. However, this has not yet been explicitly examined. The present study aimed to first characterize cough airflow variability and examine the effects of age and PD. Findings partially supported our hypotheses, suggesting that variability of cough airflow parameters increased with age and in PD.

Both HOAs and HYAs demonstrated consistent cough airflow for the majority of expiratory measures, specifically PEFR, CVA, PEFRT, and CPD. These findings suggest that healthy adults produce both effective and consistent

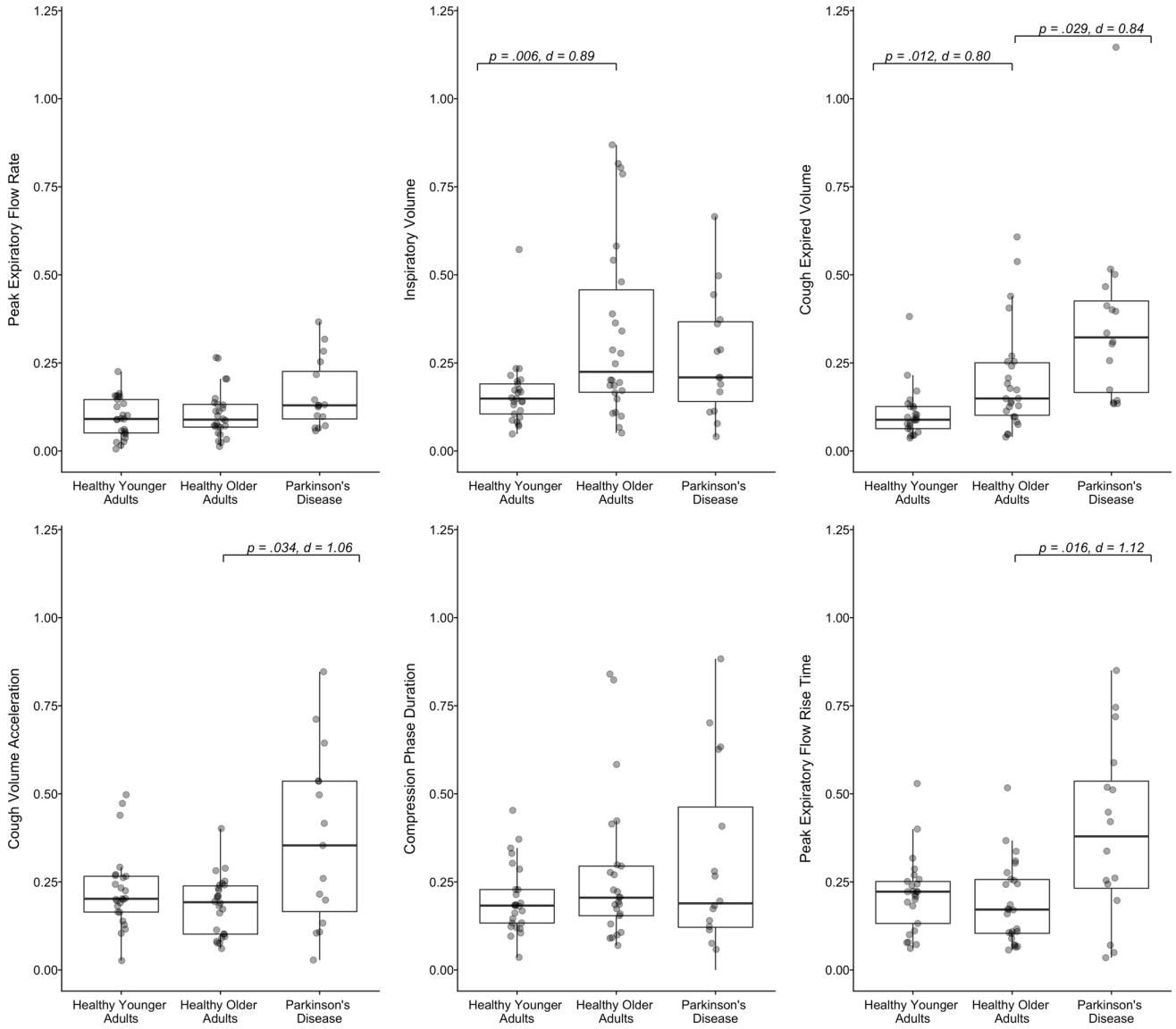

Fig. 2 Coefficients of variation across cough outcomes

Table 1 Demographic characteristics

	PD ($n=16$)	HOA ($n=26$)	HYA ($n=25$)
Age, mean (SD)	73.31 (5.91)	$M=70.42$ (6.84)	$M=23.32$ (3.51)
Sex	Male = 9	Male = 14	Male = 11
	Female = 7	Female = 12	Female = 14
Disease duration, mean years (SD)	8.93 (5.28)		
H&Y stage, median (range)	2 (1–4)		
UPDRS, mean (range)	23.31 (5–47)		

