Effects of PhoRTE on Speech, Voice and Swallowing Functions in Patients with Parkinson's Disease

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ABSTRACT

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Parkinson's disease (PD) is characterized by a combination of four primary symptoms: resting tremor, bradykinesia, rigidity, and postural instability, often accompanied by weakened laryngeal muscles. As a result, most patients experience difficulties with speech, voice, and swallowing, negatively impacting their quality of life. While the effectiveness of the Phonation Resistance Training Exercise (PhoRTE) voice therapy technique has been demonstrated in treating presbyphonia, research on its application to neurodegenerative diseases remains limited. Therefore, this study aims to apply the PhoRTE voice therapy technique to PD patients to investigate its effects not only on speech and voice but also on swallowing function and quality of life.

A total of 19 patients with PD participated in the study, comprising 10 patients in the treatment group (5 males, 5 females; age = 74.90 ± 8.73) and 9 patients in the control group (6 males, 3 females; age = 77.00 ± 10.38). There were no significant differences between the groups in terms of age, K-MMSE, ASHA NOMS swallowing level scale, or speech POT. Patients in the treatment group underwent PhoRTE therapy for four weeks, with evaluations conducted before and after the treatment. Patients in the control group completed pre- and post-evaluations over a four-week interval without receiving therapy. The evaluation metrics included measures related to speech, voice, swallowing mechanisms, and questionnaires.

The application of the PhoRTE voice therapy technique yielded significant results. From a voice perspective, the treatment group demonstrated significant improvements in MPT, jitter ($p < .01$), shimmer, CPPs (vowel) ($p < .05$), and speech intensity (vowel) ($p < .001$). In contrast, the control group showed a significant increase in jitter and shimmer ($p < .05$), indicating a worsening. From a speech perspective, the treatment group showed significant improvements in AMR /kuh/ and VSA ($p < .05$).

From a swallowing perspective, the treatment group showed significant improvement in GUSS($p < .05$). In terms of swallowing-related quality of life, the control group exhibited a significant decline in the SWAL-QOL total score ($p < .05$).

This study is significant in demonstrating the effectiveness of applying voice therapy techniques not only to voice but also to swallowing function, which shares anatomical structures with voice mechanisms. Additionally, it highlights the clinical importance of providing timely and appropriate treatment for patients with Parkinson's disease, a degenerative condition.

Key words : Parkinson’s disease, dysarthria, dysphagia, PhoRTE, voice therapy, speech, swallowing, quality of life

I. INTRODUCTION

1. Background

Parkinson's disease arises from a dopamine deficit in the substantia nigra, a part of the brain situated in the midbrain, and is driven by the abnormal build-up of α-synuclein, a neurotransmitter protein present in Lewy bodies.[1] Parkinson's disease (PD) is characterized by four primary symptoms: bradykinesia, rigidity, postural instability, and resting tremor.[2] Alongside these motor symptoms, PD patients frequently experience non-motor symptoms, which include cognitive decline, emotional disturbances such as depression, constipation, and sleep problems.[3,4] Speech and writing difficulties may also manifest in the early stages of the disease.[5] Non-motor symptoms, which often appear before motor symptoms, especially in the initial stages, complicate early detection and diagnosis, thus hindering timely treatment.[6,7]

Approximately 89% of PD patients experience dysarthria, with hypokinetic dysarthria being the most common type. The weakening of the voice observed in this condition is known to result from restricted respiration during phonation and reduced vocal fold adduction.[8,9] Additionally, vocal fold bowing leads to incomplete closure and air leakage, which consequently results in voice changes.[10,11] The perceptual voice characteristics in PD include mono pitch, mono loudness, breathy voice, harsh voice, and abnormally high pitch for age.[9] Monotonous voice quality arises from a reduction in fundamental frequency and a decreased pitch range, both in terms of minimum and maximum frequencies.[12]

Additionally, reduced respiratory cycles result in decreased word production, often leading to faster speech rates.[13] These challenges can greatly affect the quality of life, as assessments of PD patients have revealed declines in both physical functioning and mental health aspects.[14]

Over 80% of PD patients experience swallowing difficulties, which can lead to nutritional deficiencies. Simultaneously, this issue decreases the quality of life and can ultimately result in the intrusion and aspiration of food into the airway, potentially causing aspiration pneumonia.[15] Coughing is critical for reducing the risk of intrusion or aspiration, and this process is influenced by respiratory muscle strength, pharyngolaryngeal muscle strength, and the degree of vocal fold closure, which contribute to the formation of subglottic pressure. In other words, adequate vocal fold closure is crucial for airway protection during coughing.[16,17] However, PD patients often experience difficulties not only with coughing but also with swallowing due to weakened pharyngolaryngeal muscle strength. Additionally, in the oral phase, symptoms such as bradykinesia, rigidity, and tremor can cause difficulties in oral motor function.[18] As a result, there may be delays in the swallowing reflex, oral residue, and leakage prior to swallowing. Furthermore, reduced tongue pressure and movement, which are critical for bolus transfer, are also observed.[19]

Speech, voice, and swallowing functions play an essential role in daily life, and for PD patients, whose abilities in these areas are impaired, various approaches are implemented to improve overall communication abilities. The Lee Silverman Voice Treatment (LSVT) is among the most commonly employed therapies for managing speech

and swallowing difficulties in patients with PD. LSVT consists of a total of 16 sessions, conducted over four weeks with 1-hour treatment sessions. LSVT enhances vocal loudness (amplitude) in PD patients and promotes neuroplasticity through intensive and effortful therapy. Additionally, it improves and recalibrates feedback related to sensory and internal cues during training, helping patients maintain improved voice loudness.[20-22] The therapy tasks include prolonging vowels with the loudest voice possible, pitch glides (moving from a comfortable pitch to a higher pitch), reading functional words and phrases aloud (with a strong voice), and conversation tasks. In studies conducted with PD patients, following LSVT treatment, improvements were observed in Maximum Phonation Time (MPT), perceptual voice characteristics such as breathiness and hoarseness, and increased vocal intensity due to enhanced vocal fold adduction. Voice problems were also found to significantly improve as measured by the Voice Handicap Index (VHI), a tool used to evaluate the degree of disability caused by voice issues, along with improvements in communication effectiveness scales. Furthermore, results indicated an increase in pharyngeal residue clearance and prolonged opening time of the pharyngoesophageal segment (PES), both of which are closely related to swallowing function. These effects were reported to be maintained for up to six months.[23-25] In addition to LSVT, therapies such as LaxVox, the Accent Method, and voice modulation training are also being implemented, and treatment outcomes have shown significant improvements in vocal tremor, MPT, frequency range, intensity range, and voice quality.[26]

In addition to LSVT, PD patients also undergo interventions related to voice and respiration, such as the Speak Out program, Expiratory Muscle Strength Training (EMST), and music therapy. Among these interventions, Phonation Resistance Training Exercises (PhoRTE), a voice therapy technique with a protocol similar to LSVT, addresses the high-intensity demands of LSVT by offering a more time-efficient schedule. PhoRTE involves one session per week, along with six at-home assignments, with each session lasting approximately 40 minutes.[20,21] The main difference between LSVT and PhoRTE lies in the treatment frequency. While LSVT consists of four weekly sessions over four weeks, PhoRTE offers a less intensive schedule with one session per week over the same period. Additionally, in functional phrase reading, PhoRTE differs from LSVT by incorporating both high and low pitches during vocal exercises. Lastly, in home practice, PhoRTE requires 10 repetitions of each activity once per day, whereas LSVT prescribes 10 repetitions twice per day.[27,28] To date, most studies on PhoRTE have focused on its effects on voice based on presbyphonia. There have also been reports of studies combining PhoRTE with Expiratory Muscle Strength Training (EMST) to enhance its therapeutic effects.[28,29]

2. Necessity of study

PD is known to affect 1-2% of the global population. Its incidence rate is approximately 0.02% per 100,000 individuals, with a prevalence of 1% among those aged 60 and older. In other words, the prevalence increases with age, and it is recognized as the second most common neurodegenerative disorder.[1]

PhoRTE, derived from LSVT, aims to improve vocal loudness. PhoRTE consists of tasks such as producing a prolonged, loud /a/ sound, performing pitch glides from a comfortable pitch to high and low pitches, reciting functional phrases at both elevated and lowered pitches while keeping the volume high., and speaking loudly for an extended period in conversational scenarios. PD patients often experience incomplete vocal fold closure due to vocal fold bowing, which leads to a reduction in MPT. For these reasons, perceptual voice characteristics such as breathy voice, reduced loudness, and reduced utterance length are observed in terms of phonation and respiration. Therefore, activities like those in PhoRTE can help improve MPT and increase vocal loudness.[11,30] Additionally, patients often exhibit a reduced pitch range, which is closely linked to hyoid elevation, a critical factor in airway protection.[31] This can be addressed through pitch glide activities, which promote hyoid elevation and, as a result, assist in clearing the bolus during swallowing.[32] The up-and-down movement of the hyoid and larynx also contributes to increasing pitch range.[33] By promoting the forward and upward movement of the hyoid, thyroid, and cricoid cartilages, these exercises aid in keeping the vocal folds extended for

higher pitches and shortened for lower pitches, which increases the flexibility of the vocal fold muscles.[34-37]

Studies on PhoRTE have shown notable enhancements in voice-related quality of life, as measured by the Voice-Related Quality of Life (V-RQOL) scale, along with improvements in the VHI for individuals with presbyphonia.[28,29] However, there is a lack of studies applying PhoRTE to neurodegenerative populations, such as PD patients, as well as studies analyzing objective acoustic parameters or examining its impact on swallowing function.

Given that PhoRTE follows a protocol similar to the well-established and effective LSVT, this study aims to determine whether PhoRTE can improve not only speech, voice function, and quality of life but also swallowing function, which shares the same anatomical structures. Furthermore, objectively measuring the improvements in speech, voice, and swallowing function through PhoRTE, alongside patient-reported outcomes on quality of life, could provide valuable evidence to expand the clinical applicability of PhoRTE for Parkinson's patients in the future.

3. Hypothesis

The purpose of this study was to evaluate potential improvements in the severity of speech, voice, and swallowing functions after a 4-week treatment using the PhoRTE voice therapy method in patients with Parkinson's disease. The hypotheses of this research are articulated as follows:

(1) The treatment group is anticipated to exhibit preservation and enhancement of speech, voice, and swallowing functions, along with improvements in quality of life associated with these functions.

(2) The control group is expected to show a deterioration in speech, voice, and swallowing functions, accompanied by a reduction in quality of life associated with these abilities.

II. MATERIALS AND METHODS

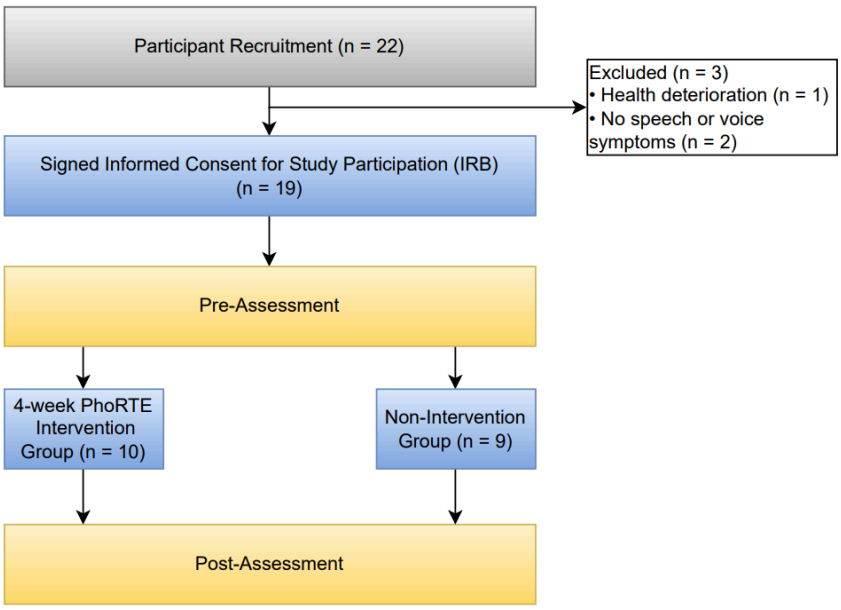

Figure 1. Participant recruitment and study procedure

Abbreviations: IRB, Institutional Review Board; PhoRTE, Phonation Resistance Training Exercises

1. Participants

The subjects of this research were individuals who had received a medical diagnosis of Parkinson's disease from a specialist in rehabilitation medicine or neurology and who indicated experiencing challenges related to speech, voice, and swallowing. Eligibility criteria included (1) individuals diagnosed with Parkinson's disease by specialists in rehabilitation medicine or neurology; (2) patients experiencing discomfort or difficulty in swallowing, as identified through a videofluoroscopic swallowing study (VFSS), and classified as levels 4–7 on the American Speech-Language-Hearing Association (ASHA)

National Outcomes Measurement System (NOMS) swallowing level scale; (3) patients reporting discomfort or difficulty with speech and voice; and (4) Participants scoring 20 or above on the Korean Mini-Mental State Examination (K-MMSE) met the inclusion criteria. Exclusion criteria included: (1) patients unable to engage in verbal communication or oral intake, (2) patients who could not follow appropriate instructions as a results of cognitive or audiovisual impairments, and (3) patients who failed to complete the 4-week intervention.

We initially recruited a total of 22 patients for the study. We excluded one patient due to worsening health conditions and two patients because they did not exhibit voice or swallowing-related symptoms. As a result, we included 19 patients in the study. After random assignment using the Excel program (version 16.89.1, Microsoft Corp., Redmond, WA, USA), 10 patients were allocated to the treatment group and 9 to the control group. Participants in the treatment group had a mean age of 74.90 ± 8.73 years, a K-MMSE score of 25.00 ± 3.07, an ASHA NOMS swallowing level of 5.40 ± 0.66, and a speech post onset time (POT) of 25.40 ± 27.25 months. Participants in the control group were, on average, 77.00 ± 10.38 years old, with a K-MMSE score averaging 22.80 ± 2.15, an ASHA NOMS swallowing level of 5.56 ± 0.83, and a speech post onset time (POT) of 26.10 ± 25.50 months. There were no statistically significant differences in age, K-MMSE, ASHA NOMS swallowing level scale, or speech POT between the treatment and control groups (Table 1 and 2).

Table 1. Participant information

Group	No.	Sex	Age	K-MMSE	ASHA NOMS Swallowing Level Scale	Speech POT (month)
Treatment (n = 10)	T1	Male	83	24	5	48
	T2	Female	77	20	6	12
	T3	Female	65	29	6	12
	T4	Male	79	20	6	8
	T5	Male	87	28	5	7
	T6	Female	64	29	4	36
	T7	Female	70	30	6	2
	T8	Male	87	25	5	24
	T9	Female	63	26	5	9
	T10	Male	74	24	6	96
		Average	74.90 ±8.73	25.00 ±3.07	5.40 ±0.66	25.40 ±27.25
Control (n = 9)	C1	Male	68	20	6	24
	C2	Male	75	20	5	12
	C3	Male	94	24	6	24
	C4	Male	90	21	4	24
	C5	Female	66	21	5	12
	C6	Male	87	25	5	24
	C7	Female	63	26	6	9
	C8	Male	74	24	6	96
	C9	Female	76	24	7	10
		Average	77.00 ±10.38	22.80 ±2.15	5.56 ±0.83	26.10 ±25.50

Abbreviations: K-MMSE, Korean Mini-Mental State Examination; ASHA NOMS Swallowing Level Scale, American Speech-Language-Hearing Association National Outcomes Measurement System swallowing level scale; Speech POT, speech post onset time

Table 2. Baseline characteristics of treatment and control groups

Measure	Treatment (n=10)			Control (n=9)			*p*-value
	Mean±SD	Median	IQR	Mean±SD	Median	IQR	
Age	74.90±8.73	75.50	15.75	77.00±10.38	75.00	19.00	0.704
K-MMSE	25.00±3.07	25.00	3.50	22.80±2.15	24.00	3.00	0.136
ASHA NOMS swallowing level scale	5.40±0.66	5.50	1.00	5.56±0.83	6.00	1.00	0.710
Speech POT	25.40±27.25	12.00	24.75	26.10±25.50	24.00	12.00	0.532

Abbreviations: IQR, Interquartile range (IQR=Q3-Q1); K-MMSE, Korean Mini-Mental State Examination; ASHA NOMS swallowing level scale: American Speech-Language-Hearing Association National Outcomes Measurement System swallowing level scale; Speech POT: speech post onset time

2. Methods

A. Data collection

This study was approved by the Institutional Review Board (IRB) of Severance Hospital, Shinchon (approval No. 4-2024-0603). Each participant received a detailed oral explanation of the study's purpose and methods from the researcher and provided written consent before proceeding. In cases in which participants had physical difficulties with writing, their legal representatives provided consent. Following consent, the participants in the treatment group followed the predetermined protocol, which included cognitive assessment, pre-evaluation, 4 weeks of voice therapy, and post-evaluation. The control group underwent evaluations at 4-week intervals without receiving voice therapy. In addition, participants completed questionnaires related to handicap and quality of life either independently or with the assistance of a caregiver. When necessary, the researcher provided supplementary explanations of the questionnaire items to ensure that all participants could understand them easily and respond accurately.

(A) Cognitive assessment

Because of the need for participants to follow instructions during treatment and engage in self-directed training at home, we deemed an evaluation of the participants' cognitive aspects necessary. The Mini-Mental State Examination (MMSE) evaluates several cognitive areas, such as language, visuospatial skills,

orientation, memory, and attention, offering a thorough assessment of overall cognitive function.[38] We administered the K-MMSE and calculated the scores based on the participant's age and years of education.[39] Once the participants met the required criteria, we conducted speech assessments.

(B) Speech functions

Speech and voice assessments were performed in a controlled conference room environment, where background noise levels were maintained at less than 50 dB. For voice recordings, we used a SONY ICD-UX560F voice recorder (SONY Corp., Tokyo, Japan). A SONY ECM-MS907 condenser microphone (SONY Corp., Tokyo, Japan) was positioned at a 90° angle, and participants were seated in either a chair or wheelchair next to the researcher, maintaining a distance of 20 to 30 cm between their lips and the microphone.

We analyzed the collected voice data using Praat software (version 6.4.07, Institute for Phonetic Sciences, University of Amsterdam, Amsterdam, the Netherlands).

(a) Maximum phonation time (MPT)

MPT is a typical task for the clinical evaluation of the respiratory and phonatory components of the speech-production mechanism. The patient is instructed to take as many breaths as they can, followed by speaking as long a vowel as they can.[40]

MPT is a measure frequently used in voice evaluations because of its affordability, quick feasibility, and noninvasiveness. In addition, MPT has been used to evaluate the

efficacy of voice therapies and to objectively measure the severity of dysphonia.[41] In this study, we instructed participants to take a deep breath and then phonate the sound /a/ at a comfortable pitch.

(b) Pitch glides

Pitch glides refer to the phonation of the vowel /a/ starting from the lowest pitch to the highest pitch.[42] This task allows for measuring both the maximum and minimum vocal frequencies.[43] As the pitch shifts from low to high, the hyoid bone and larynx rise, [44] a movement that is connected to decreased hyoid mobility during swallowing, which may increase the risk of penetration and aspiration.[45] Participants in this study listened to the researcher's demonstration and were instructed to glide their voice from a comfortable pitch to the highest pitch they could produce and then back down to the lowest pitch.

(c) Speech intensity

Patients with Parkinson's disease are known to have lower speech intensity during conversation compared with the normal population.[46] Speech intensity can be used to assess structural or functional changes in the larynx during phonation and also to evaluate the effectiveness of speech therapy or monitor a patient's vocal condition after surgery.[47] Moreover, an increased speech intensity is associated with greater vocal fold closure, and it has been found to correlate with measures such as jitter and shimmer.[48] In this study, we instructed participants to phonate the vowel /a/ as loudly as possible for 5 seconds.

(d) Diadochokinetic rate (DDK)

The DDK is a test used to evaluate the movement of articulatory organs such as the lips and tongue, and it is highly sensitive for the identification of orofacial motor impairments. This test assesses parameters such as accuracy, regularity, speed, and range of motion. DDK includes two components: alternating motion rate (AMR), where the patient repetitively articulates the sounds /puh/, /tuh/, and /kuh/ separately, and sequential motion rate (SMR), where the patient produces /puh tuh kuh/ in a continuous sequence.[11,49] In this study, were instructed the participants to produce AMR and SMR syllables as quickly, accurately, and regularly as possible.

(e) Reading passage

Paragraph reading is a task used to assist in the differential diagnosis of dysarthria and to assess its severity. It is considered easier for evaluators to analyze when phonetic characteristics or articulation errors occur because they are familiar with the context of the paragraph.[50] In this study, we used the standard paragraph titled “Autumn”[51] for acoustic analysis to evaluate the participants’ voices. The second sentence of the “Autumn” paragraph is known to serve as a substitute when participants are unable to read the entire paragraph due to visual or neurologic issues, and it can be effectively used for cepstral analysis.[52] In this study, we instructed participants to read the paragraph once at a comfortable pitch and loudness.

(f) Vowel space area (VSA)

VSA quantifies the dimensions of the oral cavity using the movements of articulatory organs, including tongue height and its front/back positioning during vowel production. Moreover, it is closely related to speech intelligibility.[53,54]

Patients with neurodegenerative diseases tend to exhibit a reduction in vowel space due to the vowel distortion caused by dysarthria. In addition, as the speech rate increases, the vowel space tends to decrease.[55,56] VSA is more reliable when calculated using three or more vowels.[57-59] Therefore, in this study, we instructed participants to produce five vowels, /a/, /e/, /i/, /o/, /u/, for 5 seconds each.

(C) Speech-related quality of life

Participants completed a standardized survey designed to evaluate their quality of life concerning speech.

(a) Speech handicap index-15 (SHI-15)

The SHI-15 is a self-assessment tool developed to evaluate speech difficulties in patients. Because acoustic and visual assessments alone have limitations in identifying related issues, it is important to measure the extent to which patients perceive their own speech disorders. The questionnaire consists of a total of 15 items, with 8 subitems related to speech function and 7 subitems related to psychosocial function.[60]

(b) Voice handicap index (VHI)

The VHI is a self-assessment tool aimed at evaluating voice-related impairments. It evaluates three domains: physical, functional, and emotional. Each domain consists of 10–30 items.[61]

(D) Swallowing functions

(a) Iowa oral performance instrument (IOPI)

The IOPI is an invasive tool effectively used to assess patients with dysphagia, and its utility has been well demonstrated. The device uses an air-filled bulb that provides a visual display of the generated pressure. This bulb allows for the objective measurement of the pressure exerted by the tongue against the palate, which is displayed on the device's screen.[62] In this study, we placed the bulb on the hard palate, and the participants were instructed to apply pressure with their tongue. We measured the tongue pressure three times.

(b) Gugging swallowing screen (GUSS)

GUSS is a diagnostic tool designed to detect patients who may be at risk of dysphagia and aspiration. Patients are assessed using various consistencies—semisolid, liquid, and solid—at different amounts to minimize the risk of aspiration during testing.[63] GUSS is also known for its high sensitivity in reflecting the findings of the VFSS examination.[64] In this study, the evaluation began by checking whether the patient could maintain an alert state for 15 minutes, whether spontaneous coughing was possible, and whether throat clearing could be performed. We then conducted the test using semisolid, liquid, and solid

consistencies. For the semisolid consistency, a thickener was used, and the researcher instructed the patient to swallow 3 to 5 teaspoons. For the liquid consistency, water was measured in 3-, 5-, 10-, and 20-mL amounts using a feeding syringe and served in a 6.5-oz paper cup. During the evaluation, if caregivers or the patient reported the regular use of a straw at home, the test was conducted using a straw. For the solid consistency, the assessment was performed using a saltine cracker (CROWN Confectionery Co., Ltd., Seoul, South Korea). After completing the swallowing task for all three consistencies, the patient was instructed to phonate /o/ to observe any perceptual voice changes. If we observed delayed swallowing, drooling, coughing, or changes in voice, the next consistency test was not conducted, and the assessment was immediately stopped.[63,64]

(c) Videofluoroscopic swallowing study (VFSS)

The VFSS is a commonly utilized tool to assess oropharyngeal swallowing function. This procedure enables the analysis of swallowing dynamics through the Penetration-Aspiration Scale (PAS) and the Videofluoroscopic Dysphagia Scale (VDS). The PAS is a highly reliable tool recognized for providing a comprehensive reflection of the patient's swallowing status.[65] The VDS is known for its sensitivity in detecting changes in the patient's swallowing condition.[66]

The PAS uses a scoring system that ranges from 1 to 8 to clinically assess penetration and aspiration in patients with dysphagia.[67] The VDS conversely evaluates 14 subcomponents of the oral and pharyngeal phases, assigning scores based on the importance of each component, with weighted scores according to clinical relevance.[68]

In this study, we analyzed VFSS images from individual patients, conducted at the Sinchon Severance Rehabilitation Hospital, to measure the PAS and VDS. Liquid of different consistencies—12% semithick was used, with each consistency administered in volume of 5 cc. For assessment, a contrast agent, barium, was mixed with the test liquid in a specified ratio.

(E) Swallowing-related quality of life

Participants completed standardized surveys aimed at assessing discomfort and quality of life related to swallowing.

(a) Swallowing-quality of life (SWAL-QOL)

The SWAL-QOL is an assessment tool that allows patients with dysphagia to self-report their swallowing symptoms, which provides a measure of the psychosocial aspects of their condition. The tool consists of 44 items divided into 10 subcategories.[69]

(b) Dysphagia handicap index (DHI)

The DHI is a screening tool used to assess subjectively the degree of handicap perceived by individuals with swallowing difficulties. It comprises 25 items that are categorized into three sections: physical, functional, and emotional.[70] In addition, the DHI is clinically easy for patients to complete and is useful for assessing swallowing problems arising from various medical conditions.[71]

(c) Brief inventory of swallowing ability-15^{+} (BISA-15^{+})

The BISA-15^{+} is a patient-reported tool intended to evaluate how individuals perceive their chewing and swallowing functions. This tool is clinically valuable, requires minimal training, and enables a quick evaluation of swallowing difficulties and the patient's awareness of these issues. The questionnaire consists of 20 items.[72]

B. Instruction

(A) Phonation resistance training exercises (PhoRTE)

PhoRTE is a therapeutic approach aimed at improving respiratory capacity, enhancing vocal fold closure, and increasing vocal intensity by strengthening the pharyngolaryngeal muscles and improving flexibility through an expanded range of motion. This technique focuses on improving voice quality and increasing volume. A certified practitioner who received formal training administered the therapy. The intervention consisted of four total sessions over a 4-week period, with one face-to-face session each week. In addition, participants were instructed to practice all therapy objectives at home six times per week, following the exercises completed during the in-person sessions.

To monitor the volume and pitch during the intervention, the Decibel X Sound Level Meter Application (version 9.8.1, SkyPaw Co., Ltd, Ho Chi Minh City, Vietnam), recommended by the official PhoRTE training organization, was suggested. However, we used Voice Tools (version 1.02.120, DevExtras Co., Ltd, London, United Kingdom) because it offered better visualization of the target volume and pitch. In cases in which errors occurred, we

used the Decibel X Sound Level Meter Application as a backup. Table 3 shows the detailed protocol for the intervention and home practice.

