ISSN: 2644-2957
DOI: 10.33552/OJCAM.2022.07.000669
Online Journal of Complementary & Alternative Medicine
Iris Publishers

Research Article

Long Haulers, Vocal Fatigue and Respiration: An Interdisciplinary Manual Therapy Approach

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Received Date: June 14, 2022

Published Date: July 06, 2022

Abstract

Coronavirus disease (COVID-19) is an infectious disease that is caused by the SARS-CoV-2 virus and is spread by respiratory droplets and small aerosols when a person coughs, breathes, or speaks. A subset of patients who recovered from the acute phase of COVID-19 reported persistent symptoms. These patients have been classified as suffering from PASC (Post-Acute Sequelae of SARS-CoV-2 infection) or "long COVID," with the patients often being referred to as "long haulers."

The purpose of the research was to determine the efficacy of a collaborative physical therapy and speech therapy intervention via telehealth on COVID-19 "long haulers." These individuals complained of overall fatigue, breathlessness with activities of daily living, and vocal fatigue.

While there is research supporting the benefit of an interdisciplinary approach to therapy, little is known about the benefits of a combination of physical and speech therapy in addressing vocal fatigue related to COVID symptoms.

We followed a non-randomized controlled AB single-subject research design, where patients' baseline measurements were compared to those after a 4-week treatment period of self manual stretching of the diaphragm, rib cage, and thoracic and cervical spine.

Overall, positive outcomes were seen with the pulse oximeter readings and modified Borg scale readings after the four-week treatment course of exercises and self manual techniques. It is hoped that this study will inform practitioners of this interdisciplinary approach to mitigate some of the effects of COVID-19 on "long haulers".

Keywords: Long COVID; Long-haulers; Vocal fatigue; Voice; Diaphragm; Physical therapy; Speech therapy; SARS-CoV-2; Exercise; Telerehabilitation

Introduction

In January 2022, the Novel coronavirus, COVID-19 was confirmed by the Centers for Disease Control and Prevention (CDC) in the United States after a patient returned from Wuhan, China, where an outbreak of the virus was detected in December 2019. The CDC first began alerting clinicians in January 2020, to be on the look-out for patients with respiratory symptoms [1]. As the number of people infected by SARS-CoV-2, the virus that causes COVID-19, grew exponentially with severe cases leading to pneumonia and death, the World Health Organization officially declared coronavirus disease (COVID-19) a pandemic in February 2020 [2]. Since then, COVID-19 has infected more than 462 million people worldwide resulting in over 990,000 deaths in the United States [3].

Many patients who recovered from COVID-19 have reported persistent symptoms after they recovered from the acute phase of the disease. According to Mancini, et al. [4], approximately 20% of patients who recover from COVID-19 remain symptomatic, however, the etiology of the syndrome remains unclear. Literature emerged throughout the pandemic described this syndrome as PASC (Post-Acute Sequelae of SARS-CoV-2 infection), which is often referred to as "long COVID." This syndrome refers to a wide range of symptoms that persist after a minimum of 4 weeks from the initial phase of the COVID-19 diagnosis [5].