PD Parkinson's disease, *HOA* healthy older adults, *HYA* healthy younger adults, *H&Y* Hoehn & Yahr, *UPDRS* unified Parkinson's disease rating scale

Table 2 Between-group comparisons across cough airflow variability outcomes

CoV outcome	Mean difference	*t* Statistic	*df*	95% CI	Unadjusted *p* value	Adjusted *p* value	Cohen's *d*
PEFR							
HOA vs HYA	0.01	0.63	49.00	(− 0.31, 0.59)	0.529	0.529	0.18
HOA vs PD	− 0.05	− 2.17	40.00	(− 0.91, − 0.03)	0.036	0.072	0.70
IV							
HOA vs HYA	0.17	3.22	32.91	(0.06, 0.28)	0.003	0.006*	0.89
HOA vs PD	− 0.01	− 0.14	24.19	(− 0.22, 0.20)	0.891	0.891	0.05
CEV							
HOA vs HYA	0.09	2.88	36.37	(0.03, 0.16)	0.006	0.012*	0.80
HOA vs PD	− 0.16	− 2.34	21.61	(− 0.30, − 0.02)	0.029	0.029*	0.84
CVA							
HOA vs HYA	− 0.04	− 1.65	44.75	(− 0.10, 0.01)	0.105	0.105	0.47
HOA vs PD	− 0.27	− 2.66	15.79	(− 0.49, − 0.05)	0.017	0.034*	1.06
CPD							
HOA vs HYA	0.11	1.81	30.63	(− 0.02, 0.24)	0.081	0.162	0.50
HOA vs PD	0.01	0.09	34.62	(− 0.17, 0.19)	0.929	0.929	0.03
PEFRT							
HOA vs HYA	− 0.02	− 0.74	48.92	(− 0.09, 0.04)	0.464	0.464	0.21
HOA vs PD	− 0.20	− 2.99	18.88	(− 0.34, − 0.06)	0.008	0.016*	1.12

CoV coefficient of variation, *CI* confidence interval, *HOA* healthy older adults, *HYA* healthy younger adults, *PD* Parkinson's disease, *PEFR* peak expiratory flow rate, *IV* inspiratory volume, *CEV* cough expired volume, *CPD* compression phase duration, *PEFRT* peak expiratory flow rise time

*$p < .05$ after Holm–Bonferroni adjustment

cough expiratory output. However, variability of the volume of inspired (IV) and expired air (CEV) was increased in HOAs compared to HYAs. Variability of these parameters in HOAs might reflect necessary physiologic compensations to achieve similar effective expiratory output as HYAs. It can be posited that this age-related variability results from flexibility in an otherwise healthy sensorimotor system in order for expiratory airflow to remain largely unaffected and airway protection to be accomplished.

In contrast to these findings, individuals with PD demonstrated greater variability in expiratory airflow compared to HOAs. Specifically, variability of cough effectiveness (CVA and CEV) and the time required to reach peak expiratory airflow (PEFRT) was increased in PD compared to HOAs. These findings are concerning given that individuals with PD also often demonstrate reduced cough strength and effectiveness [21]. Thus, this suggests that individuals with PD exhibit both inconsistent (i.e., more variable) and ineffective (i.e., unable to achieve optimal expiratory airflow) cough motor output.

Age and disease-related alterations in sensorimotor control of the peripheral and central nervous system might help explain these findings. For example, impairments in motor control can occur due to age-related neuromuscular degeneration including muscle atrophy and a reduction in the number of type II fibers [30] resulting in changes to the force, coordination, and accuracy of movements [31]. Peripherally, age-related sarcopenia of respiratory musculature may also contribute to respiratory dysfunction and discoordination [32, 33]. In PD, pathologic variability of this voluntary task is likely mediated by altered neural pathways in the basal ganglia, cerebellum, and brainstem respiratory and cough central pattern generators. Characteristic motor deficits, such as bradykinesia and increased rigidity, have been attributed to abnormal control of the basal ganglia [34, 35], potentially contributing to alterations in the accuracy and coordination of peripheral musculature during coughing. Both increased neural noise from abnormal cortical and subcortical motor pathways, as well as disease-specific sequelae, such as increased rigidity of respiratory musculature, likely contribute to alterations in motor control, resulting in increased variability.