Table 3. Phonation resistance training exercises (PhoRTE)

PhoRTE[1] task	Reps.	Instructions
Phonatory-respiratory isotonic (PhoRTE-ISO)	10	Sustain the sound /a/ in a strong, ener- gized voice for as long as possible with- out vocal strain.
Eccentric-concentric cricothyroid contraction (PhoRTE-EC)	10	On /a/, perform a strong, controlled vocal glide through the per formable pitch range; then reverse the direction of the glide.
Phonatory-respiratory power endurance (PhoRTE-PE)	10	Produce self-generated functional phrases in a higher pitch and with a strong calling voice
Phonatory-respiratory power endurance (PhoRTE-PE)	10	Produce self-generated functional phrases in a lower pitch and with a strong voice of authority
Phonatory-respiratory muscular endurance (PhoRTE-ME)	30 s-2 min	Converse in a strong, energized voice like in a noisy restaurant

Abbreviations: PhoRTE, Phonation Resistance Training Exercises

(B) Home practice

Home practice was scheduled to be conducted six times a week, with participants informed in advance that each session would take approximately 30 minutes to complete. Participants were instructed to install an app available from the app store to enable them to visually monitor their target volume and pitch during practice. During the first session, they were guided through the download and usage of the app. The same app used for the intervention, Voice Tools, was recommended for home use, with the Decibel X Sound Level Meter Application as a backup in case of any issues. In addition, we provided written guidelines on the practice method and activity logs. When necessary, a demo file containing a recording of the researcher's voice was also offered to assist the participants.

C. Data analysis

(A) Home practice completion rate

After completing the home practice each week, the participants were asked to submit their activity logs to the researcher at the next therapy session. The researcher then reviewed the activity logs and used the Excel program to calculate the adherence rate for each activity over the week.

(B) Speech task

We analyzed the collected voice recordings acoustically using Praat (version 6.4.07).

(a) Maximum phonation time (MPT)

We analyzed the extended phonation of the vowel /a/ using Praat, with the start and end points designated to measure the MPT. After three repetitions, the best performance was recorded to two decimal places. For further analysis, the stable portion of the /a/ phonation, excluding 0.25 seconds from the beginning and end, was trimmed to 3 seconds. This duration is considered sufficient for the reliable analysis of most voice assessment parameters.[73] To monitor the vocal condition of patients with PD, acoustic evaluation is considered important and reliable, as it effectively reflects disease progression and can serve as a reference for future treatment.[74,75]

We analyzed the parameters obtainable via Praat, including jitter (local), shimmer (local), noise-to-harmonics ratio (NHR), cepstral peak prominence smoothed (CPPs), low/high spectral ratio (L/H ratio), and the number of voice breaks. We specifically used the voice breaks parameter to assess interruptions and irregularities in the speech of patients with PD.[76] For participants who were unable to sustain phonation for 3 seconds, the stable portion was analyzed after excluding only 0.25 seconds, and the results were presented to two decimal places.

(b) Pitch glides

We analyzed the highest and lowest measured pitches using Praat by selecting the relevant phonation segments to measure the maximum and minimum pitches. The maximum phonational frequency range (MPFR) was calculated by subtracting the minimum pitch from the maximum pitch.

(c) Speech intensity

The intensity of the loud /a/ phonation for 5 seconds, as well as the "Autumn" paragraph reading, was measured in decibels using Praat. We selected the phonation and speech segments and calculated the intensity values and recorded them to two decimal places.

(d) Diadochokinetic rate (DDK)

We segmented the measured DDK using Praat. The number of sound waves displayed on the spectrogram was then counted and analyzed.

(e) Reading passage

The second sentence of the “Autumn” paragraph, “무엇보다도 산에 오를 땐 더욱 더 그 빼어난 아름다움이 느껴진다” (“Above all, the exquisite beauty is felt even more when climbing the mountain”), was used to analyze CPPs. The entire paragraph was used for the pitch measurement.

(f) Vowel space area (VSA)

We set formants according to gender and vowel type, and the five vowels /a, e, i, o, u/ were analyzed using Praat. The first formant (F1) and the second formant (F2) were extracted, with the maximum formant values set to 5,000 Hz for males and 5,500 Hz for females. Within the maximum formant range, we applied the following specific settings: for males, /a/ was set to 4,300 Hz, /e, i/ to 4,700 Hz, and /o, u/ to 4,200 Hz. For females,

/a/ was set to 5,300 Hz, /e, i/ to 5,400 Hz, and /o, u/ to 4,400 Hz.[77] The stable vowel segment was selected by excluding 0.25 seconds from the beginning and end, leaving a 0.5-second segment for analysis. The formants were then analyzed based on the gender and vowel settings.[73] We calculated the VSA and displayed the result to three decimal places using the following formula[78]:

$$VSA_5 = 0.5 \times [F1_{/e/}(F2_{/i/}-F2_{/a/}) + F1_{/i/}(F2_{/u/}-F2_{/e/}) + F1_{/u/}(F2_{/o/}-F2_{/i/}) + F1_{/o/}(F2_{/a/}-F2_{/u/}) + F1_{/a/}(F2_{/e/}-F2_{/o/})]$$

(C) Speech-related quality of life

(a) Speech handicap index-15 (SHI-15)

The SHI-15 consists of 15 questions addressing functional and psychosocial aspects, with responses provided on a 5-point scale (0 = *never*, 4 = *always*). The overall score ranges from 0 to 60, with higher scores indicating a greater handicap resulting from speech challenges.[60]

(b) Voice handicap index (VHI)

The VHI consists of 30 questions covering physical, functional, and emotional areas, with responses scored on a 5-point scale (0 = *never* to 4 = *always*). The total score ranges

from 0 to 120, with higher scores indicating a more severe impairment related to voice problems.[61]

(D) Swallowing functions

(a) Tongue pressure

We obtained measurements using the IOPI, with three trials conducted for each bolus based on the results showing high consistency across the measurements. Maximum tongue pressure refers to the pressure generated when the tongue is voluntarily pressed upward, and we used the highest peak value among the trials to determine the tongue pressure.[79]

(b) Gugging swallowing screen (GUSS)

We used GUSS to observe swallowing delays, coughing, drooling, and voice changes after administering three different consistencies of food. Each item, such as involuntary coughing, drooling, and voice changes, was scored as 1 point if no problem was observed and as 0 points if a problem was present. For items assessing the swallowing status, 2 points were given for normal swallowing, 1 point for delayed swallowing, and 0 points if swallowing was not possible. Participants could progress to the next consistency only if they scored a maximum of 5 points for the current consistency. The total score varied from 0 to 20, with higher scores suggesting a reduced risk of aspiration.[63,64]

(c) Penetration-aspiration scale (PAS)

The PAS scale assesses the degree of penetration and aspiration of boluses, as well as the ability to expel boluses spontaneously through coughing. It is an 8-point scale, with a score of 1 indicating *no penetration or aspiration* and a score of 8 indicating *severe aspiration*. The total score, based on a 12% semisolid small (5cc) bolus, ranges from 6 to 48 points.[67]

(d) Videofluoroscopic dysphagia scale (VDS)

In this study, the VDS was analyzed exclusively for the 12% semisolid small (5cc) bolus. It scores seven oral phase items (items 1 to 7) and seven pharyngeal phase items (items 8 to 14), with a total score ranging from a minimum of 0 to a maximum of 100. Lower scores are considered closer to normal.[68]

(E) Swallowing-related quality of life

(a) Swallowing-quality of life (SWAL-QOL)

The SWAL-QOL includes the subdomains of food selection, burden, mental health, social functioning, fear, eating duration, eating desire, communication, and sleep, with 44 items in total to be completed. Each item uses a 5-point scale, with higher scores reflecting better swallowing-related quality of life and lower scores indicating poorer quality of life. The total score ranges between 0 and 220.[80]

(b) Dysphagia handicap index (DHI)

The DHI consists of 25 questions covering physical, functional, and emotional dimensions, with responses scored on a 3-point scale (0 = *never*, 2 = *occasionally*, 4 =

always). The total score varies from 0 to 100, with higher scores indicating a greater level of disability caused by more serious swallowing difficulties.[70]

(c) Brief inventory of swallowing ability-15^{+} (BISA-15^{+})

The BISA-15^{+} contains 20 items evaluating the swallowing function in terms of frequency and severity, using a 3-point scale for responses. Ratings range from 0 to 30, with greater ratings indicating more severe impairment related to difficulties in swallowing.[72]

D. Statistical analysis

We conducted statistical analysis using IBM SPSS Statistics (Statistical Package for the Social Sciences, version 28.0, IBM Corp., Armonk, NY, USA). The statistical analysis methods were as follows.

First, we applied the Mann–Whitney U test to compare the preassessment results between the treatment and control groups to identify any baseline differences between them.

Second, we performed a two-way mixed ANOVA to investigate the main effects of group and time on speech, voice, and swallowing functions, based on pre- and post-assessment results collected at 4-week intervals. In addition, we examined the interaction between group and time to see if the treatment effects differed between the groups over time.

Third, we used the Wilcoxon signed-rank test to evaluate improvements in speech, voice, and swallowing functions by comparing pre- and post-assessment results in the

treatment group. We used the same test to assess changes in these functions within the control group.

III. Results

A. Home practice completion rate

The treatment group was assigned home practice tasks during the 4-week intervention period. The average rate of home practice completion across patients was 73.92% (Table 4).

Table 4. Home practice completion rate

Group	No.	Sex	Adherence rate(%)
Therapy (n = 10)	T1	Male	100
	T2	Female	75.81
	T3	Female	55.39
	T4	Male	53.76
	T5	Male	44.21
	T6	Female	91.67
	T7	Female	100
	T8	Male	62.5
	T9	Female	100
	T10	Male	99.8
		Average	73.92

B. Speech functions

(A) Maximum phonation time (MPT)

To investigate the presence of any significant differences in MPT performance during the pre-assessment, we conducted a Mann–Whitney U test comparing the treatment group (n = 10) with the control group (n = 9). No statistically significant differences were detected between the two groups (Table 5).

We performed a two-way mixed ANOVA to assess differences in MPT performance across groups and time, along with the interaction effect of group and time. The analysis revealed statistically significant differences between the treatment and control groups ($p = .028$) and across time ($p = .008$). In addition, the interaction effect, which assessed changes over time within each group, was also statistically significant ($p = .001$) (Table 6).

To investigate the changes in MPT over 4 weeks based on treatment, we conducted a Wilcoxon signed-rank test. The treatment group demonstrated a significant improvement between pre- and post-evaluation ($p = .002$), with all participants except T1 showing an improvement in MPT after treatment. Among these, T2, T3, T5, T6, and T9 exhibited an improvement of more than 5 seconds in MPT (Table 6) (Figure 3a).

(B) Acoustic measures (/a/ sustained phonation)

To identify any differences in the performance of acoustic measures (measured during /a/ sustained phonation) at the pre assessment stage, we conducted a Mann–Whitney U test

comparing the treatment group (n = 10) with the control group (n = 9). We detected no statistically significant differences between the two groups across the analyzed measures, such as jitter, shimmer, NHR, number of voice breaks, CPPs, and L/H ratio (Table 5).

A two-way mixed ANOVA was performed to analyze differences in voice quality across groups and time, including the interaction effect of group and time. For jitter, were observed no significant main effects of group or time, which indicates that there were no statistically significant differences based on treatment or treatment duration. However, the interaction effect between group and time was statistically significant ($p = .007$).

Neither the main effects of time nor group showed statistical significance for shimmer; however, a significant interaction between time and group was detected ($p = .032$). Neither the main effects of time and group nor the interaction effect reached statistical significance for NHR and the number of voice breaks.

With regard to the CPPs measured during the vowel tasks, we found no significant differences over time, but there was a statistically significant group effect ($p = .042$). The interaction effect between the group and time was not significant.

Finally, for the L/H ratio, neither the main effects (time or group) nor the interaction effect were statistically significant (Table 6).

We conducted a Wilcoxon signed-rank test to investigate changes in voice quality over 4 weeks based on treatment. In the treatment group, jitter exhibited significant improvement between pre- and post-evaluations ($p = .002$), with all participants

demonstrating a reduction in jitter. Among them, T9 exhibited the greatest improvement. We also observed significant changes in the control group ($p = .037$); whereas C4 showed a decrease in jitter despite not receiving treatment, the remaining participants experienced an increase.

All participants in the treatment group showed a significant decrease in shimmer, indicating improved voice quality ($p = .042$), with T9 showing the most substantial improvement. Shimmer values significantly increased in the control group, reflecting a decline in voice quality ($p = .049$). Interestingly, only C5 in the control group demonstrated an improvement, with a reduction in shimmer despite not undergoing treatment, whereas all other participants showed an increase.

We observed no statistically significant changes for NHR, number of voice breaks, and L/H ratio in either the treatment or control groups. For NHR, T2, T4, T5, and T7 in the treatment group showed an increase in values even after treatment, whereas in the control group, C1, C3, C4, and C7 exhibited increases. Interestingly, other participants in the control group showed a decrease in NHR despite not receiving treatment.

With regard to the number of voice breaks, only T6 in the treatment group demonstrated an increase despite undergoing treatment. In the control group, C2, C5, and C6 showed a reduction in the number of voice breaks, even without treatment, whereas the other participants either maintained or decreased their values. T1, T2, T3, T4, and T7 in the treatment group experienced a decrease in L/H ratio, despite receiving treatment. In the

control group, we observed increases in C2, C3, C5, C7, and C8, even though they did not receive treatment.

CPPs showed a statistically significant improvement in the treatment group ($p = .042$), with all participants except T1 and T2 demonstrating improvement. We observed no statistically significant changes in the control group, however, C1, C4, C5, and C9 showed improvements despite not receiving treatment (Table 6) (Figure 3b and c).

(C) Pitch glides

We conducted a Mann–Whitney U test to examine whether differences in performance existed by comparing the treatment group ($n = 10$) with the control group ($n = 9$) during the pre-assessment, focusing on the minimum and maximum values, as well as the MPFR, derived from pitch glides. No statistically significant differences were detected between the groups (Table 5).

We conducted a two-way mixed ANOVA to examine differences in the minimum and maximum values of pitch glides, as well as MPFR, based on group, time, and their interaction. For the minimum and maximum values of pitch glides, neither the main effects (group or time) nor the interaction effect were statistically significant. However, a significant main effect of group was observed for MPFR ($p = .048$), whereas the main effect of time and the interaction effect were not significant (Table 6).

We conducted a Wilcoxon signed-rank test to investigate the changes in the minimum and maximum values of pitch glides and MPFR over 4 weeks based on treatment. The

results showed no statistically significant changes in the minimum or maximum values of pitch glides or MPFR in both the treatment and control groups. MPFR decreased in T1, T8, and T9 in the treatment group as compared with the pre-evaluation, despite receiving treatment. In contrast, in the control group, MPFR increased in C2, C6, C7, and C8, even though they did not receive treatment (Table 6) (Figure 3d).

(D) Speech intensity

To determine whether there were any significant differences in speech intensity during vowel and paragraph reading between the treatment group (n = 10) and the control group (n = 9) in the pre assessment, we conducted a Mann–Whitney U test. No statistically significant differences were detected between the two groups (Table 5).

We performed a two-way mixed ANOVA to evaluate differences in speech intensity during vowel production and paragraph reading across groups and time, including the interaction effect of group and time. For vowel production, we observed a significant main effect of time ($p = .008$), whereas the main effect of group was not statistically significant. However, the interaction effect between group and time was found to be statistically significant ($p < .001$). The analysis of the paragraph-reading task revealed no statistically significant main effects attributable to either time or group, nor were any interaction effects identified (Table 6).

To investigate changes in speech intensity over 4 weeks based on treatment, we performed a Wilcoxon signed-rank test. The treatment group showed a statistically significant improvement in vowel speech intensity ($p < .001$), with all participants demonstrating an increase in intensity. Among them, all participants except T3, T7, and T9 exhibited an increase of greater than 5 dB. No statistically significant changes were observed in the control group; however, C2 and C3 showed an increase in intensity despite not receiving treatment. For paragraph-reading speech intensity, we observed no statistically significant changes in either the treatment or control groups. In the treatment group, T2, T5, T6, T7, and T8 experienced a reduction in speech intensity despite receiving treatment. In the control group, despite not receiving treatment, C2, C5, C6, and C7 showed an increase in intensity (Table 6) (Figure 3e).

(E) Diadochokinetic rate (DDK)

To investigate the presence of any significant differences in DDK rates at the pre-assessment, a Mann–Whitney U test was conducted comparing the treatment group ($n = 10$) with the control group ($n = 9$). No statistically significant differences were detected between the two groups (Table 5).

A two-way mixed ANOVA was conducted to investigate the differences in DDK performance, specifically assessing AMR and SMR, in relation to group and time, as well as the interaction effects between these two variables. For both AMR and SMR, the main effect of time was not statistically significant in either the treatment or control groups. However, for the main effect of group, we observed a significant change in AMR for /tuh/

(p = .02), whereas no significant differences were found in SMR. The interaction effect did not reach statistical significance for either the AMR or the SMR (Table 6).

To investigate changes in DDK counts over four weeks based on treatment, we conducted a Wilcoxon signed-rank test. In AMR, we observed no statistically significant changes in /puh/ or /tuh/ syllables for the two groups. However, in the treatment group, we noted a significant improvement in /kuh/ syllable counts (p = .023). All participants in the treatment group, except T1, T5, and T8, showed an increase in /kuh/ syllable counts. In the control group, despite not receiving treatment, C1, C2, C6, and C8 also demonstrated an increase in /kuh/ syllable counts. For /puh/ syllables, in the treatment group, T2, T3, T6, and T9 exhibited an increase in syllable counts. In the control group, all participants, except C7 and C9, showed an increase in /puh/ syllable counts despite not receiving treatment. In the /tuh/ syllable, the treatment group showed an increase in syllable counts for participants T2, T6, T8, T9, and T10. Similarly, in the control group, participants C2, C4, C6, and C8 exhibited an increase in syllable counts despite not receiving treatment. For SMR, we observed no significant changes between pre- and post-evaluation in the two groups. However, within the treatment group, participants T2, T3, T5, T8, and T10 demonstrated an increase in syllable counts. Participants C6 and C8 in the control group showed an increase in syllable counts despite not receiving treatment (Table 6) (Figure 3e and f).

(F) Acoustic measures (reading passage)

We conducted a Mann–Whitney U test to determine whether any significant differences occurred in CPPs, L/H ratio, and pitch during the paragraph-reading task by comparing the treatment group (n = 10) with the control group (n = 9) at the pre-assessment stage. Neither CPPs nor pitch showed statistically significant differences between the groups (Table 5).

We performed a two-way mixed ANOVA to analyze differences in CPPs, L/H ratio, and pitch across groups and time, including the interaction effect of group and time. For CPPs, we observed a significant main effect of time ($p = .025$), while neither the main effect of group nor the interaction effect reached statistical significance. For the L/H ratio and pitch, we observed no significant effects for time, group, or their interaction (Table 6).

To further investigate the changes in CPPs, L/H ratio, and pitch during paragraph reading based on the treatment, we conducted a Wilcoxon signed-rank test. The results showed no statistically significant differences for CPPs, L/H ratio, or pitch in either the treatment or control groups. For CPPs, we observed a decrease in T1 and T9 within the treatment group despite receiving treatment, whereas C1, C2, and C3 in the control group showed an increase despite not receiving treatment. For the L/H ratio, T1, T2, T5, and T7 in the treatment group, despite receiving treatment, demonstrated a decrease in values, whereas C5, C6, and C8 in the control group showed an increase despite not receiving treatment (Table 6) (Figure 3c and g).

(G) Vowel space area (VSA)

We performed a Mann–Whitney U test to determine whether there were any significant differences in the VSA by comparing the treatment group (n = 10) with the control group (n = 9) at the pre-assessment stage. We found no statistically significant differences between the two groups (Table 5).

We performed a two-way mixed ANOVA to analyze differences in the VSA across groups and time, including the interaction effect of group and time. The results revealed no statistically significant main effects for time or group, nor any significant interaction effects (Table 6).

To further investigate changes in the VSA over 4 weeks based on treatment, we conducted a Wilcoxon signed-rank test. The treatment group showed a statistically significant increase in the VSA (p = .042), with all participants except T3, T5, and T8 demonstrating an increase. In contrast, no statistically significant changes were exhibited by the control group. Nevertheless, VSA values for C1, C3, C6, and C8 in the control group rose even without undergoing treatment (Table 6) (Figure 3g).

Table 5. Baseline comparison of speech and voice functions between treatment and control groups (continue)

Measure		Treatment (n=10)				Control (n=9)				*p*-value
		Pre[1]	Post	Median	IQR	Pre[1]	Post	Median	IQR	
MPT	/a/	9.60 ±6.55	15.17 ±8.40	6.70	5.98	6.5 ±3.64	5.78 ±2.84	5.73	3.80	0.400
Jitter	/a/	0.60 ±0.42	0.29 ±0.14	0.46	0.49	1.02 ±1.33	1.3 ±1.59	0.45	0.48	0.661
Shim-mer	/a/	6.11 ±3.77	3.87 ±2.06	4.72	4.37	7.2 ±5.45	9.34 ±5.93	4.44	5.13	0.842
NHR	/a/	0.08 ±0.08	0.07 ±0.08	0.04	0.13	0.11 ±0.11	0.08 ±0.1	0.08	0.15	0.661
Number of voice break	/a/	1.40 ±2.95	1.60 ±4.4	0.00	0.75	3.22 ±4.12	1.89 ±4.94	0.00	7.00	0.411
CPPs	vowel	14.71 ±2.80	16.33 ±1.06	15.36	3.29	12.73 ±4.48	12.22 ±3.71	15.06	8.02	0.604
	sentence	8.08 ±2.01	8.99 ±1.41	8.40	2.26	6.47 ±2.03	8.23 ±1.99	6.02	1.46	0.113

Table 5. Baseline comparison of speech and voice functions between treatment and control groups (continue)

Measure		Treatment (n=10)				Control (n=9)				*p*-value
		Pre[1]	Post	Median	IQR	Pre[1]	Post	Median	IQR	
CPPs	L/H ratio vowel	5.57 ±1.05	5.88 ±1.72	5.87	1.89	5.25 ±1.41	6.21 ±1.59	4.96	0.40	0.604
	L/H ratio sentence	5.64 ±0.96	6.10 ±0.93	5.67	1.50	6.74 ±1.18	6.22 ±1.55	6.68	1.78	0.065
Pitch glides	min	101.22 ±32.15	96.84 ±34.83	87.63	60.87	109.19 ±40.70	116.13 ±43.32	102.95	76.83	0.905
	max	294.54 ±88.40	305.62 ±80.67	275.56	133.13	246.55 ±42.79	241.62 ±73.04	228.23	70.43	0.211
MPFR	max-min	193.32 ±104.32	208.78 ±82.29	164.96	185.09	137.36 ±49.04	125.49 ±76.45	134.86	18.68	0.400
Speech intensity	vowel	77.58 ±6.40	84.33 ±4.72	78.03	8.19	78.64 ±8.33	77.02 ±8.89	82.48	12.5	0.549
	sentence	66.19 ±5.25	65.88 ±4.10	67.69	6.83	65.23 ±7.42	64.10 ±7.61	66.40	11.88	0.905

Table 5. Baseline comparison of speech and voice functions between treatment and control groups

Measure		Treatment (n=10)				Control (n=9)				*p*-value
		Pre[1]	Post	Median	IQR	Pre[1]	Post	Median	IQR	
AMR	$p^hʌ$	18.10 ±6.82	19.80 ±7.21	18.50	8.25	12.89 ±6.59	14.00 ±5.60	12.00	9.00	0.099
	$t^hʌ$	16.80 ±6.96	17.20 ±5.71	17.00	11.75	10.22 ±5.12	11.00 ±4.95	11.00	6.00	0.061
	$k^hʌ$	14.40 ±7.26	16.90 ±6.24	13.50	13.00	10.22 ±4.92	10.33 ±6.12	9.00	5.00	0.188
SMR	$p^hʌ$ $t^hʌ$ $k^hʌ$	6.40 ±2.46	7.00 ±2.87	7.00	2.75	4.78 ±2.44	4.44 ±2.51	4.00	4.00	0.174
Pitch	sentence	151.78 ±22.84	158.60 ±17.52	156.78	16.49	141.48 ±26.96	151.08 ±26.95	148.93	38.38	0.447
VSA	/a, e, i, o, u/	336225.85 ±144140.62	369919.13 ±157761.40	294709.65	167480.21	260053.58 ±130291.47	229993.31 ±68721.60	240406.09	61756.23	0.356

[1] Mean±SD

Abbreviations: IQR, interquartile range(IQR=Q3−Q1); MPT, maximum phonation time; NHR, noise to harmonic ratio; CPPs, cepstral peak prominence smoothed; MPFR, maximum phonational frequency range; AMR, alternating motion rate; SMR, sequential motion rate; VSA, vowel space area

Table 6. Changes in speech and voice function results across time and groups (continue)

Measure		Treatment (n=10)		Control (n=9)		Time		Group		Time*Group	
		Pre[1]	Post	Pre	Post	F	*p*-value	F	*p*-value	F	*p*-value
MPT	/a/	9.60 ±6.55	15.17 ±8.40**	6.50 ±3.64	5.78 ±2.84	8.991	0.008**	5.771	0.028*	15.141	0.001**
Jitter	/a/	0.60 ±0.42	0.29 ±0.14**	1.02 ±1.33	1.30 ±1.59*	0.013	0.910	2.382	0.141	9.287	0.007**
Shim-mer	/a/	6.11 ±3.77	3.87 ±2.06*	7.20 ±5.45	9.34 ±5.93*	0.003	0.959	3.199	0.092	5.424	0.032*
NHR	/a/	0.08 ±0.08	0.07 ±0.08	0.11 ±0.11	0.08 ±0.10	0.514	0.483	0.361	0.556	0.233	0.635
Number of voice break	/a/	1.40 ±2.95	1.60 ±4.40	3.22 ±4.12	1.89 ±4.94	0.398	0.536	0.396	0.538	0.729	0.405
CPPs	vowel	14.71 ±2.80	16.33 ±1.06*	12.73 ±4.48	12.22 ±3.71	1.099	0.309	4.856	0.042*	4.109	0.059
	sentence	8.08 ±2.01	8.99 ±1.41	6.47 ±2.03	7.45 ±1.92	6.088	0.025*	4.273	0.054	0.007	0.933

Table 6. Changes in speech and voice function results across time and groups (continue)

Measure		Treatment (n=10)		Control (n=9)		Time		Group		Time*Group	
		Pre[1]	Post	Pre	Post	F	*p*-value	F	*p*-value	F	*p*-value
CPPs	L/H ratio vowel	5.57 ±1.05	5.88 ±1.72	5.25 ±1.41	6.21 ±1.59	3.669	0.072	0.000	0.995	0.973	0.338
	L/H ratio sentence	5.64 ±0.96	6.10 ±0.93	6.74 ±1.18	6.22 ±1.55	0.011	0.919	1.718	0.207	3.548	0.077
Pitch glides	min	101.22 ±32.15	96.84 ±34.83	109.19 ±40.70	116.13 ±43.32	0.012	0.913	1.114	0.306	0.238	0.632
	max	294.54 ±88.40	305.62 ±80.67	246.55 ±42.79	241.62 ±73.04	0.047	0.830	3.276	0.088	0.322	0.578
MPFR	max-min	193.32 ±104.32	208.78 ±82.29	137.36 ±49.04	125.49 ±76.45	0.010	0.922	4.533	0.048*	0.571	0.460
Speech intensity	vowel	77.58 ±6.40	84.33 ±4.72***	78.64 ±8.33	77.02 ±8.89	9.079	0.008**	0.962	0.340	24.066	<0.001 ***
	sentence	66.19 ±5.25	65.88 ±4.10	65.23 ±7.42	64.10 ±7.61	0.848	0.370	0.251	0.623	0.270	0.610

Table 6. Changes in speech and voice function results across time and groups

Measure		Treatment (n=10)		Control (n=9)		Time		Group		Time*Group	
		Pre[1]	Post	Pre	Post	F	*p*-value	F	*p*-value	F	*p*-value
AMR	$p^hʌ$	18.10 ±6.82	19.80 ±7.21	12.89 ±6.59	14.00 ±5.6	2.172	0.159	3.652	0.073	0.095	0.761
	$t^hʌ$	16.80 ±6.96	17.20 ±5.71	10.22 ±5.12	11.00 ±4.95	0.414	0.529	6.575	0.020*	0.043	0.839
	$k^hʌ$	14.40 ±7.26	16.90 ±6.24*	10.22 ±4.92	10.33 ±6.12	2.167	0.159	3.899	0.065	1.814	0.196
SMR	$p^hʌ$ $t^hʌ$ $k^hʌ$	6.40 ±2.46	7.00 ±2.87	4.78 ±2.44	4.44 ±2.51	0.217	0.647	3.300	0.087	2.657	0.121
Pitch	sentence	151.78 ±22.84	158.60 ±17.52	141.48 ±26.96	151.08 ±26.95	2.501	0.132	0.869	0.364	0.072	0.792
VSA	/a, e, i, o, u/	336225.85 ±144140.62	369919.13 ±157761.40*	260053.58 ±130291.47	229993.31 ±68721.60	0.009	0.927	3.593	0.075	2.671	0.121

[1] Mean±SD

Abbreviations: MPT, maximum phonation time; NHR, noise to harmonic ratio; CPPs, cepstral peak prominence smoothed; MPFR, maximum phonational frequency range; AMR, alternating motion rate; SMR, sequential motion rate; VSA, vowel space area

*p<.05, **p<.01, ***p<.001

The markings in the mean and standard deviation indicate statistical significance in pre- and post-comparisons within groups (Wilcoxon signed-rank test).