This population of patients with PASC, also referred to as 'long haulers', commonly complain of a variety of symptoms including: shortness of breath, cough, severe fatigue, "brain fog" or cognitive difficulty, heart palpitations, chest pain, sleep disturbance, loss of sense of taste and smell, and myalgia (muscle aches and pains) [5]. Other symptoms reported include neurological deficits, rashes, and gastrointestinal dysfunction. The latest estimates suggest that 10% to 20% of patients who experience the acute phase after being infected with SARS-CoV-2, continue to experience symptoms beyond 12 weeks after being diagnosed [6]. In their single-center observational study of 41 patients, Mancini et al. [4], found that almost all the patients with long COVID, (88%) displayed abnormal breathing patterns referred to as dysfunctional breathing. The diaphragm is acknowledged in literature to be the main respiratory muscle and plays an important role in breathing and voice projection. The diaphragm also contributes to other bodily processes such as swallowing, vomiting, expectoration, urination and defication. It also helps maintain posture, facilitates the venous and lymphatic return, helps the viscera located above and below the diaphragm work properly, and can affect pain perception and emotional state [7]. Several studies suggest there is evidence for angiotensin-converting enzyme 2 (ACE-2) expression in the human diaphragm which could make that tissue more susceptible to COVID-19 than other tissues with fewer ACE-2 receptors. ACE-2 is a primary receptor of SARS-CoV-2, allowing the virus to enter and infect human cell tissues [8,9]. One group of researchers discovered SARS-CoV-2 viral infiltration in the diaphragm of a subgroup of patients in intensive care unit (ICU) who were being treated for COVID-19 infections [10]. In their study, Shi et al. (2021) found that when comparing patients that were admitted to the ICU in hospitals with COVID-19 to those in the ICU who had non-COVID-19 issues, the epimysial and perimysial fibrosis was more than 2-fold higher in the diaphragms of COVID-19–ICU patients compared with control-ICU patients. Shi's team hypothesized that severe diaphragm myopathy associated with COVID-19 may lead to diaphragm weakness and might contribute to ventilator weaning failure, persistent dyspnea, and fatigue in patients with COVID-19 who survived their ICU stay. A study by Bordoni et al. [11], stated the health of the diaphragm muscle is critical for many patients, not just those with respiratory diseases and that proper training of the main respiratory muscle can be of benefit in several clinical scenarios [11]. Bordoni's study did state, however, there were not so many authors reporting on therapeutic techniques focused on manual approaches and on the manual evaluation of the diaphragm. Nair et al. [12], stated in their research that the function of the diaphragm can be impaired by diseases such as Chronic Obstructive Pulmonary Disease (COPD). These findings suggest that COPD shortened the diaphragm's operating length and changed its mechanical linkage, making the diaphragm's contraction less effective in raising and expanding the lower rib cage. This mechanical disadvantage led to increased work of breathing and reduced the functional capacity. Nair's team found the diaphragmatic stretch technique and manual diaphragm release technique improved diaphragmatic excursion and was safely recommended for patients with clinically stable COPD [12].

The Long Island University researchers of this study hypothesized that if SARS-CoV-2 is able to infiltrate the diaphragm and affect its function, this could potentially affect one's breathing which in turn may contribute to their perceived level of exertion in performing activities of daily living (ADL), as well as affect voice quality since the muscle is associated with the primary movement for breathing and affects the movement of the chest cage [9].

A surfacing complaint in 'long haulers' is also vocal fatigue, where patients struggled to project their voice and complained of inability to speak for periods of time and at appropriate volumes for conversation. "Trailing off" of voice was commonly experienced in this subgroup of long haulers who shared their story in support groups that the study authors met with. By definition, vocal fatigue is a functional voice disorder that is secondary to poor voice mechanics in the presence of intact physical structures. Hunter and his colleagues [13], found that one definition of vocal fatigue included increased vocal effort, neck and shoulder tension, reduced control of pitch variation, worsening of symptoms as the day progresses, compromised vocal quality, and/or a weak voice. However, improvement is said to occur following voice rest [14,15]. In essence it is said that prolonged voice use causes an increased self-perceived sense of effort [15]. Diagnosis of vocal fatigue is reliant on the patient's report as vocal folds tend to be intact. In a study by D'haeseleer and colleagues [16], vocal misuse and stress were reported in patients with vocal fatigue. Further, the most common self-reported complaint in those patients was laryngeal tension.