The present study's results have important implications for the evaluation and treatment of cough. To begin, this study further supports the need for objective spirometric assessments of cough airflow and its variability in PD given that no demographic or disease-specific characteristics explained the cough variability in individuals with PD. When designing clinical protocols, and in particular when deciding on the number of trials necessary to comprehensively capture one's cough presentation, there are important distinctions between healthy adults and

individuals with PD. Healthy adults, regardless of age, produced relatively consistent cough airflow across repetitions. If substantial within-subject variability is appreciated in an otherwise healthy individual, this might be indicative of dysfunction requiring further investigation. For an individual with PD, on the other hand, a single cough trial would not comprehensively capture their cough presentation. Instead, multiple trials are required to adequately characterize cough airflow due to heightened variability. It is clearly important to identify whether individuals are consistent and effective, as any combination of these deficits would inform our understanding of an individual's cough sensorimotor control. Additionally, cough airflow consistency might serve as a potential therapeutic target for cough rehabilitation paradigms, as well as a measure to monitor motor learning and treatment retention and generalization. Understanding both the consistency and effectiveness of an individual's cough might provide valuable information regarding their capacity for improvement, though future studies will be necessary to systematically examine if baseline variability is predictive of treatment response.

There are several limitations of this study to acknowledge. A known statistical limitation of the CoV is its tendency to become inflated in the context of negative numbers or values near zero [36]. Two temporal outcomes, CPD and PEFRT, demonstrated raw values near zero. However, negative values or substantial outliers indicative of inflated values were not observed across groups. Thus, the CoV appears to be an appropriate metric to capture cough airflow variability in this sample. Secondly, we were unable to examine the effects of reflex or single voluntary coughs in the present investigation. Results of this study can only be generalized to sequential voluntary cough in HYAs, HOAs, and individuals with PD. Future research will be required to understand the role of variability in reflex cough tasks. Finally, we were unable to explore the relationship between cough airflow variability and swallowing dysfunction. Future studies using instrumental swallowing evaluations to comprehensively characterize dysphagia will be necessary to understand the relationship between cough airflow variability, functional deficits of airway protection, and associated health outcomes.

Conclusion

This study demonstrated increased cough airflow variability during sequential voluntary coughs due to healthy aging and Parkinson's disease. Deficits in neuromotor control and coordination likely contribute to variability, which might help to explain high rates of aspiration pneumonia in Parkinson's disease. This study has important clinical implications, highlighting the need for multiple cough trials when evaluating individuals with Parkinson's disease. Cough airflow variability may also serve as an appropriate therapeutic target for cough rehabilitation paradigms in individuals at elevated risk for pulmonary compromise due to neurodegenerative disease.

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Compliance with Ethical Standards

Conflict of interest The authors have no conflicts of interest to disclose.

Ethical Approval All procedures performed were in accordance with the ethical standards of the institutional research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

Informed Consent Informed consent was obtained from all participants prior to enrollment in this research study.

References

1. Hegland KW, Okun MS, Troche MS. Sequential voluntary cough and aspiration or aspiration risk in Parkinson's disease. Lung. 2014;192(4):601–8.
2. 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(6):1426–31.
3. Bianchi C, Baiardi P, Khirani S, Cantarella G. Cough peak flow as a predictor of pulmonary morbidity in patients with dysphagia. Am J Phys Med Rehabil. 2012;91(9):783–8.
4. Tunik E, Houk JC, Grafton ST. Basal ganglia contribution to the initiation of corrective submovements. NeuroImage. 2009;47(4):1757–66.
5. Houk JC, Bastianen C, Fansler D, Fishbach A, Fraser D, Reber PJ, et al. Action selection and refinement in subcortical loops through basal ganglia and cerebellum. Phil Trans R Soc B. 2007;362(1485):1573–83.
6. Dickson DW. Neuropathology of Parkinson disease. Parkinsonism RelatDisord. 2018;46:30–3.
7. Reeves S, Bench C, Howard R. Ageing and the nigrostriatal dopaminergic system. Int J Geriat Psychiatry. 2002;17(4):359–70.
8. Baltadjieva R, Giladi N, Gruendlinger L, Peretz C, Hausdorff JM. Marked alterations in the gait timing and rhythmicity of patients with de novo Parkinson's disease. Eur J Neurosci. 2006;24(6):1815–20.
9. Callisaya ML, Blizzard L, Schmidt MD, McGinley JL, Srikanth VK. Ageing and gait variability—a population-based study of older people. Age Ageing. 2010;39(2):191–7.
10. Pradhan S, Scherer R, Matsuoka Y, Kelly VE. Grip force modulation characteristics as a marker for clinical disease progression in individuals with Parkinson disease: case-control study. Phys Ther. 2015;95(3):369–79.