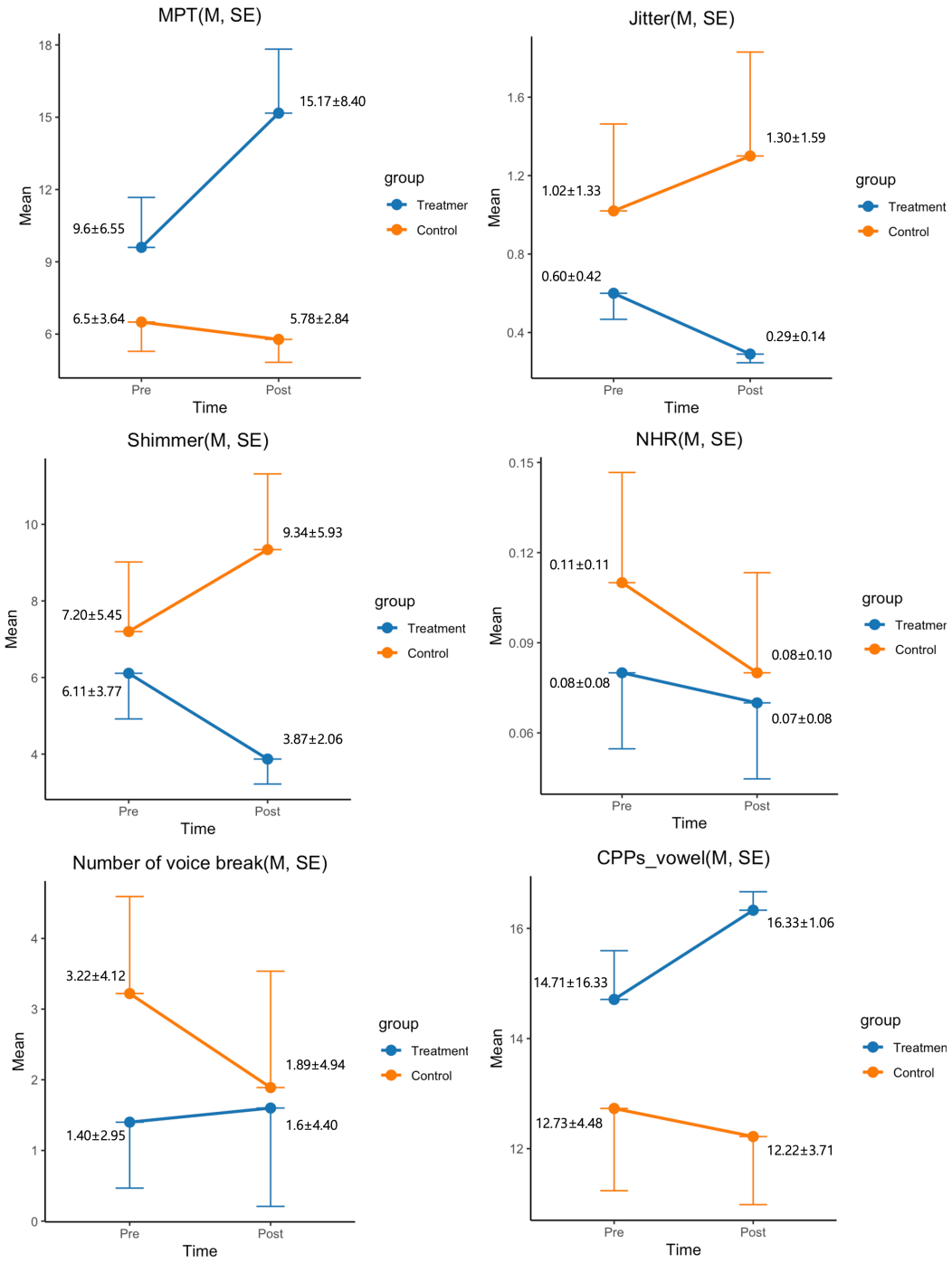

Figure 2a. Mean and standard error of speech and voice functions

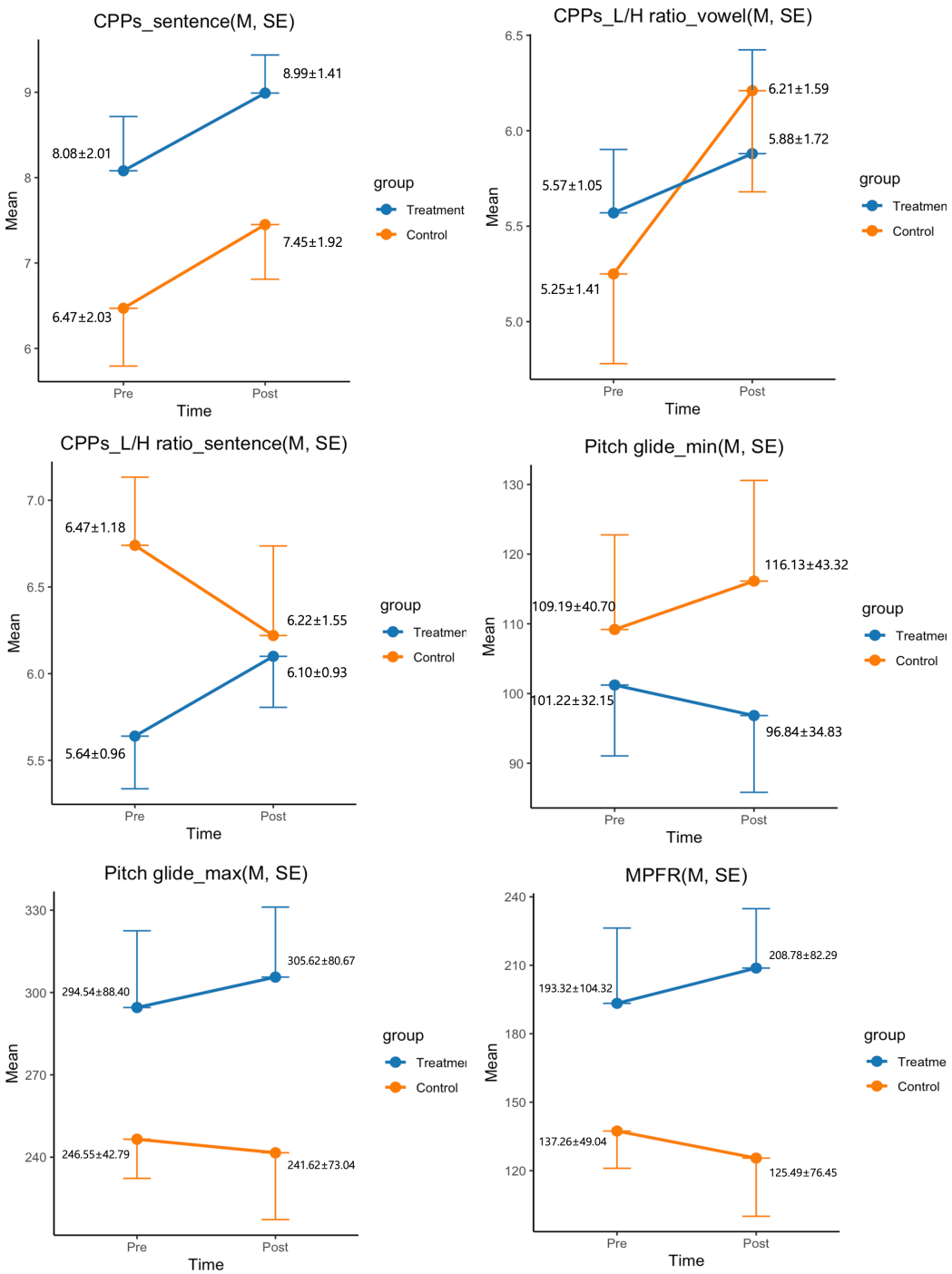

Figure 2b. Mean and standard error of speech and voice functions

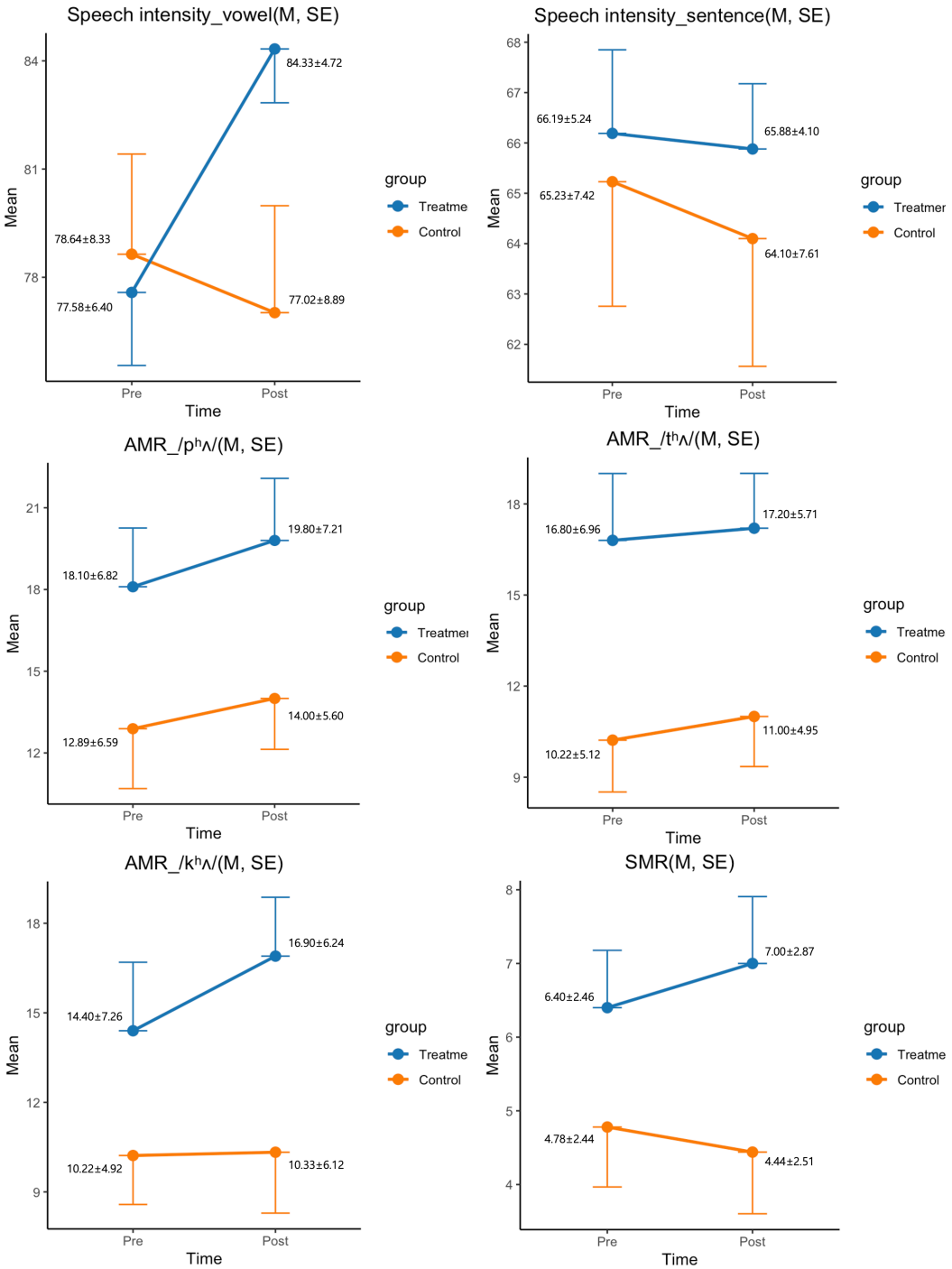

Figure 2c. Mean and standard error of speech and voice functions

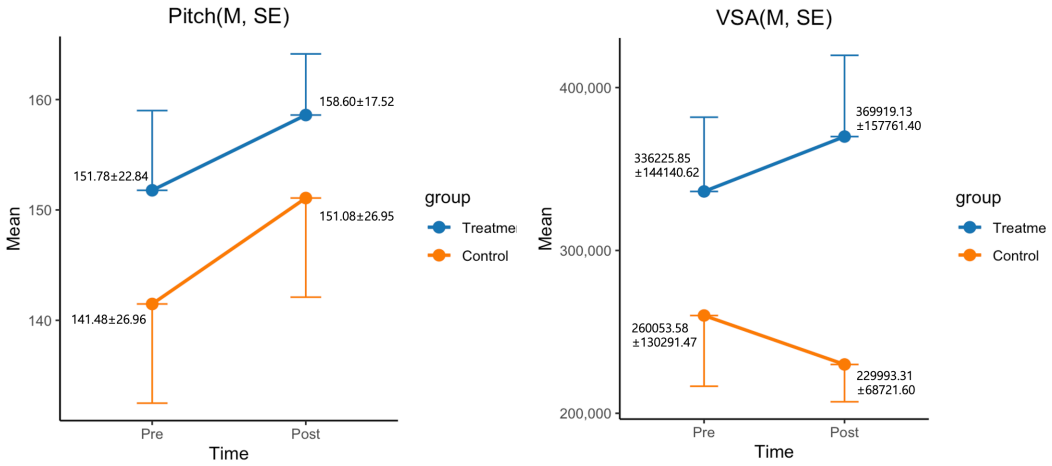

Figure 2d. Mean and standard error of speech and voice functions

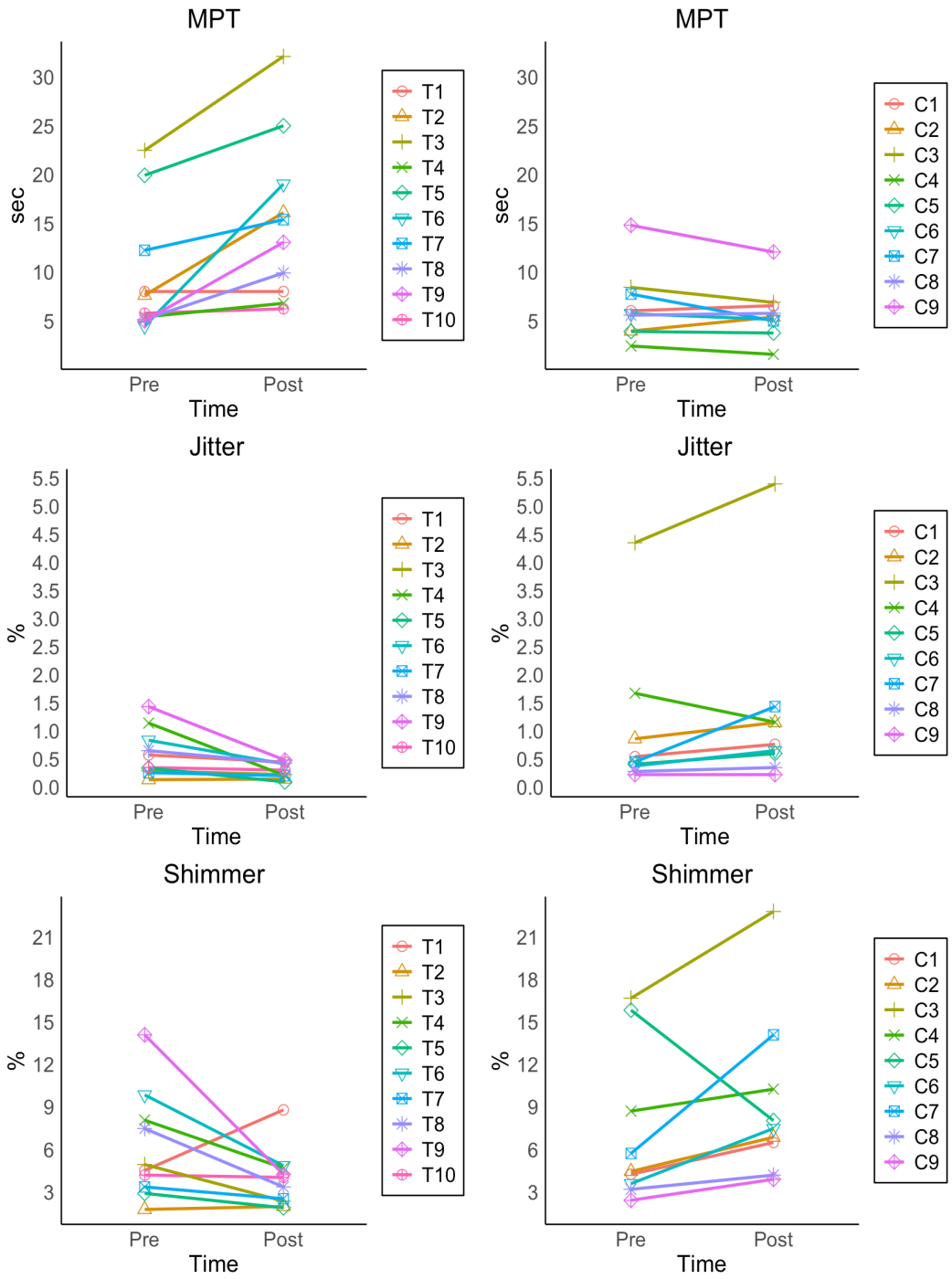

Figure 3a. Changes in speech and voice functions of all participants

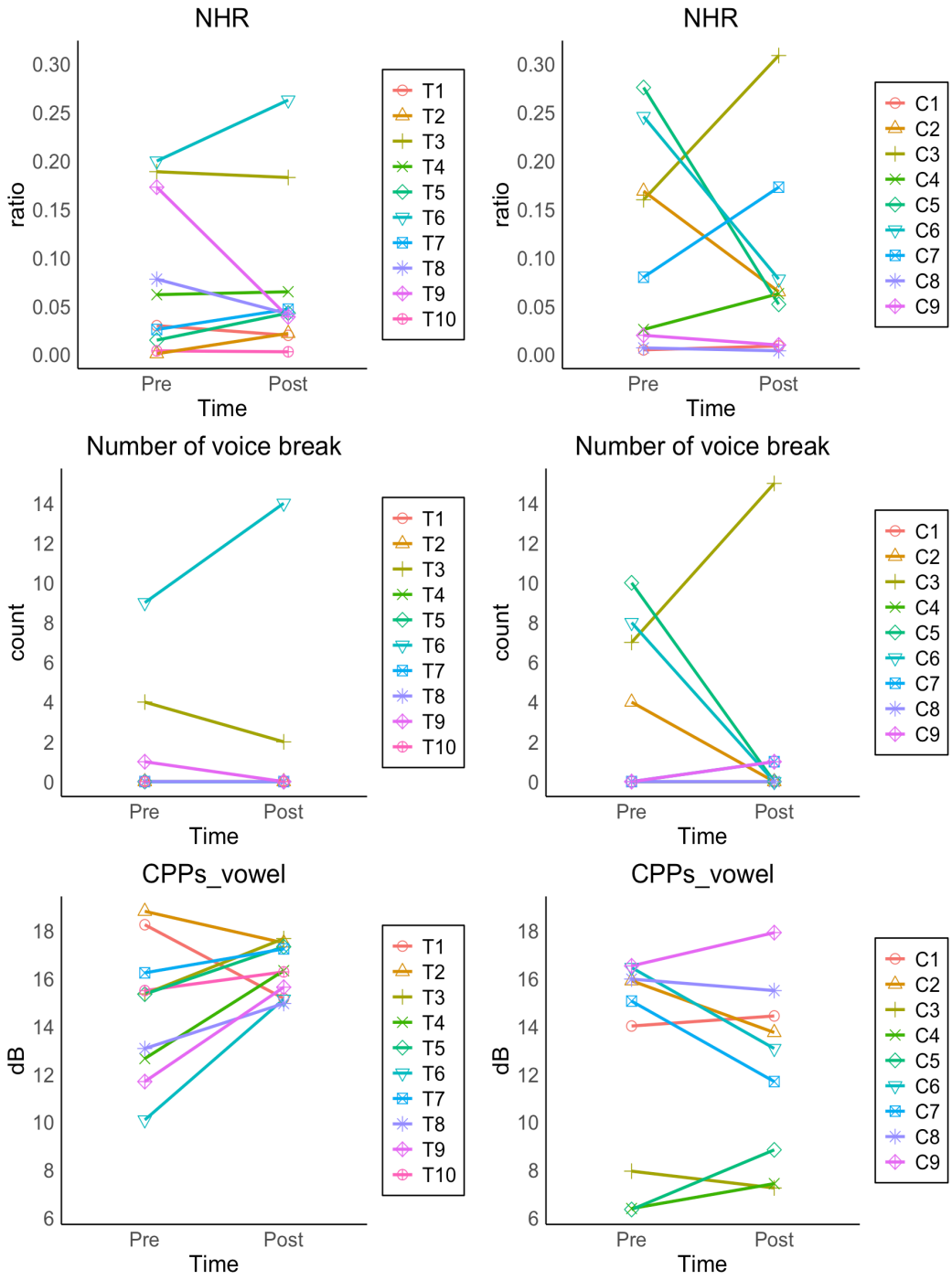

Figure 3b. Changes in speech and voice functions of all participants

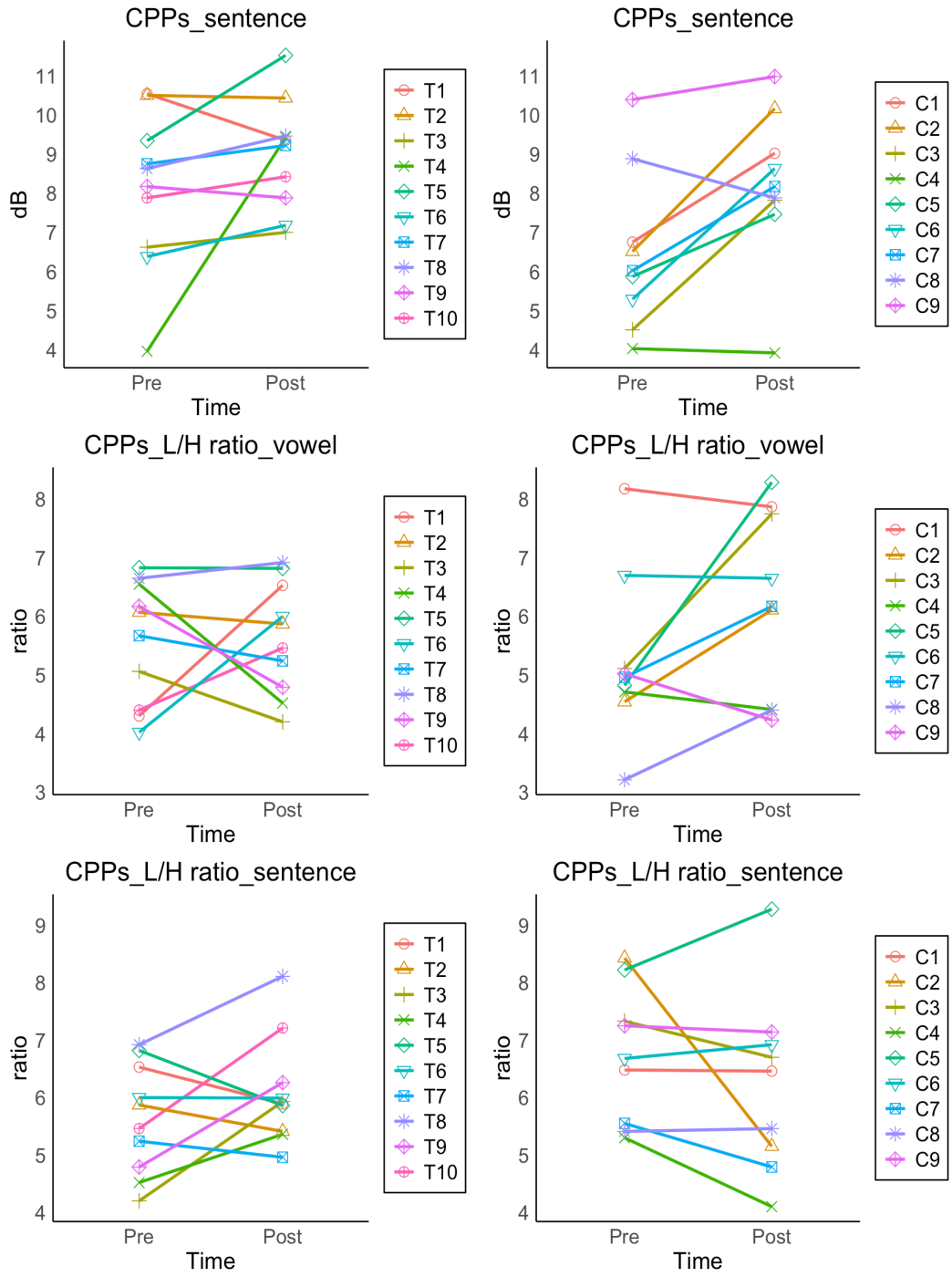

Figure 3c. Changes in speech and voice functions of all participants

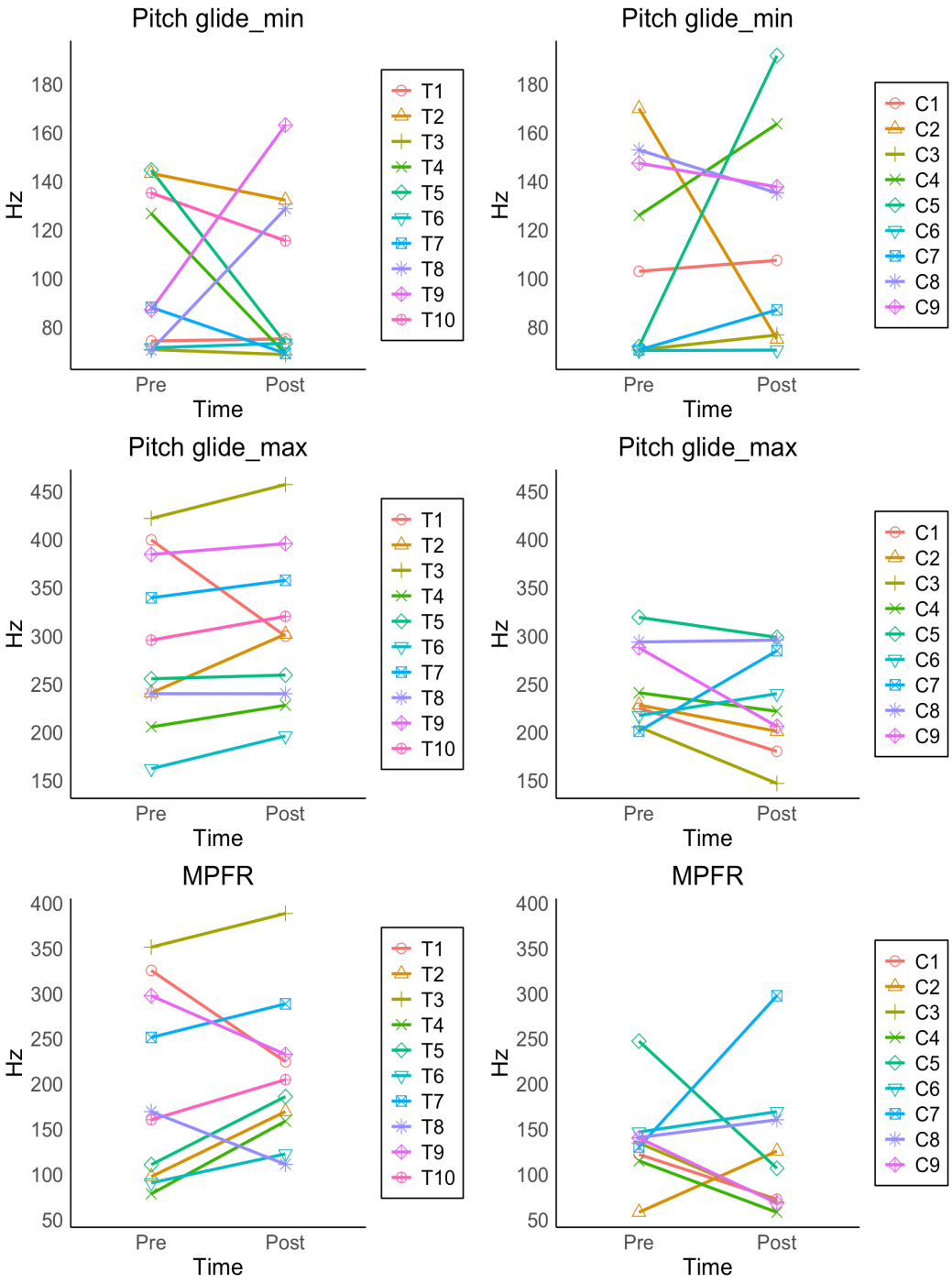

Figure 3d. Changes in speech and voice functions of all participants

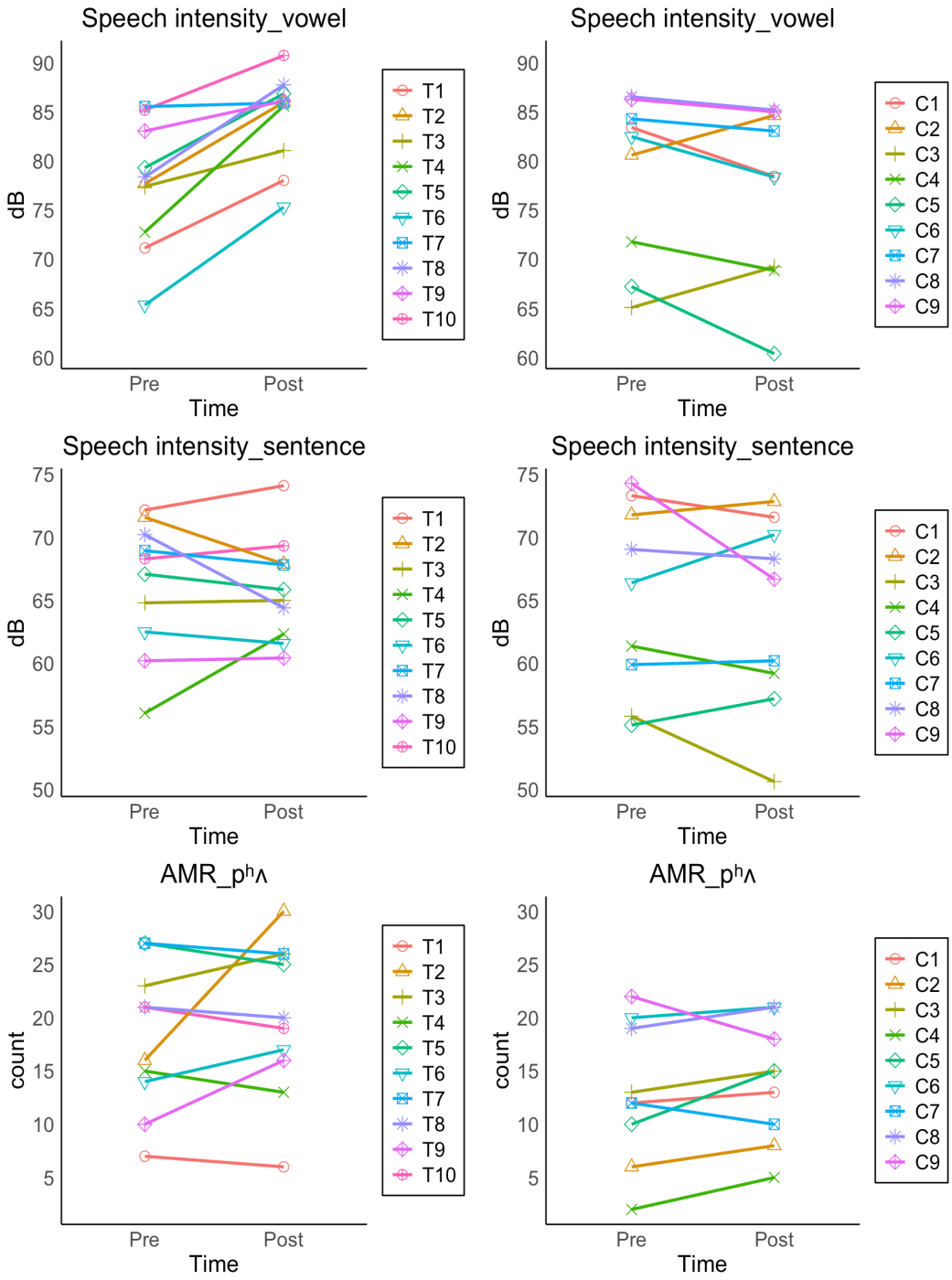

Figure 3e. Changes in speech and voice functions of all participants

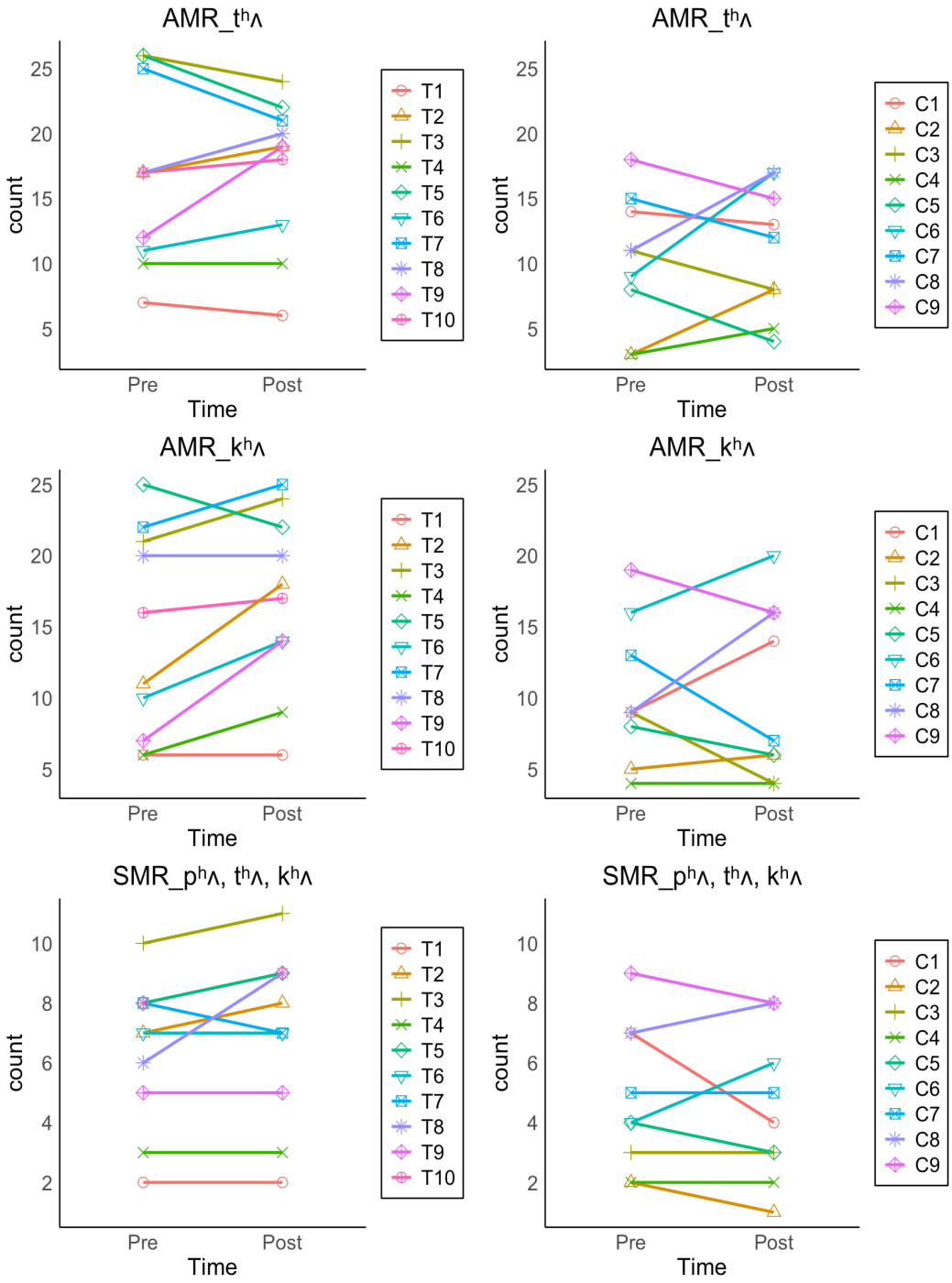

Figure 3f. Changes in speech and voice functions of all participants

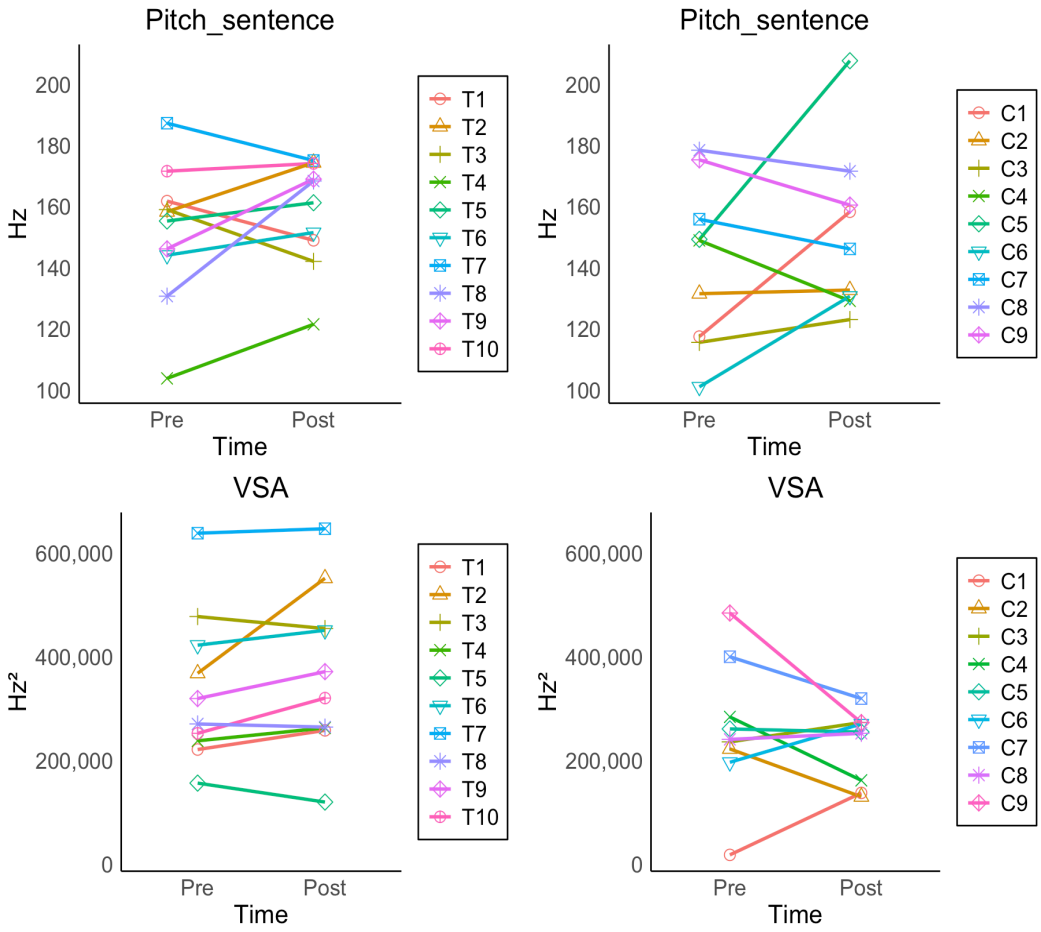

Figure 3g. Changes in speech and voice functions of all participants

C. Speech-related quality of life

(A) Speech handicap index-15 (SHI-15)

We conducted a Mann–Whitney U test to determine whether there were any significant differences in the total score and subcategories (speech and psychosocial) of the SHI-15 by comparing the treatment group (n = 10) with the control group (n = 9) during the pre-assessment. We found no statistically significant differences between the groups in any of the subcategories (Table 7).

We conducted a two-way mixed ANOVA to assess differences in voice-related handicap across groups and time, including the interaction effect of group and time. A While no statistically significant main effects were observed for time or group, the interaction effect demonstrated a notable change in the emotional subscale (p = .045) (Table 8).

To further investigate changes in speech-related handicap over 4 weeks based on treatment, we conducted a Wilcoxon signed-rank test. The results showed no statistically significant changes in the speech, psychosocial, or total scores in either the treatment or control groups. However, the total scores increased for T5 and T10 in the treatment group, indicating a worsening of the handicap even after treatment. C2 in the control group, despite not receiving treatment, demonstrated a decrease in handicap scores (Table 8) (Figure 5a).

(B) Voice handicap index (VHI)

To determine the presence of any significant differences in the total score and subcategories (physical, functional, emotional) of the VHI at the pre-assessment stage, we conducted a Mann–Whitney U test comparing the treatment group (n = 10) with the control group (n = 9). We observed no statistically significant differences between the two groups in any of the subcategories (Table 7).