The novel COVID-19 virus has impacted individuals in various ways, leaving some with long-standing symptoms in its wake. Severe muscle weakness and fatigue impairing mobility are among the common symptoms associated with the COVID-19 virus [17]. Further, patients are presenting with complaints of dysphonia following COVID-19. Aberrant acoustic parameters associated with insufficient airflow as noted by decreased maximum phonation time, aperiodicity, increased perturbation, and increased noise

were noted in those individuals presenting with a dysphonia [18]. Cantarella et al. [19], found a high prevalence (43.7%) of individuals presented with a self-evaluated mild-to-moderate dysphonia following COVID-19, despite not requiring hospitalization for the treatment of COVID. Of the 160 patients treated for mild-to-moderate COVID-19 symptoms in Lombardy, Italy, 26% of the individuals reported vocal fatigue in that particular study. Moreover, in a study by Lechien et al. [20], 26.8% of individuals studied presented with dysphonia, and of those individuals, only 3.7% reported aphonia (the most severe form of dysphonia). Although the etiology of the noted dysphonia is not clear at this time, it is suggested that the dysphonia may be attributed to an airway inflammatory process resulting from vocal fold edema. Other suggestions include vagal neuropathy, vocal fold injury due to vocal abuse and misuse, such as forceful coughing or vomiting, injury due to intubation, poor lung function, or psychogenic related causes [21]. Although, dysphonia related to the COVID-19 virus as an acute symptom has been documented, albeit limited, there is even less research related to the long-term voice effects of COVID-19.

The speech pathologist has an integral part in the rehabilitation of those individuals suffering from the effects of the COVID-19 virus, specifically in the treatment of dysphonia [22]. Moreover, physical therapy, occupational therapy, and speech therapy have been demonstrated to be efficacious in the treatment of the symptomatology related to COVID-19. These therapies as part of an interdisciplinary team are integral in increasing self-sufficiency in those affected by the virus [23].

In order to reduce muscle tension in the larynx, manual therapy can be implemented. Manual therapy serves to improve extra laryngeal muscle function and in turn yield improved voice production. Manual therapy has been found to decrease laryngeal muscle tension and improve muscle movement in the neck region [24,25]. Craig and colleagues [26], found that manual physical therapy as a part of the treatment plan in conjunction with traditional voice therapy should be considered as a therapeutic approach for certain types of dysphonia. Further, a systemic review of the efficacy of voice treatment [27] found literature supporting the use of relaxation for the treatment of hyper functional voice disorders.

Our investigative team evaluated the effect that a course of self-performed guided manual physical therapy treatment that incorporated stretching of the diaphragm, cervical, thoracic and rib cage region would have on the long-hauler's complaint of dyspnea, overall fatigue and voice quality. Previous literature has demonstrated the beneficial effects of exercise on long-haulers' symptoms. Mancini and her colleagues [4], stated that the underlying factor contributing to overall complaint of fatigue in some long haulers may be due to hyperventilation and/or dysfunctional breathing and that these abnormalities may be addressed with breathing exercises and breath retraining. Another study, carried-out by Jimeno-Almazán et al. [28], found that regular exercise helped to reduce the long-term effects of COVID-19 and improve symptoms [28].

Due to the challenge of maintaining social distancing and patient and clinician comfort during the pandemic and spikes of positive cases of COVID in the New York area such as the omicron and delta variants, the investigators chose to utilize telehealth physical therapy sessions for this study. Literature showed how telerehabilitation (telehealth physical therapy) offers a beneficial alternative to in-person physical therapy sessions [29,30]. A study by Gabriela da Silva Vieira et al. [31], found that telerehabilitation reduced dyspnea in people with COVID-19 - more specifically, patients showed improvement in functional capacity, dyspnea, performance and quality of life, without substantially increasing adverse events.

The purpose of the research was to determine the efficacy of a collaborative physical therapy and speech therapy intervention, using self-performed guided manual physical therapy treatment via telerehabilitation, on "long haulers" who complained of overall fatigue, breathlessness with activities of daily living, and vocal fatigue. To date, much is known about the benefit of an interdisciplinary approach to therapy, however not much is known about the benefits of a combination of physical and speech therapy in addressing vocal fatigue related to COVID-19 symptoms. This study aimed to investigate an interdisciplinary approach to mitigate the effects of COVID-19 on "long haulers".