11. Vaillancourt DE, Slifkin AB, Newell KM. Inter-digit individuation and force variability in the precision grip of young, elderly, and Parkinson's disease participants. Mot Control. 2002;6(2):113–28.
12. Arias P, Robles-García V, Espinosa N, Corral Y, Cudeiro J. Validity of the finger tapping test in Parkinson's disease, elderly and young healthy subjects: is there a role for central fatigue? Clin Neurophysiol. 2012;123(10):2034–41.
13. Hausdorff JM, Rios DA, Edelberg HK. Gait variability and fall risk in community-living older adults: a 1-year prospective study. Arch Phys Med Rehabil. 2001;82(8):1050–6.
14. Streicher M, Wirth R, Schindler K, Sieber CC, Hiesmayr M, Volkert D. Dysphagia in nursing homes—results from the NutritionDay Project. J Am Med Directors Assoc. 2018;19(2):141–147.e2.
15. Serra-Prat M, Palomera M, Gomez C, Sar-Shalom D, Saiz A, Montoya JG, et al. Oropharyngeal dysphagia as a risk factor for malnutrition and lower respiratory tract infection in independently living older persons: a population-based prospective study. Age Ageing. 2012;41(3):376–81.
16. Langmore SE, Terpenning MS, Schork A, Chen Y, Murray JT, Lopatin D, et al. Predictors of aspiration pneumonia: how important is dysphagia? Dysphagia. 1998;13(2):69–81.
17. Molfenter SM, Steele CM. Physiological variability in the deglutition literature: hyoid and laryngeal kinematics. Dysphagia. 2011;26(1):67–74.
18. Molfenter SM, Steele CM. Temporal variability in the deglutition literature. Dysphagia. 2012;27(2):162–77.
19. Jones CA, Ciucci MR. Multimodal swallowing evaluation with high-resolution manometry reveals subtle swallowing changes in early and mid-stage Parkinson disease. JPD. 2016;6(1):197–208.
20. 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 RelatDisord. 2015;21(9):1082–6.
21. Brandimore AE, Hegland KW, Okun MS, Davenport PW, Troche MS. Voluntary upregulation of reflex cough is possible in healthy older adults and Parkinson's disease. J ApplPhysiol. 2017;123(1):19–26.
22. Brandimore AE, Troche MS, Huber JE, Hegland KW. Respiratory kinematic and airflow differences between reflex and voluntary cough in healthy young adults. Front Physiol. 2015;6:1–10.
23. 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(3):181–4.
24. Davenport PW, Bolser DC, Vickroy T, Berry RB, Martin AD, Hey JA, et al. The effect of codeine on the Urge-to-Cough response to inhaled capsaicin. Pulm Pharmacol Ther. 2007;20(4):338–46.
25. Cohen J. A power primer. Quant Methods Psychol. 1992;112(1):155–9.
26. R Core Team. R: a language and environment for statistical computing [Internet]. Vienna, Austria: R Foundation for Statistical Computing; 2018. https://www.R-project.org/
27. Marik PE, Kaplan D. Aspiration pneumonia and dysphagia in the elderly. Chest. 2003;124(1):328–36.
28. Hely MA, Morris JGL, Traficante R, Reid WGJ, O'Sullivan DJ, Williamson PM. The Sydney multicentre study of Parkinson's disease: progression and mortality at 10 years. J Neurol Neurosurg Psychiatry. 1999;67(3):300–7.
29. Fall P-A, Saleh A, Fredrickson M, Olsson J-E, Granérus A-K. Survival time, mortality, and cause of death in elderly patients with Parkinson's disease. A 9-year follow-up: mortality in Parkinson's disease. MovDisord. 2003;18(11):1312–6.
30. Yamada H, Masuda T, Okada M. Age-related EMG variables during maximum voluntary contraction. Percept Mot Skills. 2008;95:10–4.
31. Ketcham C, Stelmach G. Movement control in the older adult, vol. 3. Washington, D.C: National Academies Press; 2004. p. 305.
32. Elliott JE, Greising SM, Mantilla CB, Sieck GC. Functional impact of sarcopenia in respiratory muscles. Respir Physiol Neurobiol. 2016;226:137–46.
33. Kim J, Sapienza CM. Implications of expiratory muscle strength training for rehabilitation of the elderly: tutorial. JRRD. 2005;42(2):183–95.
34. Berardelli A. Pathophysiology of bradykinesia in Parkinson's disease. Brain. 2001;124(11):2131–46.
35. Berardelli A, Sabra AF, Hallett M. Physiological mechanisms of rigidity in Parkinson's disease. J Neurol Neurosurg Psychiatry. 1983;46(1):45–53.
36. van Geert P, van Dijk M. Focus on variability: new tools to study intra-individual variability in developmental data. Infant Behav Dev. 2002;25(4):340–74.

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