A two-way mixed ANOVA was conducted to examine differences in voice-related handicap based on group and time, as well as the interaction between group and time. The main effects of time and group were not statistically significant; however, the interaction effect revealed a significant change in the emotional subscale ($p = .045$) (Table 8).

To further investigate changes in the voice-related handicap over 4 weeks based on treatment, we performed a Wilcoxon signed-rank test. The results demonstrated no statistically significant changes in any subscales for the two groups. In the treatment group, based on the total scores, T2, T6, and T7 exhibited an increase in handicap despite receiving treatment. In the control group, despite not receiving treatment, C2 and C5 demonstrated a decrease in handicap scores (Table 8) (Figure 5b and c).

Table 7. Baseline comparison of speech-related questionnaire results between treatment and control groups

Measure		Treatment (n=10)				Control (n=9)				*p*-value
		Pre[1]	Post	Median	IQR	Pre[1]	Post	Median	IQR	
SHI	speech	14.50±6.60	13.00±8.03	12.50	7.75	11.56±7.60	13.00±8.14	9.00	10.00	0.324
	psycho-social	10.00±7.80	8.50±7.00	6.50	11.25	9.00±6.93	9.89±8.22	9.00	7.00	0.920
	total	24.50±13.87	21.50±14.00	20.00	18.25	20.56±12.74	22.89±14.67	22.00	11.00	0.734
VHI	physical	13.00±7.83	11.90±7.30	12.00	7.50	8.00±4.64	9.89±5.64	7.00	5.00	0.161
	functional	13.40±9.83	11.70±7.48	10.00	13.50	9.22±5.94	10.44±7.13	12.00	8.00	0.562
	emotional	7.50±6.20	6.20±5.01	7.50	11.25	5.33±5.20	5.78±5.09	5.00	5.00	0.561
	total	31.50±18.58	29.80±17.54	33.00	27.50	22.56±12.17	26.11±14.98	19.00	16.00	0.278

[1]Mean±SD

Abbreviations: IQR, interquartile range(IQR=Q3−Q1); SHI, speech handicap index; VHI, voice handicap index

Table 8. Changes in speech-related questionnaire results across time and groups

Measure		Treatment (n=10)		Control (n=9)		Time		Group		Time*Group	
		Pre[1]	Post	Pre	Post	F	*p*-value	F	*p*-value	F	*p*-value
SHI	speech	14.50 ±6.60	13.00 ±8.03	11.56 ±7.60	13.00 ±8.14	0.001	0.977	0.192	0.666	2.322	0.146
	psycho-social	10.00 ±7.80	8.50 ±7.00	9.00 ±6.93	9.89 ±8.22	0.065	0.802	0.004	0.953	0.996	0.332
	total	24.50 ±13.87	21.50 ±14.00	20.56 ±12.74	22.89 ±14.67	0.028	0.868	0.045	0.835	1.812	0.196
VHI	physical	13.00 ±7.83	11.90 ±7.30	8.00 ±4.64	9.89 ±5.64	0.237	0.633	1.464	0.243	3.397	0.083
	functional	13.40 ±9.83	11.70 ±7.48	9.22 ±5.94	10.44 ±7.13	0.077	0.784	0.624	0.440	2.893	0.107
	emotional	7.50 ±6.20	6.20 ±5.01	5.33 ±5.20	5.78 ±5.09	1.127	0.303	0.278	0.605	4.683	0.045*
	total	31.50 ±18.58	29.80 ±17.54	22.56 ±12.17	26.11 ±14.98	0.433	0.519	0.753	0.398	3.474	0.080

[1]Mean±SD

Abbreviations: SHI, speech handicap index; VHI, voice handicap index

*p<.05

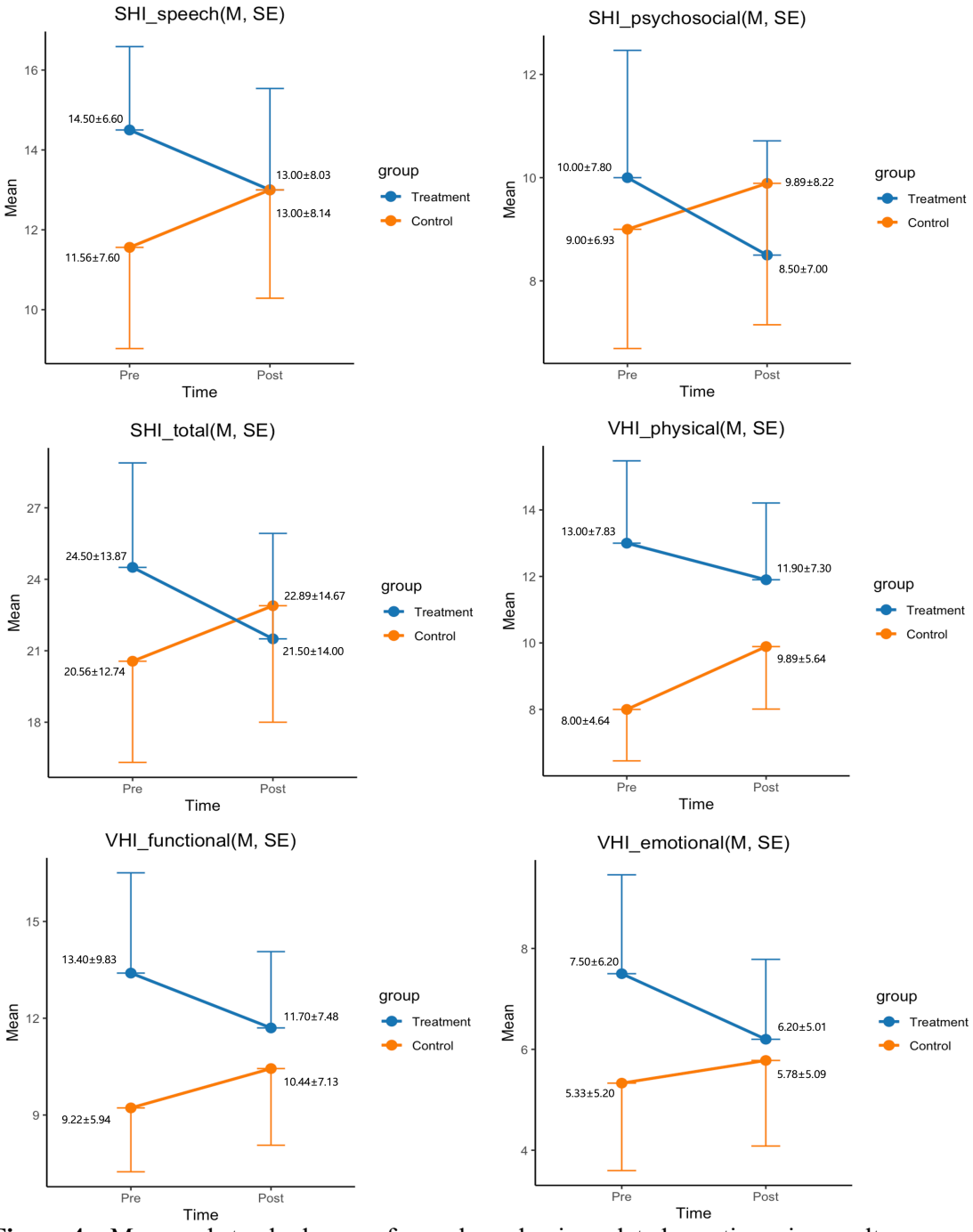

Figure 4a. Mean and standard error of speech- and voice-related questionnaire results

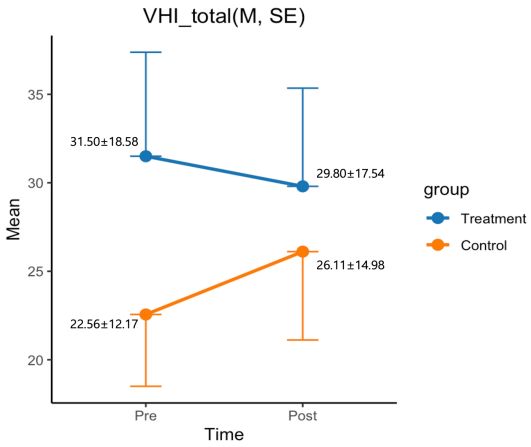

Figure 4b. Mean and standard error of speech- and voice-related questionnaire results

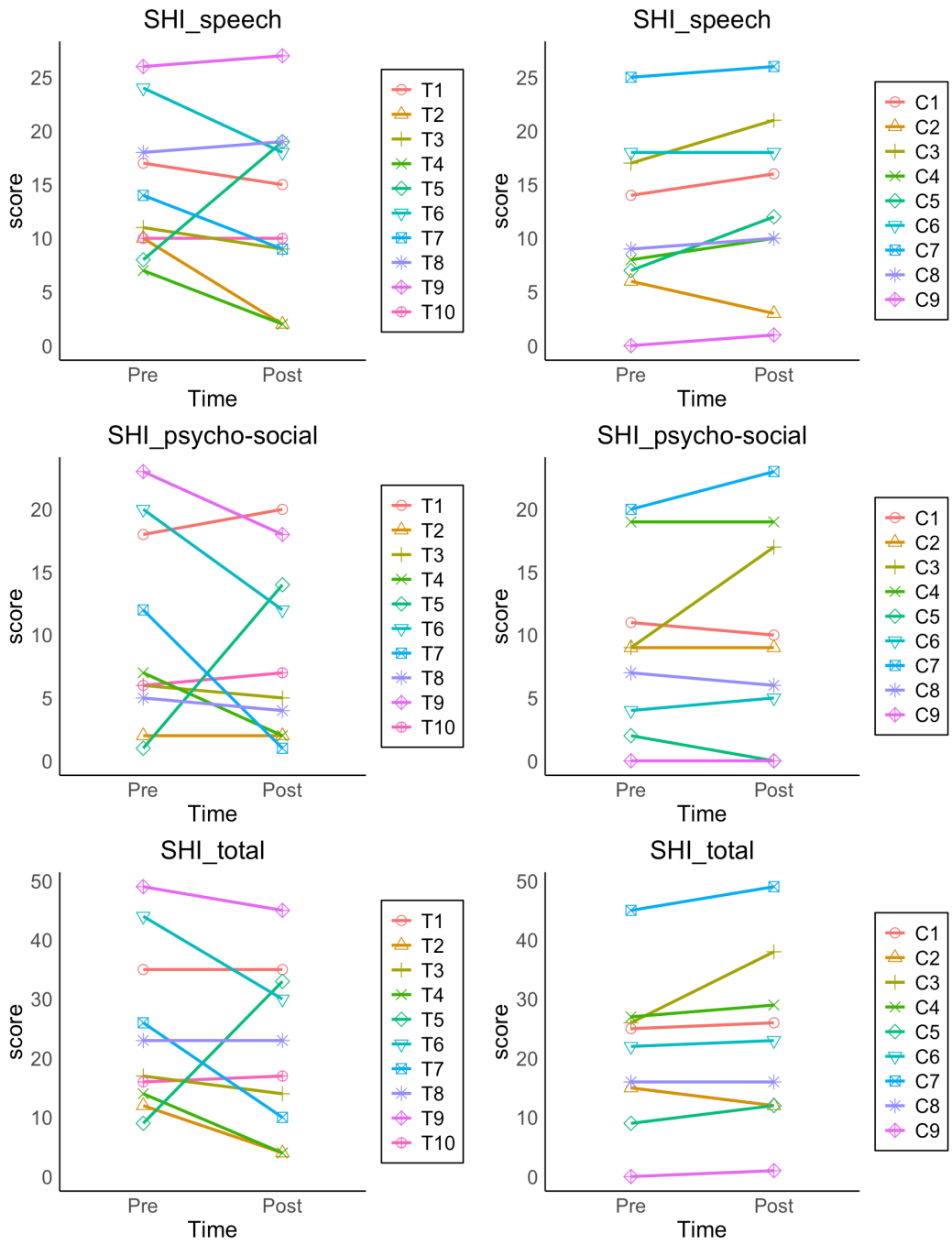

Figure 5a. Changes in speech- and voice-related questionnaire results for all participants