We hypothesized that due to the SARS-Cov-2 effect on the pulmonary system, the muscles in the lower rib cage and diaphragm became tight due to lack of deep breathing during the active infection which resulted in an inefficient, compensatory breathing pattern. Without proper breathing, proper phonation can not occur [32]. The LIU researchers speculated that by addressing the tight diaphragm and rib cage mobility, the participants would demonstrate increased ability to breathe more easily fostering better endurance overall, improved pulse oximeter readings with ADL activities and voice quality. The intent is to demonstrate this treatment approach can help foster better support of the voice and restore more efficient breathing patterns, therefore indirectly improving overall feelings of fatigue and dyspnea as well as voice index scores.

Materials and Methods

This study followed a non-randomized controlled AB single-subject research design, where patients' baseline measurements were compared to those after a 4-week treatment period of self manual stretching of the diaphragm, rib cage, thoracic and cervical spine. The participants completed two surveys pre and post treatment utilizing a pulse oximeter to check oxygen saturation

and a pedometer to ensure accurate walking length to complete a half mile walk. All participants were provided with an oximeter and encouraged to use the same device to control for variability of varying oximeters. After completion of the walk, the participants measured overall fatigue, breathlessness with activities of daily living using a modified Borg scale and logging their pulse oximeter reading after the half mile walk. Further, the participants completed a pre and post self-analysis of the impact on vocal function, using the Voice Handicap Index (VHI). Breath support for voicing was also measured using maximum phonation time as a benchmark measure.

This study was reviewed and accepted by the Long Island University Institutional Review Board (IRB #: 21/11-144). All LIU protocols were adhered to for this study.

Intervention/treatment

Treatment included manual techniques and self-massage, stretching, and strengthening of the muscles surrounding the rib cage and chest wall. Participants were guided by a licensed physical therapist in performing self manual therapy stretch and release techniques to the diaphragm, intercostals, chest and neck musculature along with stretching and strengthening exercises to the rib cage, thoracic and cervical spine region. Further, under the supervision of a licensed speech pathologist, the participants carried-out manual therapy to their neck region, progressive relaxation exercises, and sustained phonation tasks. The therapy took place two days per week for 45-minute sessions through a HIPAA compliant telerehabilitation and guided techniques by a licensed physical therapist and speech pathologist, and they also performed one additional unsupervised home session per week, for a total of three sessions per week.

During the sessions, participants performed soft tissue release to scalenes, stretch to intercostal ribs 6 – 10, self diaphragm stretch and self manual diaphragm release technique in sitting to accommodate participants request to do in sitting. For the Diaphragmatic Stretch Technique, participants were asked to sit erect and put their hands around the thoracic cage, introducing fingers in the subcostal margins. The participant rounded the trunk to relax the rectus abdominis. As the participant exhaled, the participant's hands caudally grasped the lower ribs at the subcostal margin. A firm and gentle traction was maintained as the patient inhaled. This was done for three slow breaths.

The participants then performed the self Manual Diaphragm Release Technique [33]. The participants were instructed to make manual contact with the hypothenar region and last three fingers bilaterally to the underside of the seventh to tenth rib costal cartilages. In the inspiratory phase, the participant gently pulled the contact points of both hands in the direction of the head and slightly laterally, accompanied by the elevation of the ribs. As the participant exhaled, hand contact was maintained with resistance and deepened towards the inner costal margin. During the following 5 respiratory cycles, the participant deepened the hand contact inside the costal margin.

After the release techniques participants performed stretches held for 30 seconds each for one repetition, that included: scalene, upper trap, pectoral stretches. Then they performed 5 reps each of the cat/camel thoracic stretch, threading to the thoracic and rib cages on all fours, 5 times each side, a 30 second lateral side stretch to the Quadratus lumborum, then a self intercostal rib stretch to each intercostal space between ribs 6 – 10 with one hand on the superior rib and one on the lower rib with guidance to "open up the intercostal region" as they side bend. Participants then performed the tree hugger serratus exercise for 20 repetitions and diaphragmatic breathing with hands on lower rib cage to foster proper technique for 5 breaths.