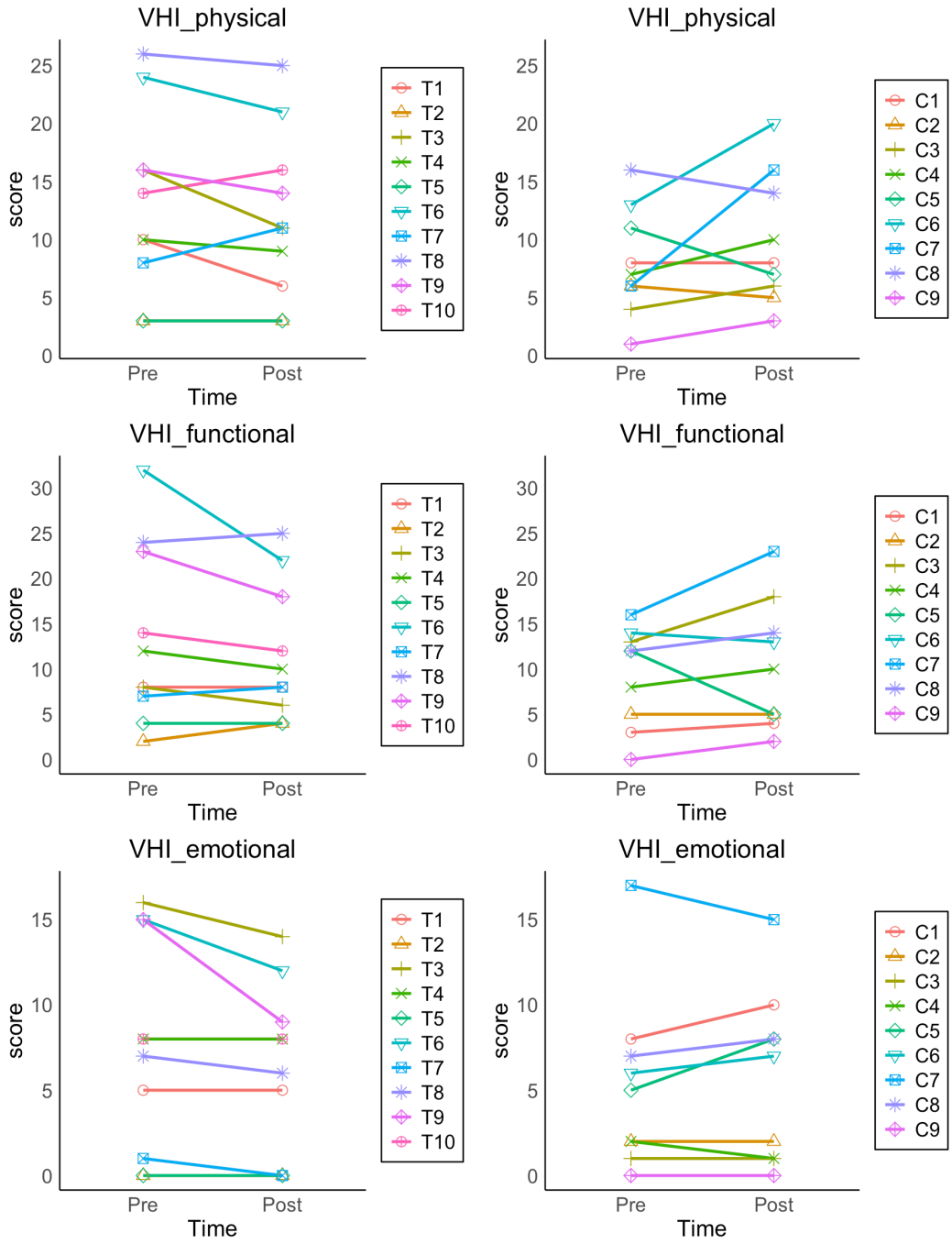

Figure 5b. Changes in speech- and voice-related questionnaire results for all participants

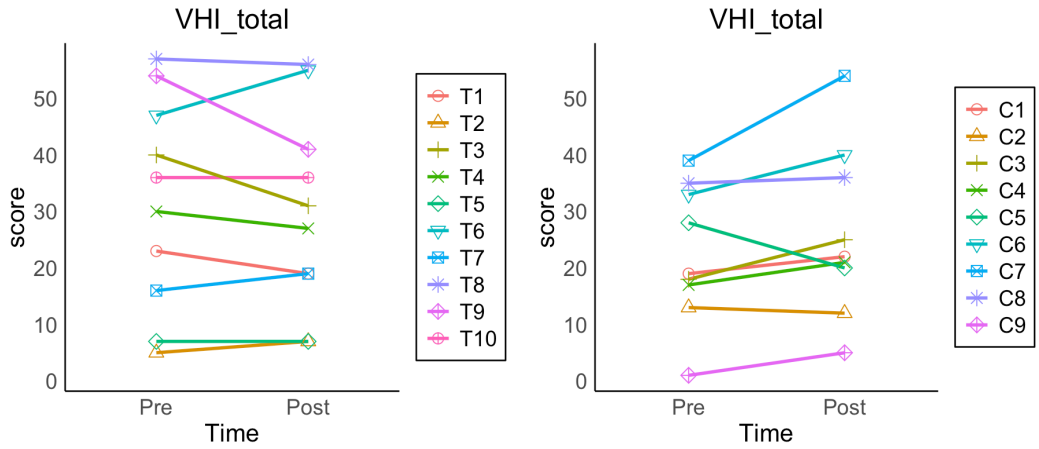

Figure 5c. Changes in speech- and voice-related questionnaire results for all participants

D. Swallowing functions

(A) Tongue pressure

To determine whether there were any significant differences in tongue pressure at the pre-assessment stage, we conducted a Mann–Whitney U test comparing the treatment group (n = 10) with the control group (n = 9). We found no statistically significant differences between the groups (Table 9).

We conducted a two-way mixed ANOVA to analyze differences in tongue pressure across groups and time, including the interaction effect of group and time. The analysis revealed no statistically significant main effect of time. However, we did observe a significant main effect of group (p = .039). The interaction effect between group and time was not statistically significant (Table 11).

To investigate changes in tongue pressure over 4 weeks based on treatment, we conducted a Wilcoxon signed-rank test. The results showed no statistically significant changes in the two groups. However, in the treatment group, all participants except T4, T5, and T8 demonstrated improvements in tongue pressure. In the control group, despite not receiving treatment, tongue pressure increased in participants C3, C6, C8, and C9 (Table 11) (Figure 7a).

(B) Gugging swallowing screen (GUSS)

To evaluate the existence of significant differences in the GUSS evaluation results at the preassessment stage, we conducted a Mann–Whitney U test comparing the treatment group (n = 10) with the control group (n = 9). We found no statistically significant differences between the groups (Table 9).

We conducted a two-way mixed ANOVA to analyze differences in GUSS scores across groups and time, including the interaction effect of group and time. The analysis revealed a statistically significant main effect of time ($p = .021$), while the group main effect did not reach statistical significance. Nevertheless, an interaction effect between group and time was identified as significant ($p < .001$) (Table 11).

We conducted a Wilcoxon signed-rank test to further investigate changes in swallowing function based on GUSS scores over 4 weeks. The treatment group exhibited a statistically significant improvement ($p = .008$), whereas no significant changes were observed in the control group. In the treatment group, all participants except T2, T3, and T6 showed increases in GUSS scores. In the control group, C1, C3, C4, C5, and C9 maintained their scores, whereas the remaining participants experienced a decline in swallowing function (Table 11) (Figure 7a).

(C) Penetration-aspiration scale (PAS)

The test was conducted based on PAS results analyzed from VFSS images, involving 5 participants (50%) from the treatment group (n = 10) and 3 participants (33.3%) from the control group (n = 9). We performed a Mann–Whitney U test to determine whether there

were differences between the groups at the pre-evaluation stage. The results showed no statistically significant differences between the two groups (Table 10).

We conducted a two-way mixed ANOVA to analyze differences in PAS scores across groups and time, including the interaction effect of group and time. There were no significant main effects for time or group, nor was there a significant interaction effect (Table 12).

To investigate changes in penetration and aspiration over 4 weeks based on treatment, we conducted a Wilcoxon signed-rank test. The results showed no statistically significant changes in the two groups (Table 12) (Figure 7a).

(D) Videofluoroscopic dysphagia scale (VDS)

The test was conducted based on VDS results analyzed from VFSS images using the 12% semisolid small (5cc) bolus, involving five participants (50%) from the treatment group (n = 10) and three participants (33.3%) from the control group (n = 9). To determine whether there were differences between the groups at the pre-evaluation stage, we performed a Mann–Whitney U test. The results showed no statistically significant differences between the treatment and control groups. (Table 10).

A two-way mixed ANOVA was conducted to examine differences in 12% semisolid small bolus scores across swallowing phases (oral, pharyngeal, total) based on group, time, and their interaction. In the oral phase, neither the group nor time showed significant main

effects, but a significant interaction effect was detected (p = .04). In the pharyngeal phase, none of the main effects (group or time) nor the interaction effect were significant. For the total score encompassing the oral and pharyngeal phases, neither group nor time showed significant main effects; however, a significant interaction effect was noted (p = .04) (Table 12).

We conducted a Wilcoxon signed-rank test to investigate differences in the 12% semisolid small bolus across swallowing phases over 4 weeks based on treatment. The results showed no statistically significant changes in boluses for the oral or pharyngeal phases, nor for the total score, in either group.

In the oral phase for the 12% semisolid small bolus, only T7 in the treatment group showed improvement, while the other participants maintained their scores. In the control group, only C9 maintained their score, while the other participants experienced a decline in function.

In the pharyngeal phase for the 12% semisolid small bolus, T1 in the treatment group showed improvement, while the other participants maintained their scores. In the control group, only C9 showed a decline, while the other participants demonstrated improvement.

For the total score, T1 and T7 in the treatment group showed improvement, while the other participants maintained their scores. In the control group, all participants exhibited increased scores, indicating a decline in function. (Table 12) (Figure 7b).

Table 9. Baseline comparison of swallowing functions between treatment and control group

Measure		Treatment (n=10)				Control (n=9)				*p*-value
		Pre[1]	Post	Median	IQR	Pre	Post	Median	IQR	
TPL	hard palate	23.00 ±10.70	25.50 ±12.34	24.50	15.00	14.44 ±8.14	14.00 ±.8.10	15.00	4.75	0.061
GUSS		14.90 ±2.18	17.90 ±1.66	14.00	0.00	14.00 ±4.15	13.22 ±4.02	14.00	1.00	0.926

[1]Mean±SD

Abbreviations: IQR, interquartile range(IQR=Q3−Q1); TPL, tongue pressure level; GUSS, gugging swallowing screen

Table 10. Baseline comparison of swallowing functions (VFSS) between treatment and control group

Measure		Treatment (n=5)				Control (n=3)				*p*-value
		Pre[1]	Post	Median	IQR	Pre	Post	Median	IQR	
PAS		1.00 ±0.00	1.00 ±0.00	1.00	0.00	1.00 ±0.00	2.50 ±3.00	1.00	0.00	1.000
VDS	Oral phase	4.20 ±3.27	3.60 ±3.78	3.00	4.00	2.00 ±1.73	6.33 ±2.89	3.00	1.50	0.518
	Pharyngeal phase	12.80 ±5.81	11.50 ±5.18	15.50	8.50	11.83 ±4.91	10.50 ±5.20	9.00	4.25	1.000
	Total (Oral + pharyngeal)	17.00 ±8.20	15.10 ±8.86	20.50	13.50	13.83 ±5.97	16.83 ±4.51	12.00	5.75	0.786

PAS and VDS were administered to only a subset of patients (treatment group n = 5(50%), control group n = 3(33.3%)).

[1]Mean±SD

Abbreviations: IQR, interquartile range(IQR=Q3−Q1); PAS, penetration-aspiration scale; VDS, videofluroscopic dysphagia scale

Table 11. Changes in swallowing function results across time and groups

Measure		Treatment (n=10)		Control (n=9)		Time		Group		Time*Group	
		Pre[1]	Post	Pre	Post	F	*p*-value	F	*p*-value	F	*p*-value
TPL	hard palate	23.00 ±10.70	25.50 ±12.34	14.44 ±8.14	14.00 ±.8.10	0.850	0.370	5.019	0.039*	1.859	0.191
GUSS		14.90 ±2.18	17.90 ±1.66**	14.00 ±4.15	13.22 ±4.02	6.460	0.021*	4.113	0.059	18.670	<0.001 **

[1] Mean±SD
Abbreviations: TPL, tongue pressure level; GUSS, gugging swallowing screen
*p<.05, **p<.001
The markings in the mean and standard deviation indicate statistical significance in pre- and post-comparisons within groups (Wilcoxon signed-rank test).

Table 12. Changes in swallowing function (VFSS) results across time and groups

Measure		Treatment (n=5)		Control (n=3)		Time		Group		Time*Group	
		Pre[1]	Post	Pre	Post	F	*p*-value	F	*p*-value	F	*p*-value
PAS		1.00 ±0.00	1.00 ±0.00	1.00 ±0.00	2.50 ±3.00	1.296	0.292	1.296	0.292	1.296	0.292
VDS	Oral phase	4.20 ±3.27	3.60 ±3.78	2.00 ±1.73	6.33 ±2.89	3.933	0.095	0.016	0.905	6.868	0.040*
	Pharyngeal phase	12.80 ±5.81	11.50 ±5.18	11.83 ±4.91	10.50 ±5.20	0.918	0.375	0.072	0.797	0.000	0.991
	Total (Oral + pharyngeal)	17.00 ±8.20	15.10 ±8.86	13.83 ±5.97	16.83 ±4.51	0.343	0.580	0.017	0.900	6.804	0.040*

[1] Mean±SD
PAS and VDS were administered to only a subset of patients (treatment group n = 5(50%), control group n = 3(33.3%)
Abbreviations: PAS, penetration-aspiration scale; VDS, videofluroscopic dysphagia scale
*p<.05

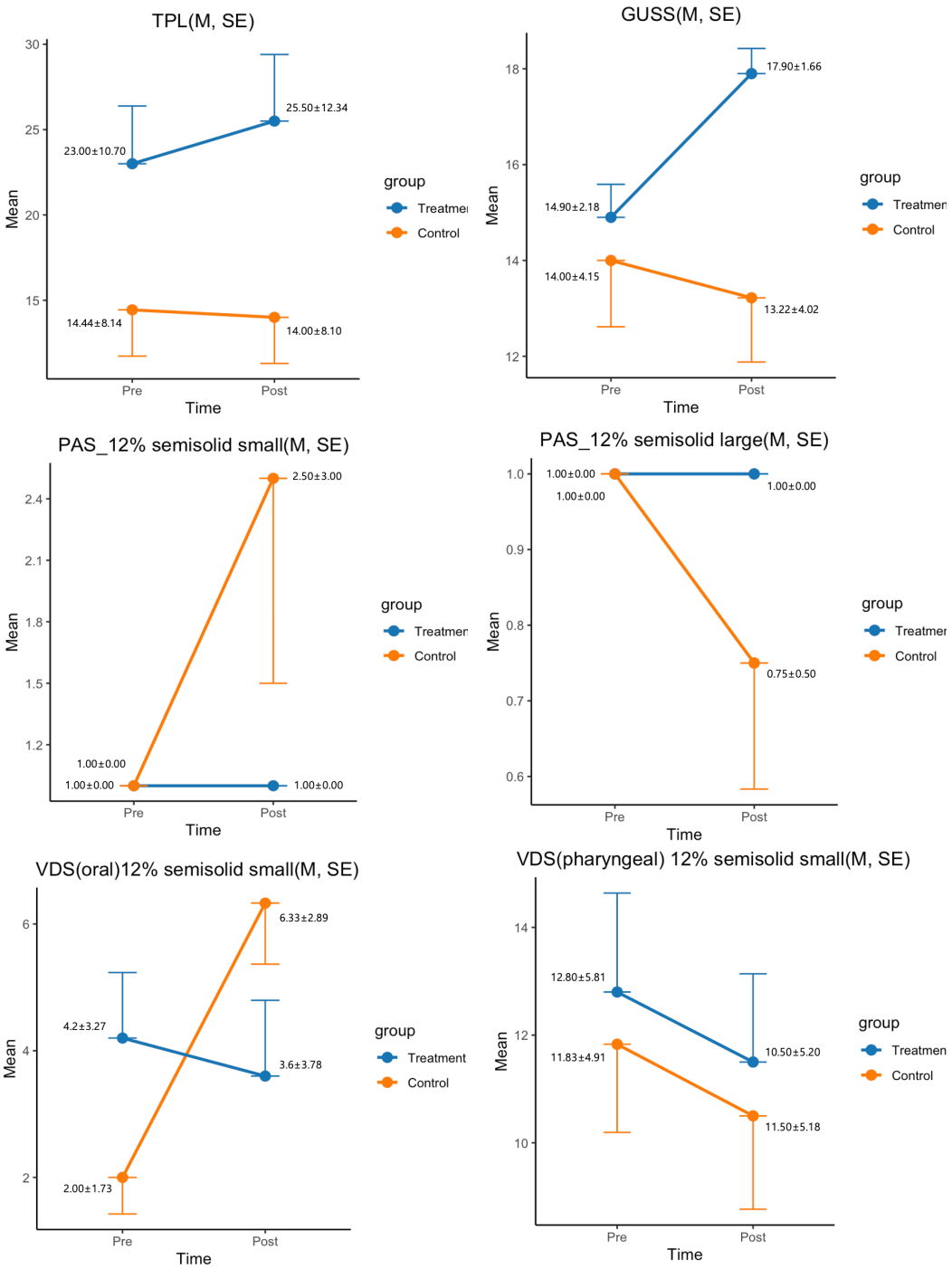

Figure 6a. Mean and standard error of swallowing functions

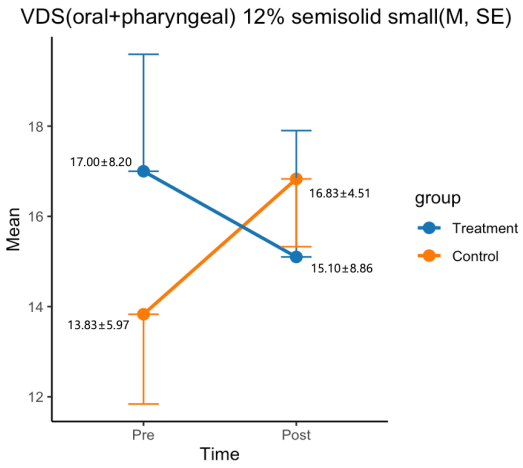

Figure 6b. Mean and standard error of swallowing functions

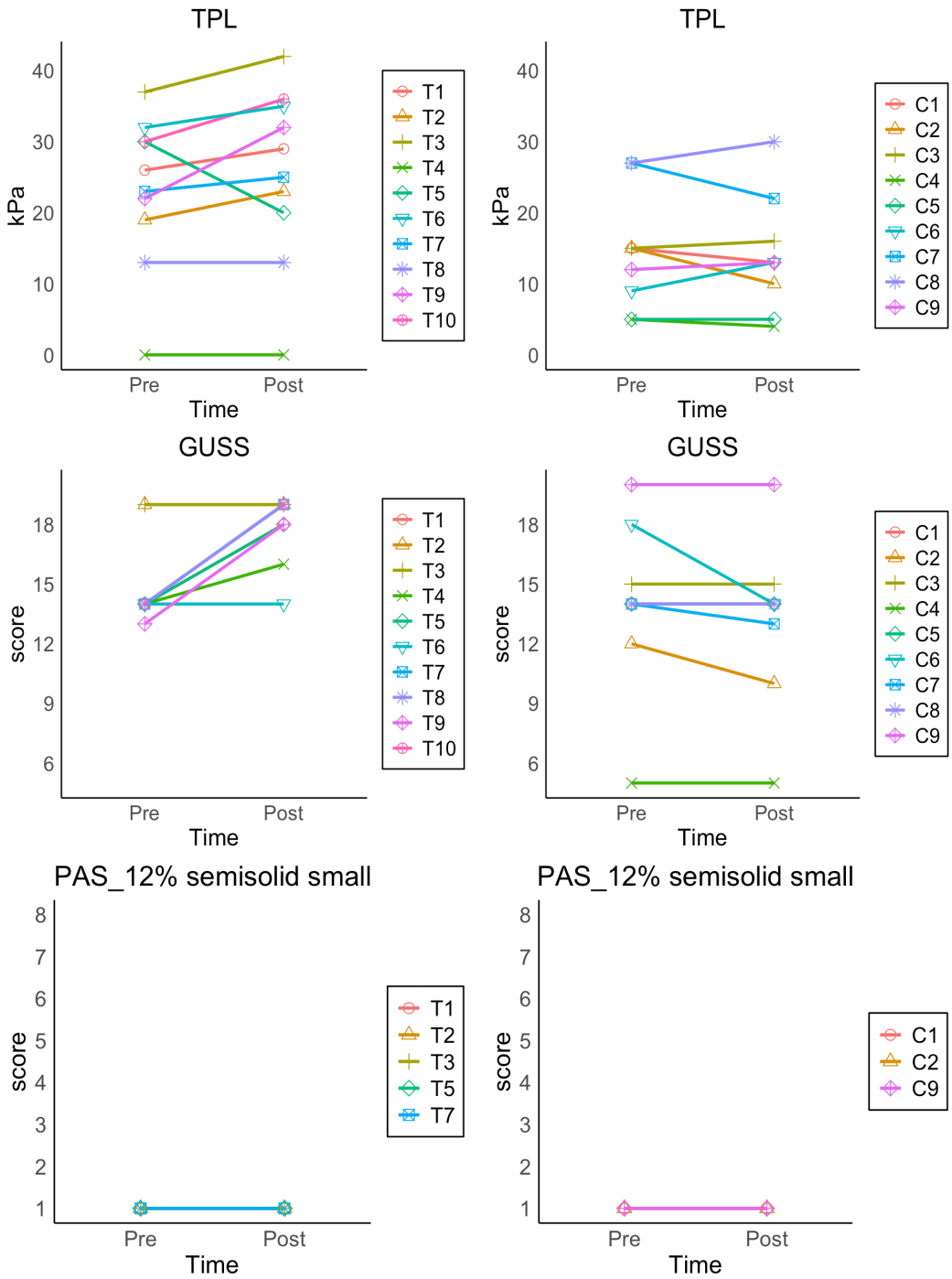

Figure 7a. Changes in swallowing functions for all participants

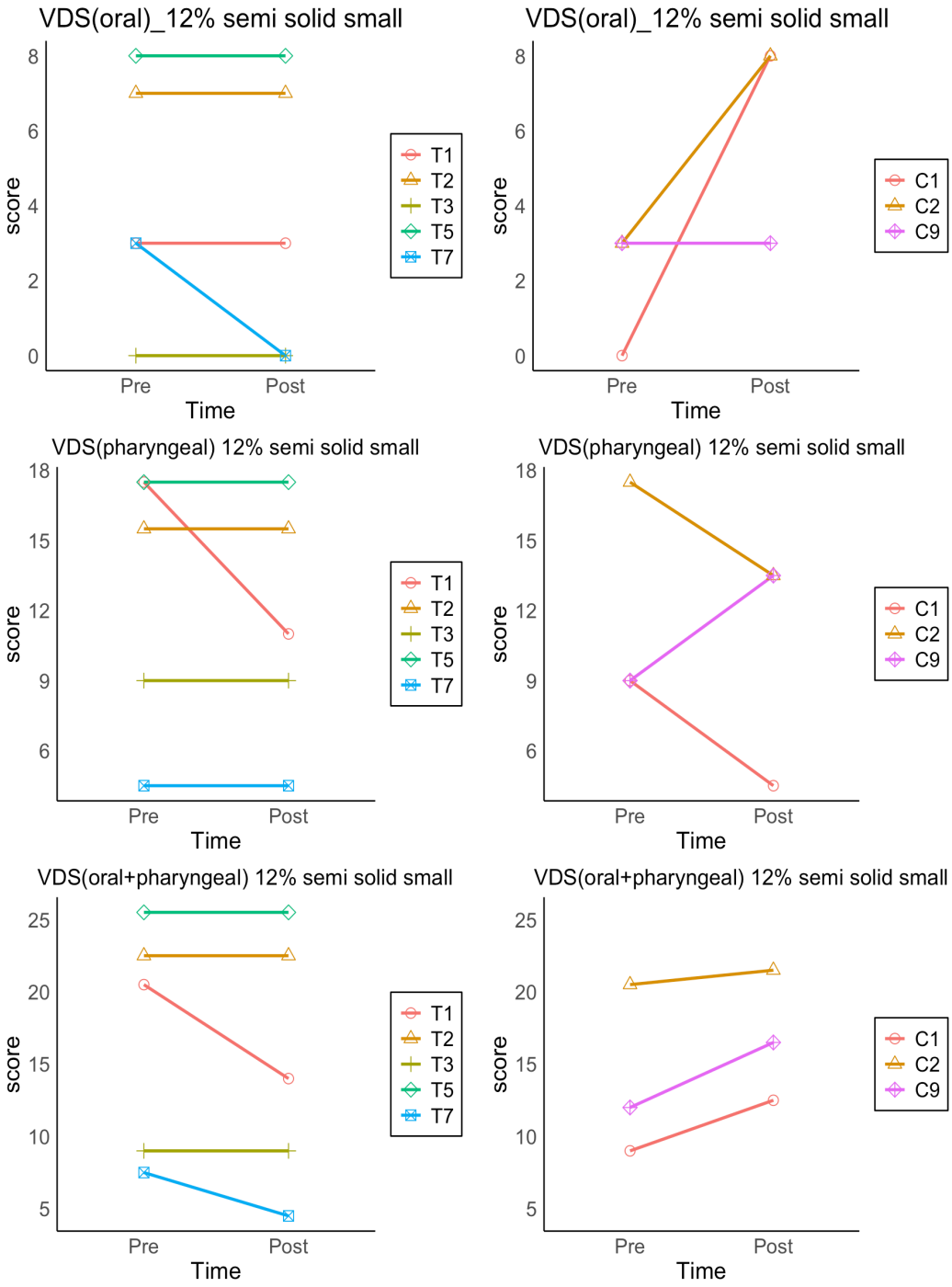

Figure 7b. Changes in swallowing functions for all participants

E. Swallowing-related quality of life

(A) Dysphagia handicap index (DHI)

We conducted a Mann–Whitney U test to identify any significant differences in the DHI results between the treatment group (n = 10) and the control group (n = 9) at the pre-assessment stage. We found no statistically significant differences between the groups in the total scores or in the functional, physical, and emotional subdomains (Table 13).

We conducted a two-way mixed ANOVA to analyze differences in DHI scores across groups and time, including the interaction effect of group and time. The analysis revealed no statistically significant main effects of time or group, nor any significant interaction effects (Table 14).

We conducted a Wilcoxon signed-rank test to investigate changes in the swallowing-related handicap over 4 weeks based on treatment. The results showed no statistically significant changes in any subdomains for the two groups. The DHI total scores indicated that participants T2, T5, and T8 in the treatment group experienced an increase in handicap despite receiving treatment. In the control group, participants C1 and C5 demonstrated a decrease in handicap despite not receiving treatment (Table 14) (Figure 9a and b).

(B) Swallowing-quality of life (SWAL-QOL)

We conducted a Mann–Whitney U test to identify significant differences in the total score and subdomain scores of the SWAL-QOL at the pre-assessment stage, comparing the

treatment group (n = 10) with the control group (n = 9). We found no statistically significant differences between the groups across all subdomains (Table 13).

We conducted a two-way mixed ANOVA to analyze differences in swallowing-related quality of life across groups and time, including the interaction effect of group and time. The results of the analysis showed no statistically significant main effects of time or group across all subdomains. However, for the interaction effect, significant differences were observed in the subdomain related to fear (p = .024) and in the total score (p = .036), which indicated significant group differences over time (Table 14).

We conducted a Wilcoxon signed-rank test to investigate changes in the quality of life related to swallowing over 4 weeks based on treatment. In the treatment group, none of the subdomains exhibited statistically significant changes. However, in the control group, a significant decline in the overall quality of life was observed in the total score (p = .031). The total scores indicated that participants T3, T7, and T10 in the treatment group experienced a decline in quality of life even after treatment. In the control group, despite not receiving treatment, participant C3 demonstrated an improvement in the quality of life (Table 14) (Figure 9b and f).

(C) Brief inventory of swallowing ability-15^{+} (BISA-15^{+})

We conducted a Mann–Whitney U test to detect significant differences in the self-perception of chewing and swallowing functions at the pre-assessment stage, comparing

the treatment group (n = 10) with the control group (n = 9). No statistically significant differences were detected between the two groups (Table 13).

We conducted a two-way mixed ANOVA to analyze differences in the perception of chewing and swallowing functions across groups and time, including the interaction effect of group and time. Our analysis revealed no statistically significant main effects of time or group, nor any significant interaction effects (Table 14).