Participants

Three English-speaking individuals were recruited from various COVID-19 Long Hauler support groups. All participants had previously been diagnosed with the COVID-19 virus; the time between diagnosis and the start of this study ranged from 1 to 2 years with two out of the three participants having a 2-year lapse in time. There were two men and one woman whose ages ranged from 34 to 53, and averaged 40.3 years. The participants met screening criteria in order to participate in the study, including having prolonged symptoms for more than 4 weeks after SARS-CoV-2 infection. All participants were required to have the medical clearance form signed prior to participation in the therapies. The participants had to have healthy lungs. Individuals that were smokers, diagnosed with COPD, emphysema or asthma were excluded. Other exclusion factors included: undergoing treatment for cancer, radiation treatment, surgical removal of lung (whole or partial), active COVID-19 infection, active rheumatological disease, autoimmune disease affecting cartilage, muscles, lungs, or joints (scleroderma, rheumatoid arthritis, lupus, etc). Further the participants were excluded if they were currently receiving physical therapy for the treatment of an injury or illness. Participants with prior history of neurological deficits, head and neck cancer, or voice disorders or those previously treated for any voice dysfunction were not included in this study.

Interventions

The psychosocial impact of the voice disorder pre- and post-treatment were captured via the Voice Handicap Index, where patients fill out a questionnaire for self-analysis of vocal function. The VHI is a 5-point scale developed to quantify the effects of voice disorders within three subscales: 1) the functional subscale investigates the impact on activities of daily living, 2) the emotional scale assesses the affective response to the voice disorder, and

3) the physical subscale investigates the self-perceived vocal characteristics [34]. The participants were asked to complete the questionnaire and the scores were then obtained for baseline (pre-) and post-treatment measures. Voice measures were assessed by measuring their maximum sustain phonation time (recorded in seconds).

This study analyzed the effect of manual physical therapy techniques on the ribcage, diaphragm, intercostal and neck muscles on a patient's pulse oximeter reading and modified Borg Scale rating after walking half a mile. The modified Borg Scale is a 10-point scale developed to quantify the perceived rate of difficulty breathing or dyspnea associated with an activity. Studies have shown that the modified Borg Scale is a simple, valid tool to monitor exercise intensity [35]. The scale is based from zero to ten, zero meaning "nothing at all", through ten which is "maximal difficulty". The participants were asked to complete the modified Borg Scale questionnaire and perform a pulse oximeter reading immediately after completing the task of walking a half mile using a pedometer provided by the researchers for consistency pre- and post- course of a 4-week treatment. The scores were then obtained for pre- and post-treatment measures.

Results

Participant One

Participant one was a 53 year old female who was diagnosed with COVID-19 during the first wave in New York in 2020 and displayed long-haul symptoms for two years. Participant one complained of voice trailing off during social engagements and teaching professional lectures. Participant one rated her perceived level of breathlessness/difficulty breathing as a 4/10 on the modified Borg scale after completing a half mile walk tracked with a pedometer. Participant one's pulse oximeter reading was at 92% after the half mile walk. After completing the four-week treatment sessions, the participant performed the half mile walk again. The Borg scale rating improved to a 2/10 perceived level of breathlessness/difficulty breathing and her pulse oximeter rating also improved to 96% after walking the half mile distance. She stated she feels her pace of walking also increased, however it was not timed for comparison to the first attempt at walking the distance.

Participant one demonstrated an improvement in both of the voice benchmark assessments. The participant demonstrated an improvement in maximum phonation time, with an increase of 11.81 seconds between the pre- and post-treatment measurements, demonstrating a 198% increase (baseline = 5.97 s; post treatment–= 17.78 s). Self perception of voice difficulties using the Voice Handicap Index yielded a decrease in scores for this participant, indicative of decreased functional, physical, and emotional perception of voice deficits. She scored a total of 96 at baseline and decreased to 60 after the treatment, reducing in severity from a rating of severe to moderate. The functional subsection yielded a baseline score of 28 and a post-treatment score of 19; the physical subsection yielded a baseline score of 36 and a post-treatment score of 22; and the emotional subsection of the VHI yielded a baseline score of 32 and a post-treatment score of 19. These scores demonstrate a decrease in self perceived voice deficits in all three subsections.