To investigate changes in the quality of life related to swallowing over 4 weeks based on treatment, we conducted a Wilcoxon signed-rank test. The results showed no statistically significant differences in either the treatment or control groups. Participants T2, T3, T6, and T7 in the treatment group continued to report difficulties with chewing and swallowing function even after treatment. In the control group, despite not receiving treatment, participants C5, C8, and C9 reported improvements in their chewing and swallowing function (Table 14) (Figure 9f).

Table 13. Baseline comparison of swallowing-related questionnaire results between treatment and control group (continue)

Measure		Treatment (n=10)				Control (n=9)				*p*-value
		Pre[1]	Post	Median	IQR	Pre	Post	Median	IQR	
DHI	Functional	5.10±5.74	4.20±3.94	2.00	10.00	6.22±8.74	7.89±8.87	2.00	6.00	0.887
	Physical	7.00±4.55	6.00±4.22	5.00	7.50	7.78±5.33	8.56±4.61	8.00	6.00	0.795
	Emotional	3.00±5.44	1.20±1.40	0.00	3.00	2.89±4.01	3.11±4.26	2.00	4.00	0.549
	Total	15.10±12.88	11.40±8.33	9.00	20.25	16.89±13.86	19.56±15.40	12.00	20.00	0.952
SWAL-QOL	Burden	9.40±0.84	9.70±0.48	10.00	1.00	8.89±1.83	8.67±1.73	10.00	2.00	0.894
	Eating duration	7.70±2.31	8.10±1.85	8.00	2.00	7.44±2.01	6.89±2.57	7.00	3.00	0.584
	Eating desire	11.80±1.87	12.50±2.55	11.50	3.00	11.00±2.40	10.00±2.29	11.00	3.00	0.512
	Symptom frequency	63.00±3.56	61.40±5.08	62.00	5.50	60.22±2.03	59.00±8.29	58.00	7.00	0.363

Table 13. Baseline comparison of swallowing-related questionnaire results between treatment and control group (continue)

Measure		Treatment (n=10)				Control (n=9)				*p*-value
		Pre[1]	Post	Median	IQR	Pre	Post	Median	IQR	
SWAL-QOL	Food selection	9.20±1.14	9.40±0.70	10.00	1.75	8.89±2.03	8.11±2.32	10.00	2.00	1.000
	Communi-cation	8.40±1.90	8.70±1.57	8.50	2.00	8.33±1.22	7.67±1.66	8.00	2.00	0.632
	Fear	18.50±2.07	18.80±2.04	19.50	2.50	18.44±1.74	17.44±2.19	19.00	3.00	0.931
	Mental health	23.60±1.96	23.70±1.70	25.00	2.75	23.44±2.35	23.33±2.06	25.00	4.00	1.000
	Social function	23.50±2.92	23.60±1.96	25.00	2.25	22.33±5.50	21.33±6.10	25.00	0.00	1.000
	Sleep	7.30±2.50	7.90±2.33	7.00	3.50	7.89±2.20	7.78±2.33	8.00	1.00	0.637
	Fatigue	9.20±3.12	9.20±3.19	8.50	3.50	8.89±2.26	8.67±3.64	9.00	1.00	1.000
	Total	191.20±11.56	192.90±13.65	190.50	9.50	184.78±21.68	178.89±26.88	185.00	17.00	0.618

Table 13. Baseline comparison of swallowing-related questionnaire results between treatment and control group

Measure		Treatment (n=10)				Control (n=9)				*p*-value
		Pre[1]	Post	Median	IQR	Pre	Post	Median	IQR	
BISA-15+	Total	7.80±5.07	7.70±7.01	6.50	8.00	10.11±7.39	11.00±7.89	8.00	7.00	0.458

[1]Mean±SD

Abbreviations: IQR, interquartile range(IQR=Q3−Q1); DHI, dysphagia handicap index; SWAL-QOL: swallowing-quality of life; BISA-15+, brief inventory of swallowing ability-15+

Table 14. Changes in swallowing-related questionnaires results across time and groups (continue)

Measure		Treatment (n=10)		Control (n=9)		Time		Group		Time*Group	
		Pre[1]	Post	Pre	Post	F	*p*-value	F	*p*-value	F	*p*-value
DHI	Functional	5.10 ±5.74	4.20 ±3.94	6.22 ±8.74	7.89 ±8.87	0.115	0.739	0.634	0.437	1.285	0.273
	Physical	7.00 ±4.55	6.00 ±4.22	7.78 ±5.33	8.56 ±4.61	0.025	0.876	0.673	0.423	1.615	0.221
	Emotional	3.00 ±5.44	1.20 ±1.40	2.89 ±4.01	3.11 ±4.26	0.867	0.365	0.295	0.594	1.425	0.249
	Total	15.10 ±12.88	11.40 ±8.33	16.89 ±13.86	19.56 ±15.40	0.078	0.783	0.796	0.385	2.962	0.103
SWAL-QOL	Burden	9.40 ±0.84	9.70 ±0.48	8.89 ±1.83	8.67 ±1.73	0.064	0.804	1.729	0.206	2.869	0.109
	Eating duration	7.70 ±2.31	8.10 ±1.85	7.44 ±2.01	6.89 ±2.57	0.086	0.773	0.567	0.462	3.250	0.089
	Eating desire	11.80 ±1.87	12.50 ±2.55	11.00 ±2.40	10.00 ±2.29	0.088	0.770	3.199	0.092	2.835	0.110

Table 14. Changes in swallowing-related questionnaires results across time and groups (continue)

Measure		Treatment (n=10)		Control (n=9)		Time		Group		Time*Group	
		Pre[1]	Post	Pre	Post	F	*p*-value	F	*p*-value	F	*p*-value
SWAL-QOL	Symptom frequency	63.00 ±3.56	61.40 ±5.08	60.22 ±2.03	59.00 ±8.29	2.124	0.163	0.920	0.351	0.038	0.848
	Food selection	9.20 ±1.14	9.40 ±0.70	8.89 ±2.03	8.11 ±2.32	1.403	0.252	1.254	0.278	4.019	0.061
	Communi-cation	8.40 ±1.90	8.70 ±1.57	8.33 ±1.22	7.67 ±1.66	0.337	0.569	0.672	0.424	2.344	0.144
	Fear	18.50 ±2.07	18.80 ±2.04	18.44 ±1.74	17.44 ±2.19	1.785	0.199	0.629	0.439	6.158	0.024*
	Mental health	23.60 ±1.96	23.70 ±1.70	23.44 ±2.35	23.33 ±2.06	0.000	0.989	0.096	0.760	0.072	0.792
	Social function	23.50 ±2.92	23.60 ±1.96	22.33 ±5.50	21.33 ±6.10	1.391	0.255	0.756	0.397	2.078	0.168
	Sleep	7.30 ±2.50	7.90 ±2.33	7.89 ±2.20	7.78 ±2.33	0.826	0.376	0.050	0.826	1.748	0.204

Table 14. Changes in swallowing-related questionnaires results across time and groups

Measure		Treatment (n=10)		Control (n=9)		Time		Group		Time*Group	
		Pre[1]	Post	Pre	Post	F	*p*-value	F	*p*-value	F	*p*-value
SWAL-QOL	Fatigue	9.20 ±3.12	9.20 ±3.19	8.89 ±2.26	8.67 ±3.64	0.034	0.856	0.107	0.747	0.034	0.856
	Total	191.20 ±11.56	192.90 ±13.65	184.78 ±21.68	178.89 ±26.88*	1.575	0.226	1.404	0.252	5.170	0.036*
BISA-15^{+}	Total	7.80 ±5.07	7.70 ±7.01	10.11 ±7.39	11.00 ±7.89	0.165	0.690	0.870	0.364	0.259	0.617

[1]Mean±SD
Abbreviations: DHI, dysphagia handicap index; SWAL-QOL: swallowing-quality of life; BISA-15^{+}, brief inventory of swallowing ability-15^{+}
*p<.05
The markings in the mean and standard deviation indicate statistical significance in pre- and post-comparisons within groups (Wilcoxon signed-rank test).

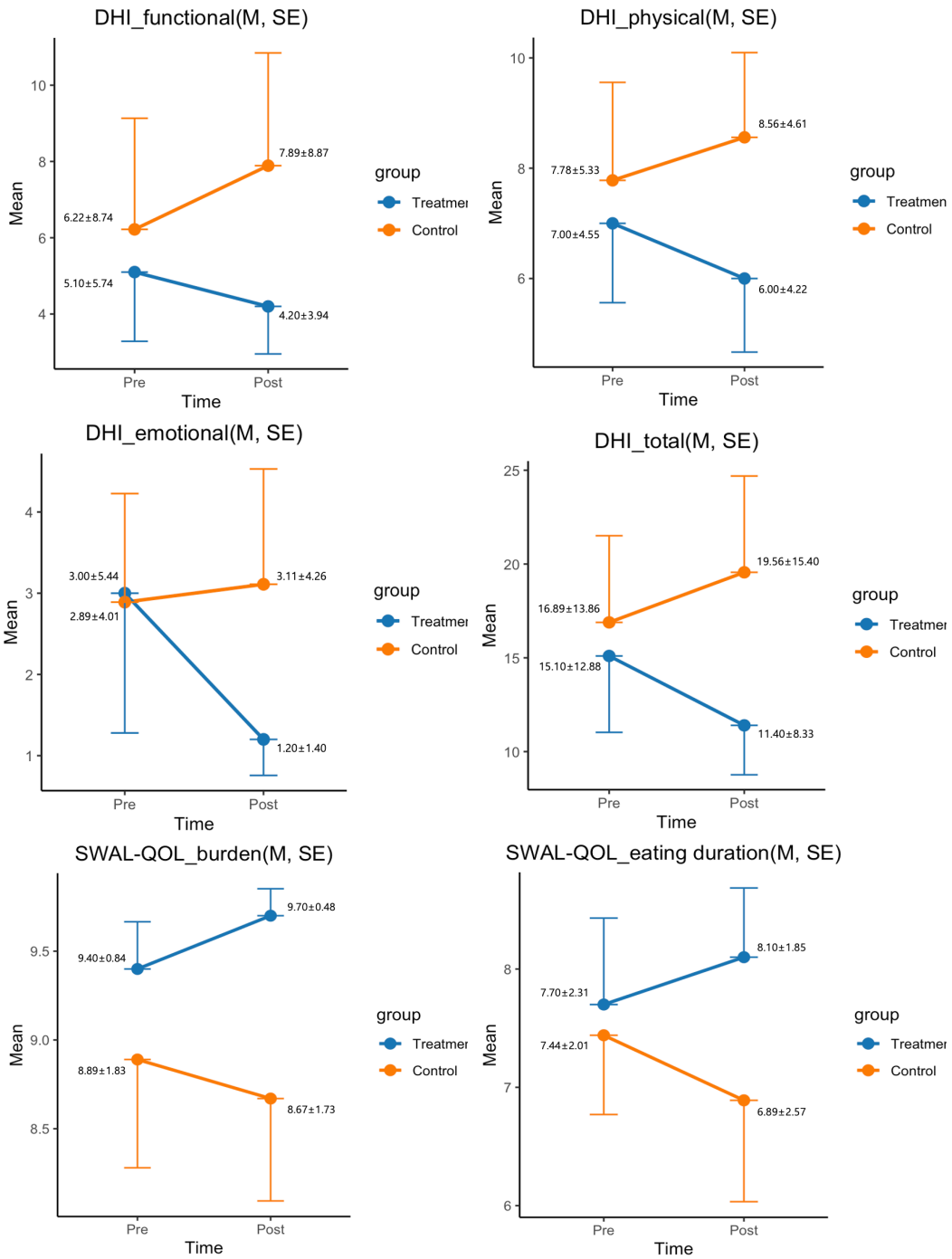

Figure 8a. Mean and standard error of swallowing-related questionnaire results

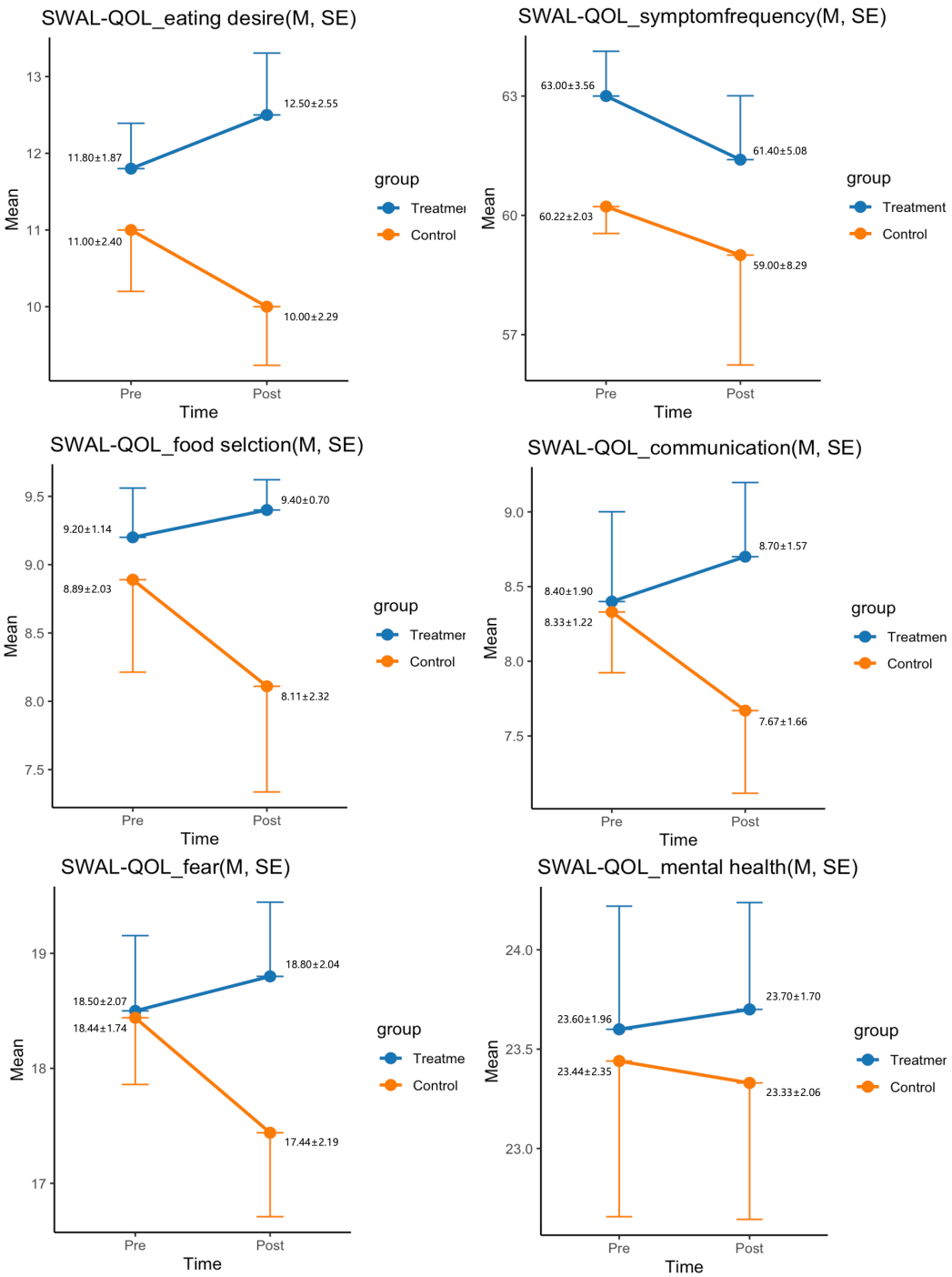

Figure 8b. Mean and standard error of swallowing-related questionnaire results

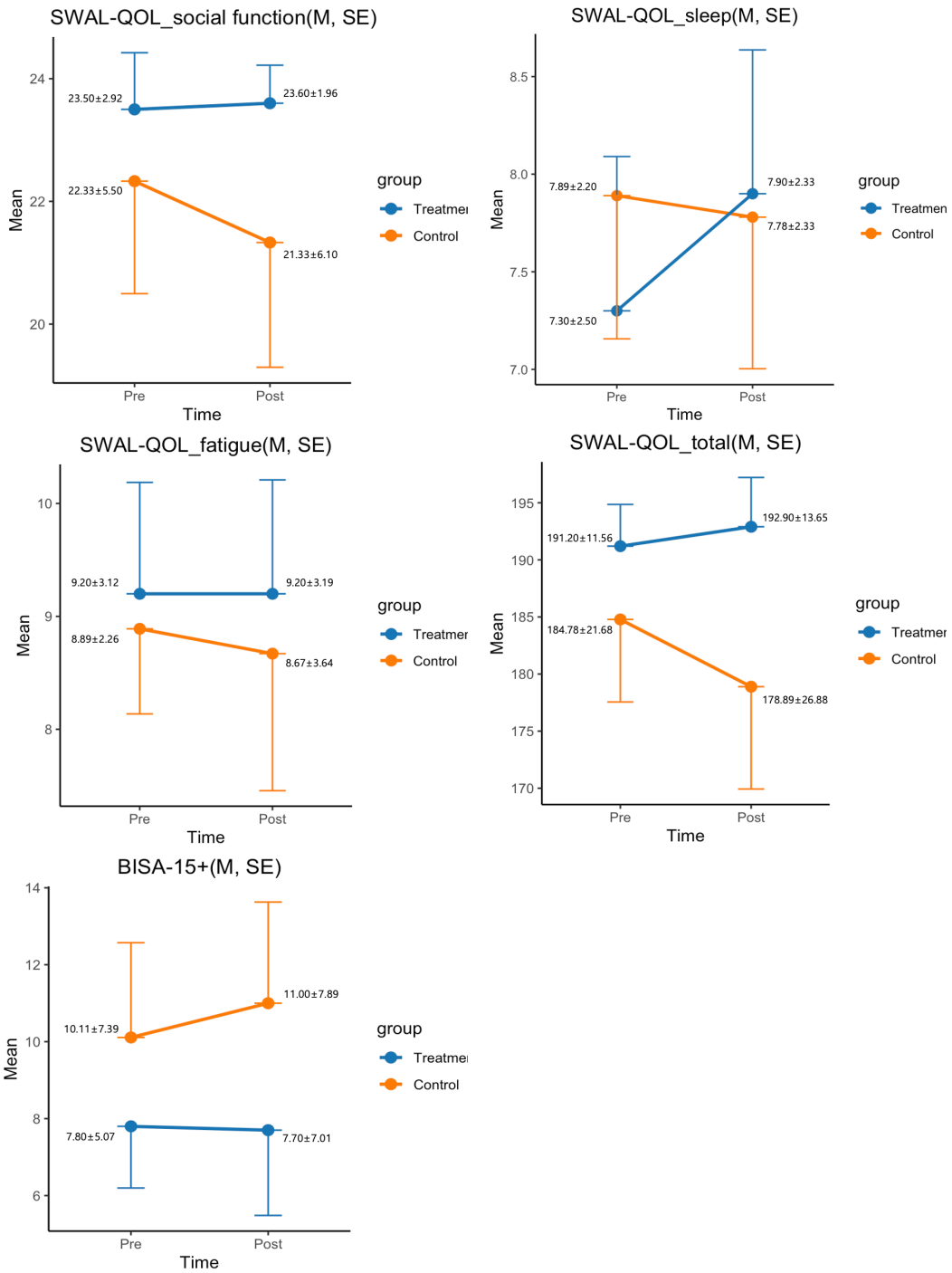

Figure 8c. Mean and standard error of swallowing-related questionnaire results

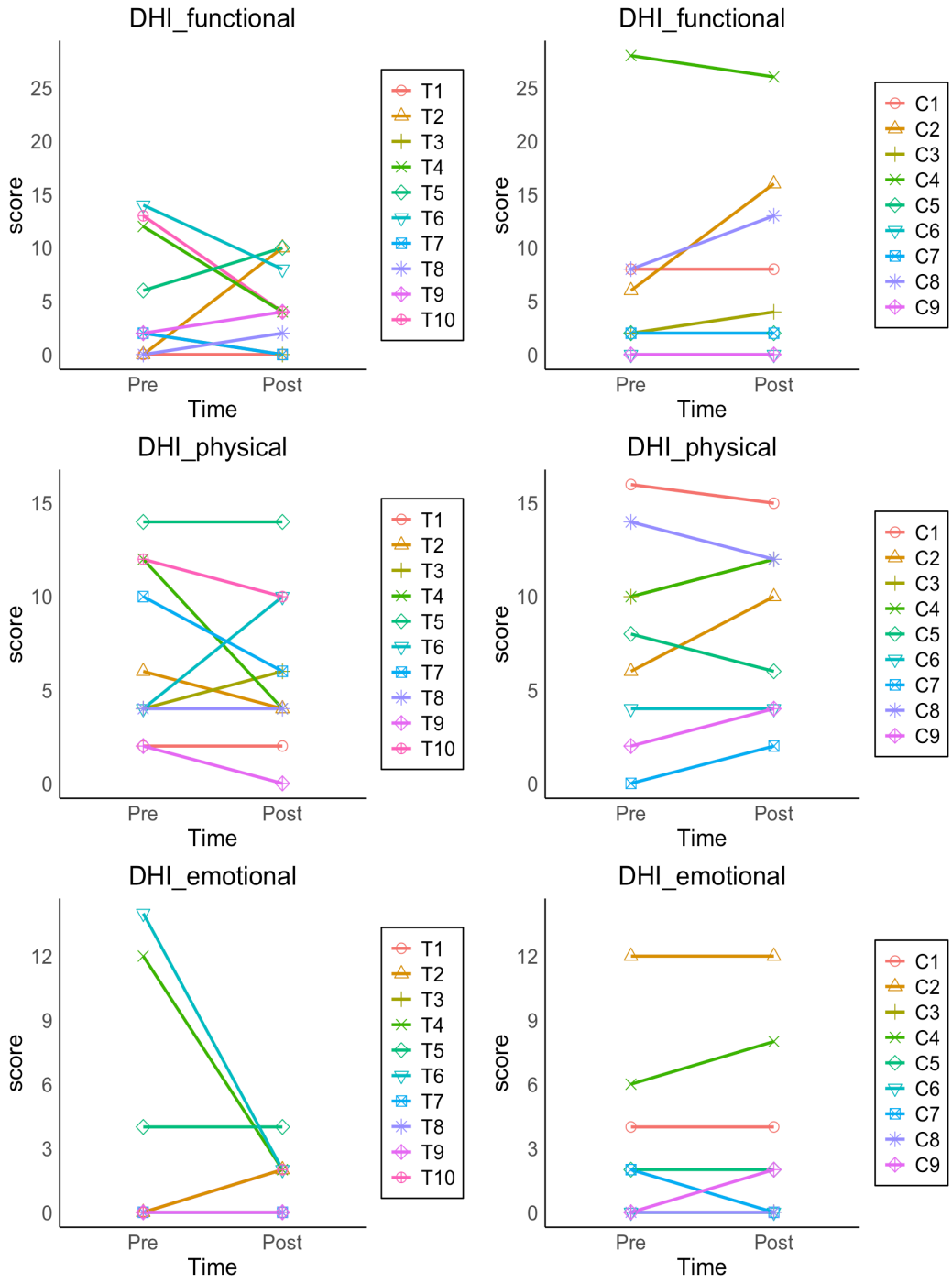

Figure 9a. Changes in swallowing-related questionnaire results for all participants

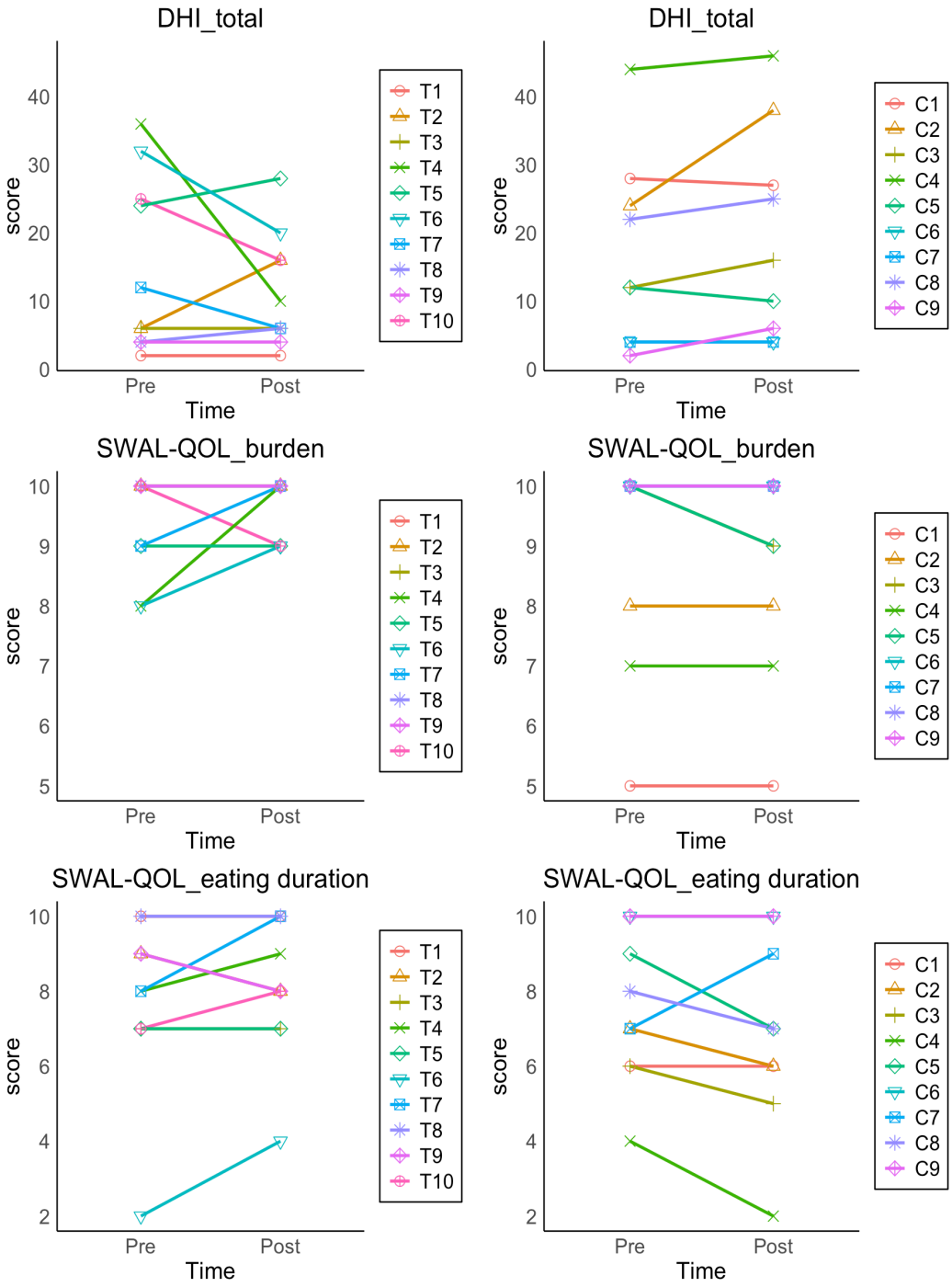

Figure 9b. Changes in swallowing-related questionnaire results for all participants

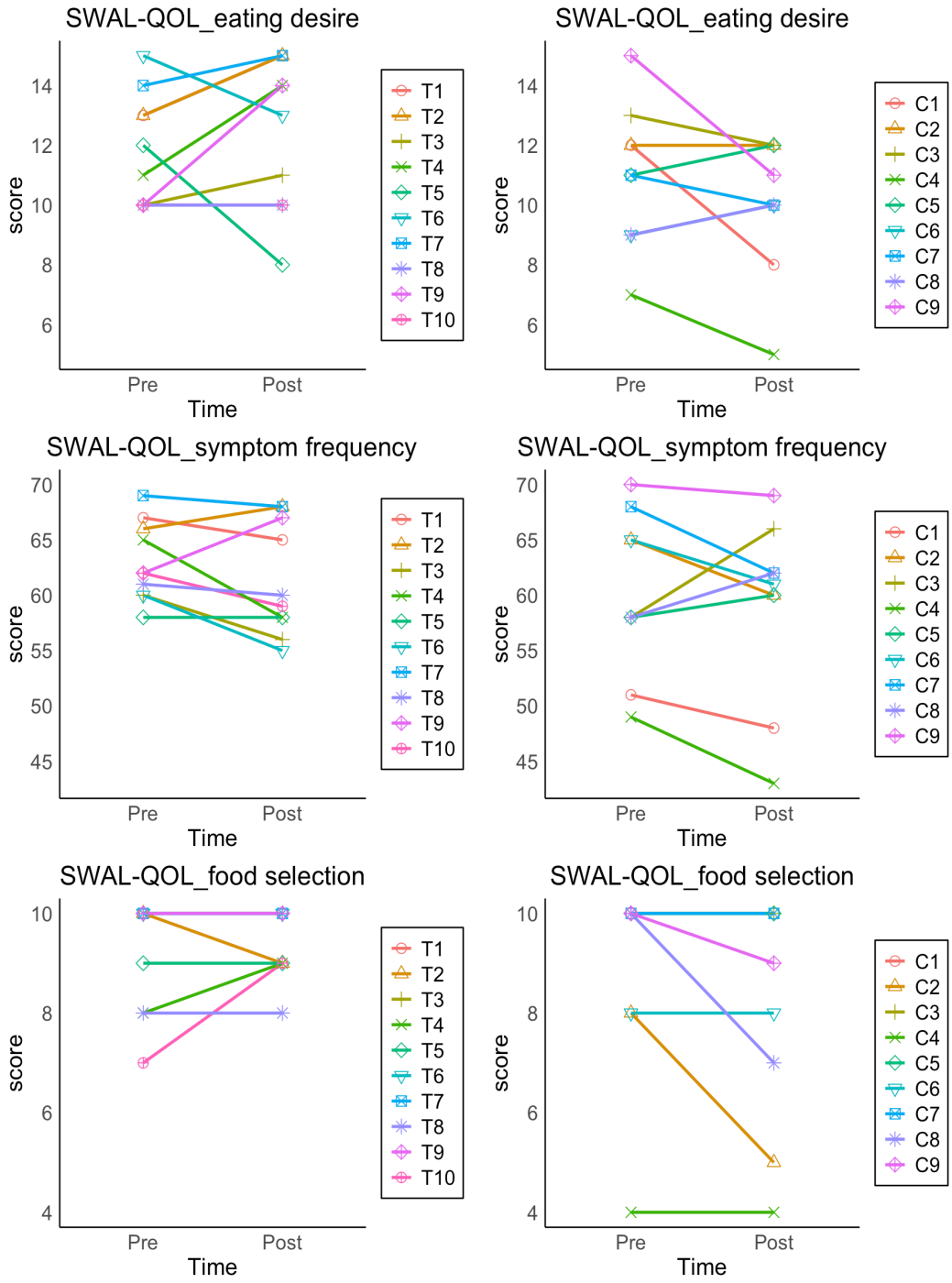

Figure 9c. Changes in swallowing-related questionnaire results for all participants

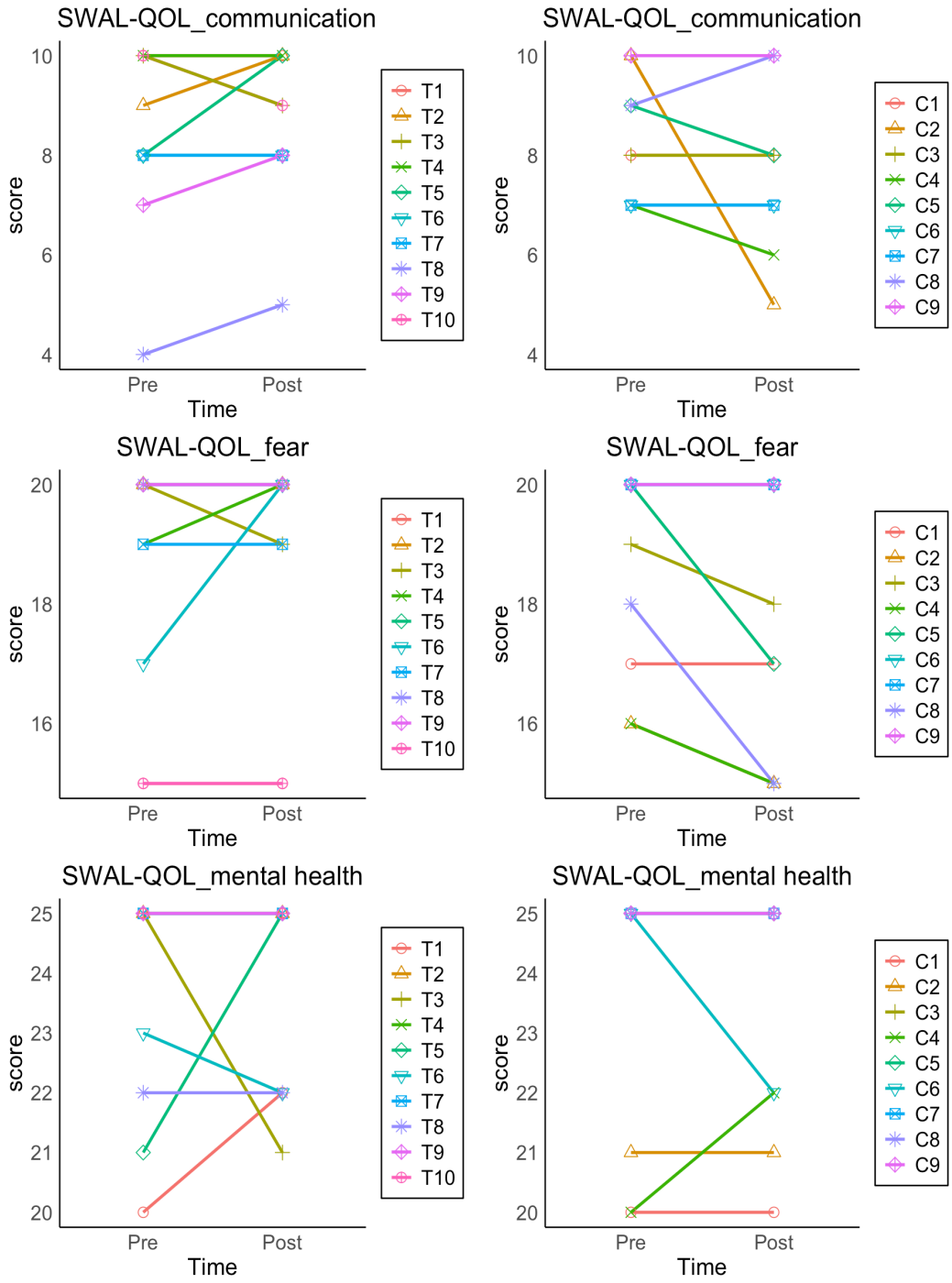

Figure 9d. Changes in swallowing-related questionnaire results for all participants

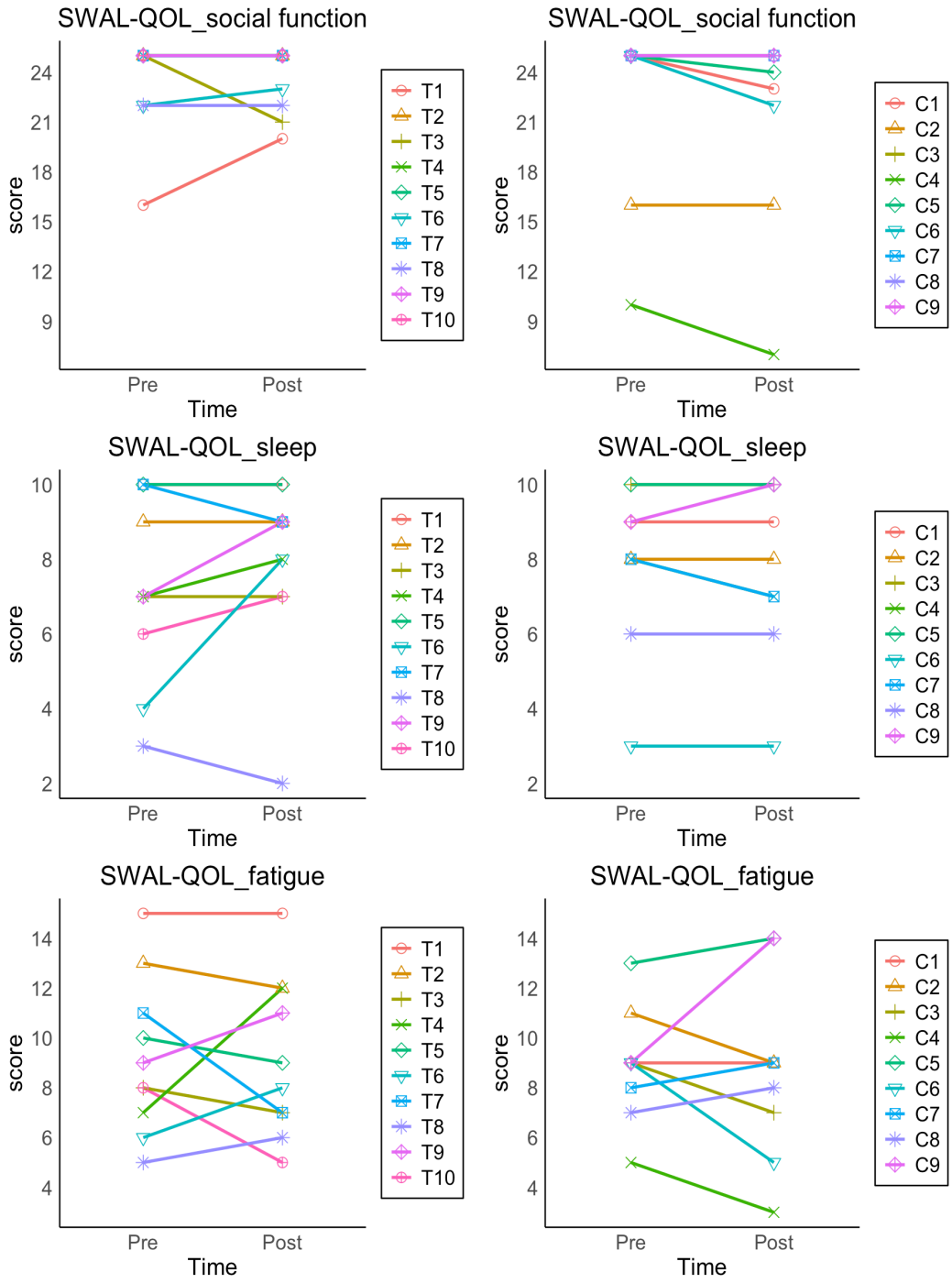

Figure 9e. Changes in swallowing-related questionnaire results for all participants

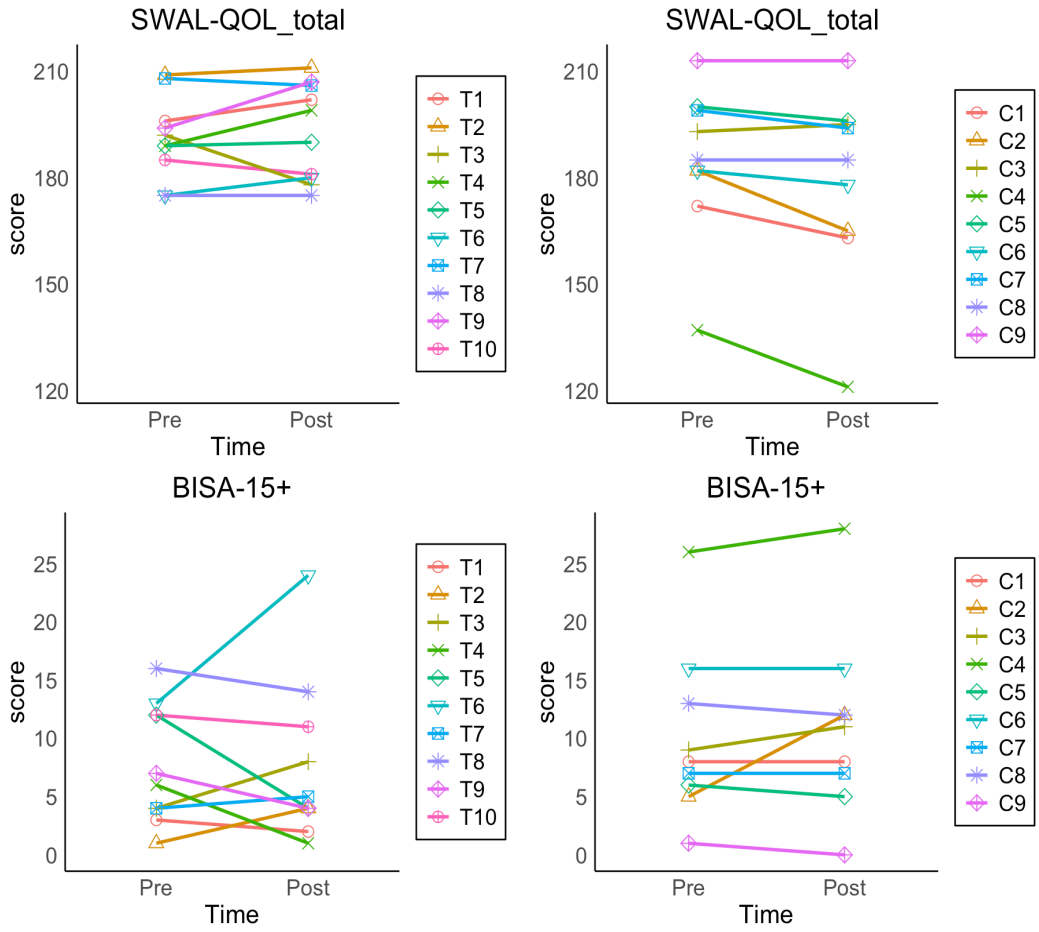

Figure 9f. Changes in swallowing-related questionnaire results for all participants

IV. DISCUSSION

Parkinson's disease (PD) has a negative effect on patients' speech, voice, swallowing functions, and overall quality of life. Thus, interventions that use voice therapy techniques are crucial for these patients. The PhoRTE voice therapy method, which has proven effective in treating presbyphonia, can be applied to patients with PD to strengthen the laryngeal muscles and enhance flexibility. This, in turn, can positively affect not only speech and voice but also the swallowing process, which shares a similar mechanism. In this study, this study involved 19 participants with PD, including 10 in the treatment group and 9 in the control group, to assess the impact of PhoRTE on speech, voice, swallowing, and overall quality of life. The discussion based on the study's results is as follows.

From a voice perspective, first, the treatment group showed a significant increase in MPT after the intervention. Most patients with PD experience reduced respiratory efficiency, which is primarily due to the weakening of respiratory muscles, resulting in less efficient breathing compared with healthy individuals. In addition, vocal fold bowing, which leads to incomplete vocal fold closure, causes air leakage, further contributing to a decline in respiratory efficiency.[11,81] As a result, it can become challenging to sustain phonation and effectively convey specific messages to others, potentially leading to a reduction in speech-processing speed. This can be a contributing factor to the overall decline in communication ability.[82] In PhoRTE, the exercise of sustaining a prolonged /a/ vowel at a loud volume can strengthen the laryngeal muscle and improve vocal fold contact through increased subglottic pressure.[83] This activity involves progressively increasing the

target loudness (dB) each week, and the goal-oriented nature of the task, along with repetitive practice, can contribute to improvements in MPT.[84] Although not specifically focused on the application of PhoRTE, studies on the widely used LSVT LOUD in patients with IPD and MSA-c have demonstrated improvements in utterance duration, expiratory muscle function, and vocal and respiratory efficiency as vocal duration increases.[85,86] Breathy voice, one of the perceptual characteristics observed in patients with PD, is associated with a higher noise-to-signal ratio and reduced periodicity of the voice signal during acoustic analysis, which can affect MPT performance. MPT and the breathy voice characteristic are known to be correlated with CPPs, as more stable vocal fold vibrations are associated with an increased duration of sustained phonation.[87,88] In this study, the significant improvement we observed in CPPs aligns with the findings of previous studies mentioned earlier. This may also suggest that pitch glides contributed to MPT improvement. In cases in which vocal fold closure is challenging, such as in patients with vocal fold paralysis or inefficient respiration, treatment involving pitch glides has been reported to help improve the closure of the glottal gap.[89] As a result, the air previously escaping through the glottal gap might have been used more effectively, enabling louder and stronger phonation for an extended duration, ultimately resulting in an increase in MPT.

Second, the treatment group showed significant improvements in acoustic parameters, whereas the control group exhibited a significant decline. Jitter and shimmer, parameters that reflect the irregularity of periodic vibrations in the voice signal, significantly decreased in the treatment group, while CPPs significantly increased, indicating improvement. In

contrast, jitter and shimmer significantly increased in the control group, indicating a deterioration in voice quality. Jitter and shimmer tend to be elevated in patients with PD during voice analysis, primarily due to the instability of the vocal fold caused by bradykinesia and rigidity, which are hallmark symptoms of the disease. As previously mentioned, difficulties in achieving proper vocal fold closure can exacerbate voice instability, leading to higher jitter and shimmer values.[90-92] Additionally, an increase in noise, unstable pitch, and voice breaks may result in lower cepstral values.[93] The sustained loud /a/ phonation exercise in PhoRTE might have contributed to these improvements. The production of loud and strong sounds increases the subglottic pressure, which in turn enhances the contact area of the vocal folds. Additionally, studies on PD patients have reported that CPPs significantly increased in the treatment group compared to the control group following LSVT and SPEAK OUT therapies.[94-96] As confirmed in previous research, the treatment group in this study also demonstrated improvements in jitter, shimmer values. The pitch glide activity might have contributed to this improvement as well. This exercise aims to enhance the flexibility of the vocal folds, which could have led to improvements in jitter by addressing structural abnormalities, such as vocal fold bowing, often observed in patients with PD.[34,35] Previous studies have reported that jitter and shimmer were elevated in the voice signals of untreated patients with PD.[76] This is related to abnormal changes in the larynx and may be indicative of characteristics such as a rough and hoarse voice.[92] In this study, the control group that did not receive treatment showed a significant increase in

jitter and shimmer values over the 4-week period, indicating a deterioration. This aligns with the findings of previous studies mentioned earlier.

Third, the speech intensity significantly increased in the treatment group during the sustained vowel /a/ task. Patients with PD often exhibit reduced vocal tension, which can lead to a weakened intensity during speech production.[12,46,76] All activities conducted in this study were designed to encourage patients to produce sounds at a louder volume than they typically could. These activities likely contributed to the increase in speech intensity. In addition, the vowel /a/ is not influenced by articulation and does not encounter air resistance from oral structures such as the tongue or lips, allowing for clearer and stronger phonation.[97] Therefore, because of its nature, this vowel may have shown significant changes. The degree of vocal fold closure is also improved as speech intensity increases.[48] The increase in vocal fold closure due to the rise in intensity is also related to duration of phonation, which aligns with the previously mentioned improvement in MPT observed in this study. Similarly, previous studies using LSVT, which followed a comparable intervention approach, reported significant improvements in vocal intensity following training.[21,25,98] This is consistent with the findings of this study. The task of conversing in noisy environments may also have had an impact. Previous studies have reported that vocal intensity in hypokinetic patients increased through the use of the Lombard effect.[46] Similarly, practicing speaking louder than their usual voice in response to environmental noise may have contributed to the increase in intensity. In addition, in this study, we set individualized target volumes for each patient weekly. Setting specific goals can increase

patient motivation during therapy, and reports have indicated that caregivers experienced reduced anxiety about the patient while therapists were able to explain the goals more clearly.[99] Moreover, visual feedback might have also contributed to the improvements. Patients with PD experience a decline in proprioception, which is responsible for the detection and control of bodily movements. This sensory impairment can lead to reduced vocal intensity.[100,101] Thus, visual feedback is considered essential in voice therapy. Studies have shown that when visual feedback is incorporated, improvements are observed in acoustic parameters, including an increase in F0 and reductions in jitter, shimmer, and NHR, all contributing to enhanced voice quality and increased vocal intensity.[102] Although not specific to patients with PD, a study conducted with adults using cochlear implants demonstrated that the provision of visual feedback during pitch therapy resulted in a decrease in both fundamental frequency and speaking pitch, which confirms the effectiveness of such feedback.[103] For these reasons, providing real-time feedback on vocal intensity to patients with PD could similarly result in increased vocal intensity. The ability of patients to monitor their own performance during phonation may enhance the effectiveness of the therapy.

From a speech perspective, AMR and VSA significantly increased in the treatment group. Reduced mobility of the lips, jaw, and tongue in patients with PD often results in a decreased VSA and a tendency toward vowel centralization due to vowel distortion. As a result, reductions in AMR and VSA are observed.[55,104] Oral mobility is a factor that affects both speech and swallowing. Previous studies have reported that decreased DDK

performance is associated with reduced swallowing function.[105] This indicates that the oral mobility required for DDK performance may affect tongue movement, drooling, and oral transit time during the oral phase of swallowing. In addition, during PhoRTE activities, tasks such as reading functional phrases aloud with maximum vocal intensity and conversing in noisy environments might have contributed to these improvements. In the case of functional phrase reading, participants were required to articulate sentences composed of various phonemes for 10 times at a high pitch and 10 times at a low pitch, for a total of 20 repetitions during therapy. This repetitive training with loud phonation might have contributed to improvements in articulation and oral mobility. Previous studies on patients with IPD have reported an increase in the vowel triangle area and DDK performance following LSVT, which aligns with the findings of this study.[106]

From a swallowing perspective, the treatment group showed a significant increase in GUSS scores, indicating improvement. The vocal folds are among the structures involved in the final stage of swallowing, closing to protect the airway and prevent food from entering.[107] This demonstrates that the anatomical structures involved in both swallowing and voice production are shared.[108] In addition to sharing anatomical structures, the sensory systems are also interconnected, allowing training aimed at improving symptoms in the oral and laryngeal regions to enhance swallowing ability following voice therapy.[109] However, patients exhibit impairments in these abilities. Studies using fiber-optic endoscopic evaluation of swallowing to examine swallowing difficulties in patients with PD have commonly reported premature spillage, residue in the valleculae, delayed

swallowing reflex, and a combination of these challenges.[110] The sustained phonation of /a/ conducted in this study might have contributed to the results. As indicated in previous research, loud phonation can strengthen the laryngeal muscles and enhance vocal fold adduction, potentially reducing premature spillage. This, in turn, may have helped prevent the penetration and aspiration of food into the airway. In addition, patients often experience reduced hyoid movement, leading to swallowing difficulties.[45] The pitch glide activity and functional sentence reading with sustained pitch may have positively influenced this aspect of swallowing function. These activities may assist in elevating the hyoid bone. Previous studies have shown that in healthy adults, increasing pitch during phonation is related to hyoid movement and its role in swallowing. Researchers found that hyoid elevation during swallowing helps clear the bolus from the airway.[32] This finding aligns with the results of the present study, in which we observed an improvement in swallowing ability. As mentioned earlier, this study demonstrated significant improvements in DDK and VSA, which were also associated with enhanced articulation abilities. Improved articulation abilities are linked to enhanced oral mobility, which in turn may be related to the coordination of structures during the oral phase of swallowing.

From a quality-of-life perspective, the control group demonstrated a significant decrease in quality of life, as assessed by the SWAL-QOL questionnaire, which evaluates swallowing-related quality of life. This suggests that, in the absence of PhoRTE voice therapy, the participants in the control group may have developed a more negative perception of their swallowing difficulties. Previous studies have reported that patients with

dysphagia experience a decline in their quality of life.[111] Furthermore, researchers have reported that timely treatment for swallowing difficulties can improve the quality of life. Although not a study on the application of PhoRTE, research on patients with IPD and MSA-c has shown that administering LSVT improved swallowing-related quality of life.[86] This suggests that receiving treatment can contribute to improving the quality of life affected by the disease. These findings contrast with the results of this study, in which the control group, who did not receive PhoRTE voice therapy, experienced a decrease in quality of life, highlighting the importance of treatment.

In summary, the five training exercises in PhoRTE contributed to strengthening the laryngeal muscles and improving flexibility, resulting in enhancements in voice quality and vocal intensity. In addition, it is expected that these exercises would help maintain or improve the quality of life as compared with the control group. A key finding of this study is the significant improvement in swallowing function, despite the intervention being focused on voice training. Given that voice and swallowing share similar anatomical mechanisms, there could be significant clinical value in implementing voice therapy aimed at improving swallowing abilities.

We present the following limitations of this study and suggestions for future research.

First, we did not control for factors such as gender distribution, postonset time, or severity during random assignment. To allow for a more rigorous acoustic comparison and analysis, future research should consider matching the gender distribution and controlling for severity.

Second, although this study focused solely on the PhoRTE voice therapy technique, it would be beneficial to compare and analyze the effectiveness of similar techniques, such as LSVT, within the same patient population.

Third, although this study was conducted over a 4-week period, it would be important to assess whether the treatment group maintains or improves their functional gains at 8 weeks and beyond.

Fourth, the trends in this study must be analyzed to determine at which week during the 4-week intervention period the participants began to show improvement, when the improvement plateaued, and whether the enhanced function was maintained.

V. CONCLUSION

In this study, we investigated the effects of a 4-week intervention using the PhoRTE voice therapy technique on speech, voice, swallowing abilities, and quality of life in patients with PD. We included 19 participants (5 men and 5 women in the treatment group [n = 10]; 6 men and 3 women in the control group [n = 9]), with the treatment group undergoing pre- and postintervention assessments, whereas the control group completed two assessments at 4-week intervals without receiving any intervention. As a result, in the treatment group, the results demonstrated improvements in all aspects, including respiration, voice quality, resonance, and articulation, highlighting its utility as a holistic voice therapy technique. Furthermore, the functional improvements observed in swallowing suggest that timely and appropriate swallowing actions may help prevent penetration and aspiration. Additionally, this study demonstrated that functional improvements were observed when treatment was provided, whereas functional decline occurred in the absence of treatment. Through this research, it was established that timely and appropriate intervention can be clinically beneficial for neurodegenerative diseases such as PD. Moreover, this study highlights the potential of utilizing voice therapy techniques to improve swallowing abilities. By applying PhoRTE to address the frequently occurring voice and swallowing disorders in this patient population, this research provides clinically valuable evidence supporting the effectiveness of this approach for therapeutic interventions.

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APPENDICES

APPENDIX 1. Autumn passage

<가을>

우리나라의 가을은 참으로 아름답다. 무엇보다도 산에 오를 땐 더욱더 그 빼어난 아름다움이 느껴진다. 쓰다듬어진 듯한 완만함과 깎아 놓은 듯한 뾰족함이 어우러진 산등성이를 따라 오르다 보면 절로 감탄을 금할 수가 없게 된다. 붉은 색, 푸른 색, 노란 색 등의 여러 가지 색깔들이 어우러져, 타는 듯한 감동을 주며 나아가 신비롭기까지 하다. 숲 속에 누워서 하늘을 바라보라. 쌍쌍이 짝지어져 있는 듯한 흰 구름, 높고 파란 하늘을 쳐다보고 있노라면 과연 예부터 가을을 천고마비의 계절이라 일컫는 이유를 알게 될 것만 같다. 가을에는 또한 오곡백과 등 먹거리가 풍성하기 때문에 결실의 계절이라고도 한다. 햅쌀, 밤, 호두 뿐만 아니라 대추, 여러 가지 떡, 크고 작은 과일들을 맛볼 수 있는데, 가을의 대표적인 명절인 추석에 우리는 이것들을 쌓아 놓고 조상님들께 차례를 지내기도 한다. 또한, 가을은 독서의 계절이라고도 하여 책을 읽으며 시시때때로 명상에 잠기기도 하는데, 독서는 우리에게 마음을 살찌우고 아름답게 하는 힘을 주기 때문이다.