Participant Two

Participant two was a 34 year old male diagnosed with COVID-19 during the first wave in spring of 2020. He complained of issues of long-COVID for 2 years. From the start, participant two struggled with compliance and consistency in attendance and performing required tasks of the study. He failed to perform the half mile walk and therefore no baseline measurements were available for the pulse oximeter reading and the Borg scale measure. Participant two dropped out of the study after missing some sessions due to work schedule and also said he had a preexisting hernia and stomach issues so chose to drop out of study during the third week of the treatment protocol.

He did however perform the voice fatigue index benchmark assessments. Participant 2 had an increase of 0.69 seconds demonstrating a 0.36% increase (baseline = 18.92 s; post treatment = 19.61 s). The Voice Handicap Index yielded a total baseline score of 12 and a total post treatment score of 11. This was a decrease in scores, however the participant maintained a rating of mild post treatment. The functional subsection of the VHI yielded a baseline score of 2 and a post-treatment score of 2; the physical subsection yielded a baseline score of 10 and a post-treatment score of 9; and the emotional subsection of the VHI yielded a baseline score of 0 and a post-treatment score of 0.

Participant Three

Participant three is a 33 year old male who was diagnosed with COVID-19 one year ago in 2020 during the delta variant strain and then for a second time in December 2021 during the omicron variant surge where his complaints of voice fatigue and overall breathlessness became more apparent. Participant three is a professional drummer and after two months of the second diagnosis, still could not perform drum tasks on a professional tour for more than 10 minutes due to dyspnea. Participant three's baseline measurements included a pulse oximeter reading of 85% after the initial half-mile walk that improved to 98% after the second half-mile walk after the four-week course of treatment. Participant three said his Borg scale rating after the baseline half-mile walk was a 4/10 but when completing the course of treatment said he felt 50% better regarding dyspnea and asked to change that original 4/10 score to an 8/10 and rated the post-treatment Borg scale as a 4/10. Participant three also returned to touring and drumming, and was able to complete a two-hour concert.

Voice parameters post treatment reflected an improvement in vocal function. Participant three demonstrated an improvement in both of the voice benchmark assessments. The participant demonstrated an improvement in maximum phonation, with an increase of 12.29 seconds between the pre- and post-treatment measurements, demonstrating an increase of 133% (baseline = 9.21 s; post-treatment = 21.50 s). Self perception of voice difficulties using the Voice Handicap Index yielded a decrease in scores for this participant, indicative of decreased functional, physical, and emotional perception of voice deficits. Participant three scored a total of 22 at baseline and decreased to 15, however the rating was maintained at mild. The functional subsection yielded a baseline score of 0 and a post-treatment score of 1; the physical subsection yielded a baseline score of 16 and a post-treatment score of 10; and the emotional subsection of the VHI yielded a baseline score of 6 and a post-treatment score of 4. These scores demonstrate a decrease in self perceived voice deficits in all three subsections. The above stated findings indicate an increase in function for both quantitative and qualitative analysis.

Incidental findings

All three participants shared the experience of feeling their heart rates jump during long periods of speaking. All three had medical evaluations throughout their long-hauler diagnosis and said their physician had cleared them for activity and said it was part of the residual effect of the virus. More research is needed to better understand the relationship between potential heart rate abnormalities and COVID-19 status.

Discussion

To date there have been limited studies of COVID-19 patients who later present with vocal fatigue and the potential beneficial effects of self manual stretching treatment, as derived from an inter-professional collaboration effort. We aimed to investigate the effect of manual physical therapy combined with speech therapy intervention on patients' with long haul COVID-19 complaints of vocal fatigue and overall fatigue combined with a speech therapy intervention.

The ultimate goal of the study was to determine if an inter-professional treatment approach including treatment with a speech therapist and a physical therapist utilizing a manual physical therapy regimen to the thoracic, ribcage, diaphragm and neck musculature should be standard of care for all patients with long haul COVID-19 with complaints of dyspnea, overall fatigue and vocal fatigue.