APPENDIX 2. Gugging swallowing screen (GUSS)

1. Preliminary Investigation /Indirect Swallowing Test

	YES	NO
Vigilance (The patient must be alert for at least for 15 minutes)	1	0
Cough and/or throat clearing (voluntary cough) (Patient should cough or clear his or her throat twice)	1	0
Saliva Swallow: • Swallowing successful	1	0
• Drooling	0	1
• Voice change (hoarse, gurgly, coated, weak)	0	1
SUM		(5)
	1~4= Investigate further[1] 5= Continue with part 2	

2. Direct Swallowing Test

In the following order:	1→ SEMISOLID*	2→ LIQUID**	2→ SOLID ***
DEGLUTITION:			
• Swallowing not possible	0	0	0
• Swallowing delayed (>2sec.) (Solid texture>10sec.)	1	1	1
• Swallowing successful	2	2	2
COUGH(involuntary):			

(before, during or after swallowing-until 3 minutes later)			
• Yes	0	0	0
• No	1	1	1
DROOLING			
• Yes	0	0	0
• No	1	1	1
VOICE CHANGE (listen to the voice before and after swallowing - Patient should speak "O")			
• Yes	0	0	0
• No	1	1	1
SUM	(5) 1~4= Investigate further[1] 5= Continue liquid	(5) 1~4= Investigate further[1] 5= Continue solid	(5) 1~4= Investigate further[1] 5= Normal
SUM: (Indirect Swallowing Test AND Direct Swallowing Test			(20)

* First administer 1/3 up to a half teaspoon water with food thickener (pudding-like consistency). If there are no symptoms apply 3 to 5 teaspoons. Assess after the 5th spoonful.

** 3, 5, 10, 20 ml water - if there are no symptoms continue with 50 ml water Assess and stop the investigation when one of the criteria is observed!

*** Clinical: Dry bread

[1] Use functional investigations such as Videofluoroscopic Evaluation of Swallowing (VFES), Fiberoptic Endoscopic Evalutation of Swallowing (FEES)

APPENDIX 3. Short form of speech handicap index (SHI-15)

Short form of Speech Handicap Index Korean version(SHI-15)

본 설문지는 언어장애지수(Speech Handicap Index, SHI)를 통하여 말 기능과 심리사회적 기능을 평가하기 위해 고안된 자기보고식 평가입니다.
다음 문장을 읽고, 현재 말 상태에 맞는 곳에 응답해주시면 됩니다.

성함/성별: **생년월일:**

0=전혀 없다 1=거의 없다 2=가끔 있다 3= 자주 있다 4=항상 있다

1	사람들은 내 말을 이해하기 어려워한다.	0 1 2 3 4
2	나는 말 때문에 무능력하게 느껴진다.	0 1 2 3 4
3	사람들은 내 말을 이해하지 못하고, 나에게 되물어본다.	0 1 2 3 4
4	나는 전화 사용을 피한다.	0 1 2 3 4
5	나는 발음이 부정확하다.	0 1 2 3 4
6	나는 말의 문제로 인해 친구, 이웃 혹은 친척들과 말을 덜하게 된다.	0 1 2 3 4
7	나는 말할 때 힘을 줘서 말해야 할 것 같다.	0 1 2 3 4
8	다른 사람들은 나의 말 문제를 이해하지 못하는 것 같다.	0 1 2 3 4
9	말 정확도(명료도)를 예측할 수 없다.	0 1 2 3 4
10	나는 말 문제 때문에 대화에서 소외감을 느낀다.	0 1 2 3 4
11	나는 말을 정확하게 하기 위해 노력한다.	0 1 2 3 4
12	저녁이 되면 말소리가 더 나빠진다.	0 1 2 3 4
13	나는 말 문제 때문에 장애가 있다고 느껴진다.	0 1 2 3 4

14	나는 말 문제 때문에 대화를 계속(지속)하기 어렵다.	0 1 2 3 4
15	나는 사람들이 다시 말해 달라고 하면 당혹스럽다.	0 1 2 3 4

APPENDIX 4. Dysphagia handicap index (DHI)

Dysphagia Handicap Index(DHI)

본 설문은 삼킴 문제 때문에 귀하께서 느끼는 어려움을 조사하고자 합니다.

다음 문장을 읽고 해당하는 곳에 표시해주세요.

성함/성별: **생년월일:**

0=결코 그렇지 않다 2=때때로 그렇다 4=항상 그렇다

1P. 나는 액체를 마실 때 기침을 한다.	0	2	4
2P. 나는 고체 음식(예: 빵, 과자, 엿, 땅콩, 오징어)을 먹을 때 기침을 한다.	0	2	4
3P. 내 입은 건조하다.	0	2	4
4P. 나는 음식물이 내려가도록 하기 위해 액체를 마셔야 한다.	0	2	4
5P. 나는 삼킴 문제 때문에 체중이 감소한다.	0	2	4
1F. 나는 내 삼킴 문제 때문에 특정 음식들은 피한다.	0	2	4
2F. 나는 더 먹기 쉽도록 삼키는 방법을 바꾸었다.	0	2	4
1E. 나는 공공장소에서 먹는 것이 창피하다.	0	2	4
3F. 나는 예전보다 식사를 하는데 좀 더 많은 시간이 걸린다.	0	2	4
4F. 나는 내 삼킴 문제 때문에 소량의 음식을 자주 먹는다.	0	2	4
6P. 나는 음식물이 내려가기 전에 다시 한 번 삼켜야 한다.	0	2	4
2E. 나는 내가 원하는 것을 먹을 수 없기 때문에 우울하다.	0	2	4
3E. 나는 예전만큼 먹는 것을 즐기지 않는다.	0	2	4
5F. 나는 내 삼킴 문제 때문에 사람들과 많이 어울리지 않는다.	0	2	4

6F. 나는 내 삼킴 문제 때문에 먹는 것을 피한다.	0 2 4
7F. 나는 내 삼킴 문제 때문에 덜 먹는다.	0 2 4
4E. 나는 내 삼킴 문제 때문에 불안하다.	0 2 4
5E. 나는 내 삼킴 문제 때문에 장애가 있다고 느낀다.	0 2 4
6E. 나는 내 삼킴 문제 때문에 내 자신에게 화가 난다.	0 2 4
7P. 나는 약을 삼킬 때 숨이 막힌다.	0 2 4
7E. 나는 내 삼킴 문제 때문에 숨이 멈추거나 질식할까봐 걱정이다.	0 2 4
8F. 나는 내 삼킴 문제 때문에 다른 방법(예: 경관 영양)으로 먹어야만 한다.	0 2 4
9F. 나는 내 삼킴 문제 때문에 음식 종류를 변경했다.	0 2 4
8P. 나는 삼킬 때 목이 졸라 죽을 것 같은 느낌이 든다.	0 2 4
9P. 나는 삼킨 후에 음식물을 토할 정도로 기침을 한다.	0 2 4
* 본인의 삼킴 장애 정도가 어디에 해당하는지 표시해 주십시오. (1-2 점=정상, 3-5 점=중간 정도, 6-7 점=심한 정도)	1 2 3 4 5 6 7

APPENDIX 5. Swallowing-quality of life (SWAL-QOL)

Swallowing-Quality Of Life(SWAL-QOL)

이 설문지는 삼킴 문제가 당신의 삶의 질에 얼마나 영향을 미치는지 알아보기 위해 제작되었습니다.
설문 내용을 주의 깊게 읽고 각 질문에 답해주십시오. 모든 항목이 다르게 구성되어 있으므로 유사한 질문에도 모두 답해주시기 바랍니다.

성함/성별: **생년월일:**

1=항상 그렇다 2=대부분 그렇다 3=보통 그렇다 4=가끔 그렇다 5=전혀 아니다

1. 다음은 삼킴 문제를 가진 사람들이 일반적으로 말하는 내용입니다. 지난 한 달 동안, 다음의 내용이 본인에게 얼만큼 해당했나요?	
1-1. 삼킴문제를 대하는 것이 매우 어렵다.	1 2 3 4 5
1-2. 삼킴문제는 내 삶의 주 방해요소이다.	1 2 3 4 5
2. 다음은 삼킴문제를 가진 사람들이 먹는 것에 관해 가끔씩 이야기 하는 내용입니다. 지난 한 달 동안, 다음의 내용이 본인에게 얼만큼 해당했나요?	
2-1. 늘상 먹든 안 먹든 상관하지 않는다	1 2 3 4 5
2-2. 다른 사람들보다 먹는데 시간이 오래걸린다.	1 2 3 4 5
2-3. 거의 배고픔을 느끼지 못한다.	1 2 3 4 5
2-4. 식사를 마치는데 오래 걸린다.	1 2 3 4 5
2-5. 더 이상 먹는게 즐겁지 않다.	1 2 3 4 5
3. 다음은 삼킴문제를 가진 사람들이 가끔씩 경험하는 신체적인 문제 입니다. 지난 한 달 동안, 본인은 삼킴장애로 인해 다음의 문제를 얼마나 자주 경험했나요?	

3-1. 기침	1 2 3 4 5
3-2. 음식을 먹을 때 숨이 막힘	1 2 3 4 5
3-3. 액체를 마실 때 숨이 막힘	1 2 3 4 5
3-4. 걸쭉한 침 또는 가래 생김	1 2 3 4 5
3-5. 구역질	1 2 3 4 5
3-6. 침 흘림	1 2 3 4 5
3-7. 씹기 어려움	1 2 3 4 5
3-8. 과도한 침 또는 가래 생김	1 2 3 4 5
3-9. 목을 가다듬어야 함	1 2 3 4 5
3-10. 목구멍에 음식물이 들러붙음	1 2 3 4 5
3-11. 입에 음식물이 들러붙음	1 2 3 4 5
3-12. 입 밖으로 음식 또는 액체가 흘러 나옴	1 2 3 4 5
3-13. 코로 음식 또는 액체가 나옴	1 2 3 4 5
3-14. 음식물이나 액체가 목에 걸리면 기침을 해서 입 밖으로 뱉어냄	1 2 3 4 5
4. 지난 한 달동안, 삼킴문제가 본인의 식사에 어떻게 영향을 미쳤나요?	
4-1. 내가 먹을 수 있는 것과 먹을 수 없는 것을 구별하기가 어렵다.	1 2 3 4 5

4-2. 내가 좋아하면서 동시에 먹는 것이 가능한 음식을 정하는 것이 어렵다.	1 2 3 4 5
5. 지난 한 달 동안, 삼킴문제로 인해 다음의 항목이 본인의 의사소통에 얼마나 자주 영향을 미쳤나요?	
5-1. 사람들은 내 말을 이해하기 어려워한다.	1 2 3 4 5
5-2. 명료하게 말하는 것이 어렵다.	1 2 3 4 5
6. 다음은 삼킴 문제를 가진 사람들이 가끔씩 말하는 걱정에 관한 내용입니다. 지난 한 달 동안, 다음의 느낌을 얼마나 자주 경험했나요?	
6-1. 나는 음식을 먹을 때 숨이 막힐까봐 두렵다.	1 2 3 4 5
6-2. 나는 폐렴에 걸릴까봐 걱정이다.	1 2 3 4 5
6-3. 나는 액체를 마실 때 숨이 막힐까봐 두렵다.	1 2 3 4 5
6-4. 나는 음식을 먹으면서 언제 숨이 막힐 지 알 수 없다.	1 2 3 4 5
7. 지난 한 달 동안, 삼킴문제로 다음의 내용을 얼마나 자주 경험했나요?	
7-1. 삼킴문제는 나를 우울하게 한다.	1 2 3 4 5
7-2. 조심해서 먹거나 마셔야 하는 것이 나를 화나게 한다.	1 2 3 4 5
7-3. 삼킴문제는 나를 낙담시킨다.	1 2 3 4 5
7-4. 삼킴문제는 나를 절망스럽게 한다.	1 2 3 4 5
7-5. 삼킴문제를 대할 때 나는 참을성이 없어진다.	1 2 3 4 5
8. 지난 한 달 동안, 본인의 사회생활을 생각해보세요. 다음의 항목에 얼만큼 동의하십니까?	

8-1. 삼킴문제 때문에 외식을 하지 않는다.	1 2 3 4 5
8-2. 삼킴문제 때문에 사회생활이 어렵다.	1 2 3 4 5
8-3. 삼킴문제 때문에 나의 일 또는 여가 활동이 변했다.	1 2 3 4 5
8-4. 삼킴문제 때문에 사람들과의 모임이 즐겁지 않다.	1 2 3 4 5
8-5. 삼킴문제 때문에 가족과 친구들 사이에서 나의 역할이 바뀌었다.	1 2 3 4 5
9. 지난 한 달 동안, 다음의 신체적 증상을 얼마나 자주 경험했나요?	
9-1. 신체적으로 약한가?	1 2 3 4 5
9-2. 잠드는게 어려운가?	1 2 3 4 5
9-3. 피곤함을 느끼는가?	1 2 3 4 5
9-4. 잠든 상태를 유지하는게 어려운가?	1 2 3 4 5
9-5. 신체적으로 지치는가?	1 2 3 4 5
10. 지금 섭식관으로 음식이나 액체를 먹고 있나요?	1=아니오 2=네

11. 지난 한 주 동안, 가장 자주 먹었던 음식의 농도와 질감을 가장 잘 묘사한 항목에 표시하세요.	☐정상적인 식이(예: 갈비, 당근, 빵, 샐러드, 팝콘과 같이 씹기 어려운 다양한 종류의 음식 ☐씹기 쉽고 부드러운 음식 섭취(예: 찜 요리, 과일 통조림, 부드럽게 익힌 야채, 다진 고기 또는 크림스프) ☐갈거나 가공된 음식 섭취(예: 푸딩이나 생크림) ☐대부분 섭식관으로 영향을 섭취하지만, 가끔 아이스크림, 푸딩, 사과 주스, 또는 다른 군것질 섭취 ☐섭식관을 통해서만 영양 섭취

12. 지난 한 주 동안, 가장 자주 마신 액체의 농도를 가장 잘 묘사하고 있는 항목에 표시하세요.	☐물, 우유, 차, 과일주스, 커피와 같은 액체를 마신다. ☐액체의 대부분이 농도가 짙어서, 숟가락을 뒤집으면 천천히 아래로 흐른다.(예: 토마토 주스, 두유) ☐액체가 중간 정도의 농도여서, 빨대로 빨기 어렵고, 꿀처럼 숟가락을 뒤집으면 한 방울씩 떨어진다.(예: 호박죽, 꿀) ☐액체의 농도가 상당히 진해서, 숟가락을 뒤집으면 숟가락에 붙어있다.(예: 푸딩, 생크림) ☐입으로 액체를 전혀 마시지 못하거나, 얼음조각만 먹는다.
13. 일반적으로 당신의 건강은 어떠한지 표시하세요.	☐약함 ☐보통 ☐좋음 ☐매우 좋음 ☐최상

APPENDIX 6. Voice handicap index (VHI)

Voice Handicap Index(VHI)

본 설문은 목소리(거친 목소리, 쥐어짜는 목소리 등) 문제 때문에 귀하께서 느끼는 어려움을 조사하고자 합니다.
다음 문장을 읽고 해당하는 곳에 표시해 주세요.

성함/성별: **생년월일:**

0 = 전혀 그렇지 않다 1 = 거의 그렇지 않다 2 = 가끔 그렇다 3 = 자주 그렇다 4 = 항상 그렇다

F1. 목소리 때문에 상대방이 내 말을 알아듣기 힘들어한다.	0 1 2 3 4
P2. 말을 할 때 숨이 차다.	0 1 2 3 4
F3. 시끄러운 곳에서는 사람들이 내 말을 이해하기 어려워 한다.	0 1 2 3 4
P4. 하루 중에도 목소리가 자주 변한다.	0 1 2 3 4
F5. 집안 어디서든 내가 부르는 말소리를 가족들이 잘 듣지 못한다.	0 1 2 3 4
F6. 목소리 때문에 전화 통화를 가급적 줄인다.	0 1 2 3 4
F7. 목소리 때문에 타인과 대화를 할 때 긴장한다.	0 1 2 3 4
F8. 내 목소리 때문에 여러 사람이 모인 자리를 피하게 된다.	0 1 2 3 4
F9. 내 목소리 때문에 사람들은 짜증이 날 것이다.	0 1 2 3 4
P10. 사람들이 나에게 목소리가 왜 그러냐고 묻는다.	0 1 2 3 4
F11. 내 목소리 때문에 친구, 친척 혹은 이웃들과 대화를 덜 하게 된다.	0 1 2 3 4
F12. 얼굴을 마주보고 대화할 때도 상대방이 다시 말해 달라고 한다.	0 1 2 3 4
P13. 목소리가 갈라지고 탁하다.	0 1 2 3 4

P14. 목소리를 내려면 힘을 주어야 나오는 것 같다.	0 1 2 3 4
E15. 다른 사람들은 내 음성 문제를 잘 이해하지 못한다고 생각한다.	0 1 2 3 4
F16. 음성 문제로 개인 생활과 사회 생활에 제한을 받는다.	0 1 2 3 4
P17. 목소리가 언제쯤 맑게 잘 나올지 알 수가 없다(예측이 어렵다).	0 1 2 3 4
P18. 목소리를 잘 나오게 하려고 음성을 달리 내보기도 한다.	0 1 2 3 4
F19. 내 목소리 때문에 대화에 끼지 못하여 소외감을 느낀다.	0 1 2 3 4
P20. 말할 때는 애를 많이 쓰게 된다.	0 1 2 3 4
P21. 저녁이 되면 목소리가 더 잠긴다.	0 1 2 3 4
F22. 음성 문제로 인해 소득(수입)에 감소가 생긴다.	0 1 2 3 4
E23. 내 목소리 문제로 속이 상한다.	0 1 2 3 4
E24. 내 목소리 문제로 적극적이지 못할 때가 있다.	0 1 2 3 4
E25. 음성 문제가 장애로(핸디캡으로) 여겨진다.	0 1 2 3 4
P26. 말하다가 목소리가 나오지 않아 말을 이어나갈 수 없을 때도 있다.	0 1 2 3 4
E27. 사람들이 나에게 다시 말해 달라고 할 때 기분이 언짢다.	0 1 2 3 4
E28. 사람들이 나에게 다시 말해 달라고 할 때 창피함을 느낀다.	0 1 2 3 4
E29. 목소리 때문에 무능력하게 느껴져 자신감이 떨어진다.	0 1 2 3 4
E30. 목소리 때문에 수치심을 느낀다.	0 1 2 3 4

APPENDIX 7. Brief inventory of swallowing ability-15^{+} (BISA-15^{+})

삼킴기능 간이평가(BISA-15^{+})

성함/성별: **생년월일:**

0=전혀 그렇지 않다 1=그렇다 2=자주/많이 그렇다

1	물이나 음식이 코로 넘어온다.	0	1	2
2	(딱딱한) 음식을 씹기가 힘들다.	0	1	2
3	평소에 식사할 때 숨이 차다.	0	1	2
4	컵으로 물 마실 때 흘린다.	0	1	2
5	마른 음식(예: 크래커)을 먹기가 힘들다.	0	1	2
6	예전에 비해 말하는 목소리가 변했다.	0	1	2
7	알약을 넘기기가 힘들다.	0	1	2
8	음식을 먹은 후에 혀 밑에 음식물이 남아있다.	0	1	2
9	평소에 숨 쉬는 것이 힘들다.	0	1	2
10	예전에 비해 (집에서의) 식사 시간이 오래 걸린다.	0	1	2
11	물이나 액체에 사레가 걸린다.	0	1	2
12	음식을 씹으면서 흘린다.	0	1	2
13	음식을 입에 넣으면서 흘린다.	0	1	2
14	나에게 씹는 문제가 있다.	0	1	2
15	나에게 삼키는 문제가 있다.	0	1	2
16	씹는 문제 때문에 한 끼 식사량이 줄었다.	0	1	2
17	씹는 문제 때문에 사람들과의 모임을 꺼린다.	0	1	2
18	씹는 문제 때문에 속상하다.	0	1	2

19	삼키는 문제 때문에 식사시간이 오래 걸린다.	0	1	2
20	삼키는 문제 때문에 사람들과의 모임을 꺼린다.	0	1	2

APPENDIX 8. Penetration aspiration scale (PAS)

침습-흡인 척도 (Penetration Aspiration Scale, PAS)							
척도	기준	결과					
		12% semi thick		6% semi thin		liquid	
		5cc	15cc	5cc	15cc	5cc	15cc
1	음식물이 기도로 들어가지 않음	정상	정상	정상	정상	정상	정상
2	음식물이 기도로 들어가서 성대 위에 머물러 있을 때에, 기도 밖으로 배출할 수 있음	침습	침습	침습	침습	침습	침습
3	음식물이 기도로 들어가서 성대 위에 머물러 있지만, 기도 밖으로 배출할 수 없음	침습	침습	침습	침습	침습	침습
4	음식물이 기도로 들어가서 성대에 닿아 있는 상태이며, 스스로 기도 밖으로 배출할 수 있음	침습	침습	침습	침습	침습	침습
5	음식물이 기도로 들어가서 성대에 닿아 있는 상태에서 스스로 기도 밖으로 배출할 수 없음	침습	침습	침습	침습	침습	침습
6	음식물이 기도로 들어가서 성대 아래쪽으로 내려갔을 때에 스스로 후두 또는 기도 밖으로 배출할 수 있음	흡인	흡인	흡인	흡인	흡인	흡인
7	음식물이 기도로 들어가서 성대 아래쪽으로 내려갔을 때에 스스로 배출하려는 노력을 함에도 후두 또는 기도 밖으로 배출할 수 없음	흡인	흡인	흡인	흡인	흡인	흡인

8	음식물이 기도로 들어가서 성대 아래쪽으로 내려갔지만, 배출하려는 어떠한 노력이 이루어지지 않는 상태임	흡인	흡인	흡인	흡인	흡인	흡인

APPENDIX 9. Videofluorscopic dysphagia scale(VDS)

VDS (Videofluorscopic dysphagia scale)							
Parameter	**Coded value**	**12% semi (thick)**		**6% semi (thin)**		**liquid**	
		5cc	**15cc**	**5cc**	**15cc**	**5cc**	**15cc**
Lip Closure	Intact	0	0	0	0	0	0
	Inadequate	2	2	2	2	2	2
	None	4	4	4	4	4	4
Bolus formation	Intact	0	0	0	0	0	0
	Inadequate	3	3	3	3	3	3
	None	6	6	6	6	6	6
Mastication	Intact	0	0	0	0	0	0
	Inadequate	4	4	4	4	4	4
	None	8	8	8	8	8	8
Apraxia	None	0	0	0	0	0	0
	Mild	1.5	1.5	1.5	1.5	1.5	1.5
	Moderate	3	3	3	3	3	3
	Severe	4.5	4.5	4.5	4.5	4.5	4.5
Tongue to palate contact	Intact	0	0	0	0	0	0
	Inadequate	5	5	5	5	5	5
	None	10	10	10	10	10	10
Premature bolus loss	None	0	0	0	0	0	0
	<10%	1.5	1.5	1.5	1.5	1.5	1.5
	10-50%	3	3	3	3	3	3
	>50%	4.5	4.5	4.5	4.5	4.5	4.5
Oral transit time	<1.5s	0	0	0	0	0	0
	>1.5s	3	3	3	3	3	3
Triggering of pharyngeal swallow	Normal	0	0	0	0	0	0
	Delayed	4.5	4.5	4.5	4.5	4.5	4.5
	None	0	0	0	0	0	0

Vallecular residue	<10%	2	2	2	2	2	2
	10-50%	4	4	4	4	4	4
	>50%	6	6	6	6	6	6
Laryngeal elevation	Normal	0	0	0	0	0	0
	Impaired	9	9	9	9	9	9
Pyriform sinus residue	None	0	0	0	0	0	0
	<10%	4.5	4.5	4.5	4.5	4.5	4.5
	10-50%	9	9	9	9	9	9
	>50%	13.5	13.5	13.5	13.5	13.5	13.5
Coating of pharyngeal wall	No	0	0	0	0	0	0
	Yes	9	9	9	9	9	9
Pharyngeal transit time	≤1.0s	0	0	0	0	0	0
	>1.0s	6	6	6	6	6	6
Aspiration	None	0	0	0	0	0	0
	Supraglottic penetration	6	6	6	6	6	6
	Subglottic aspiration	12	12	12	12	12	12
Total							

Abstract in Korean

파킨슨병 환자 대상의 PhoRTE 음성치료가 말, 음성, 삼킴 기능에 미치는 영향

파킨슨병 (Parkinson's disease, PD)는 주요 4 가지 증상으로 resting tremor, bradykinesia, rigidity and postural instability의 조합을 보이며 인후두 근력 약화가 나타난다. 따라서 환자 대부분이 말, 음성 및 삼킴에 어려움을 보이며 삶의 질에도 부정적 영향을 미친다. Phonation Resistance Training Exercise (PhoRTE) 음성치료 기법으로 노인성 발성장애를 치료했을 때 그 효과성은 입증되었으나 이를 신경학적 퇴행성 질환에 적용한 연구는 미비한 실정이다. 때문에 본 연구는 PhoRTE 음성치료 기법을 PD 환자에게 적용하여 말, 음성 뿐만 아니라 삼킴 기능의 개선과 삶의 질 변화를 알아보고자 한다.

총 19 명의 PD 환자를 대상으로 치료군 10 명(남: 5 명, 여: 5 명, 연령 = 74.90±8.73), 대조군 9명(남: 6명, 여: 3명, 연령 = 77.00±10.38)의 대상자로 연구를 진행하였다. 이들의 연령, K-MMSE, ASHA NOMS swallowing level scale, speech POT에 대해서는 그룹 간 유의한 차이가 없었다. 치료군에 속하는 환자들은 4주 간 PhoRTE 치료를 받았으며 치료 전·후로 평가를 진행하였다. 대조군에 속하는 환자들은 4주 간격으로 사전, 사후 평가 만을 진행하였다. 실시한 평가 지표는 말, 음성, 삼킴 기제, 설문지를 포함하여 수집하였다.

PhoRTE 음성치료 기법을 적용한 결과, 음성 측면에서 치료군의 경우 MPT, jitter($p<.01$), shimmer, CPPs(vowel)($p<.05$), speech intensity(vowel)($p<.001$)에서 유의한 변화를 보였고, 대조군의 경우 jitter, shimmer 에서 유의한 증가를 보였다.($p<.05$) 말 측면에서는 AMR/kuh/, VSA 에서 유의한 변화를 보였다($p<.05$). 삼킴 측면에서 치료군의 경우 GUSS에서 유의미한 증가를 보였으며($p<.05$) 삼킴 관련 설문지에서는 대조군이 SWAL-QOL 총점에서 유의미하게 감소되었다($p<.05$).

본 연구는 음성 뿐만 아니라 이와 해부학적 구조를 공유하는 삼킴 기능에 대해 음성치료 기법을 적용하여 그 효과성을 검증하였고, 퇴행성 질환인 PD 환자들이 적시에 적절한 치료를 받는 것이 임상적으로 도움이 됨을 입증한데 의의가 있다.

핵심되는 말 : 파킨슨병, 마비말장애, 삼킴장애, 발성저항훈련(PhoRTE), 음성치료, 말, 삼킴, 삶의 질