Information gathered from this study will help improve patient-care practices by demonstrating that a collaborative effort in treatment of long hauler COVID-19 with overall fatigue and vocal fatigue is necessary given that the novel coronavirus has been found to have a multisystem impact on infected individuals [36]. Our findings show a correlation with a four week course of exercise and self performed manual therapy techniques addressing the ribcage, thoracic, cervical and diaphragm guided by a licensed physical therapist and speech therapist with overall long-haulers' complaints of fatigue and vocal fatigue. Two of the three participants showed improvements with their pulse oximeter readings (4% and 13% increase) and their reported modified Borg scale readings improved by 50% after completing a half mile walk. The third participant, Participant Two, was not consistent with attending sessions, failed to provide baseline measures with the walking test and dropped out of the research study. Participant Two did however perform baseline and follow up voice measures.

Vocal fatigue and overall fatigue were found to be common symptoms reported by those with Long COVID, according to the literature and what has been reported by multiple long-hauler support groups interviewed by the researchers [37]. Vocal fatigue was a primary complaint of the participants in this study. They described it as if their "voice is trailing off", or the inability to maintain prolonged conversation in social situations. The participants also experienced general fatigue in performing ADL's. Participant Three is a professional drummer who stated he used to perform drumming tasks for two hours but after contracting COVID-19, tolerated only 10 minutes of drumming before collapsing from breathlessness and fatigue during a practice session. Participant One is a professor and said vocal fatigue caused her to struggle with giving lectures since being diagnosed with COVID. Both participants said it had affected their professional and social life, however a marked improvement was reported following this 4-week course of therapy.

The participants were evaluated through a telehealth visit prior to the first exercise session. It was observed that all three participants displayed dysfunctional breathing motions that included increased apical and upper chest breathing with a lack of lateral expansion with the lower rib cage with deep inhalation. All three participants demonstrated increased tone of the neck musculature, particularly the scalenes and sternocleidomastoid (SCM), when they inhaled deeply. The participants in the study demonstrated accessory breathing and an inability to take full breaths. They also noted lack of rib mobility in the lower rib cage (ribs 7- 11) upon lateral side excursion motions. The participants felt tightness when palpating their diaphragms and noted resistance with lower rib cage while performing motions such as side bending. The accessory muscles of inspiration, (sternocleidomastoid and scalenes) and expiration (abdominal) are not normally used in the resting state, and abnormalities in breathing may be demonstrated with breathing rate, rhythm, and effort [38].

These observations suggested that a dysfunctional diaphragm and tight intercostal and neck musculature along with limited rib mobility could be an underlying reason for the dysfunctional breathing patterns that in return would affect overall breathing

efficiency leading to fatigue and compensation that would affect the projection and voice quality [39].

The researchers hypothesized that due to the SARS-CoV-2 virus' effect on the pulmonary system, the muscles in the lower rib cage and diaphragm became tight due to shallow breathing during the active infection which resulted in an inefficient, compensatory breathing pattern. The researchers speculated that by addressing the tight diaphragm and rib cage mobility, along with the tight neck musculature such as the SCM and scalenes, the participants would demonstrate increased ability to breathe more easily-fostering better endurance overall, improved pulse oximeter readings with ADL activities and voice quality.

Past research has shown that when the diaphragm is dysfunctional, abnormalities in breathing may occur [40]. More efficient breathing patterns could occur by restoring proper diaphragm and rib cage mobility and flexibility and strength of the chest and neck musculature. Restoring muscle balance would help eliminate muscle compensation in the cervical musculature and lessen the strain on the neck musculature, promoting better breathing patterns and thus better voice projection and endurance.

Limitations

A limitation to this study was the sample size. Two participants successfully completed the treatment intervention in this single-subject research design. However, this preliminary study provides some evidence of beneficial effects from self-manual stretching exercises and serves as a pilot study to further analyze this interdisciplinary collaborative treatment design for individuals presenting with the long-haul effects from the COVID-19 virus.

Future Research

This was a single center study. Future research of the efficacy of collaborative physical and speech therapy for the treatment of the long-haul effects of COVID-19 should incorporate a multicenter design, which would allow for a larger sample size. The larger sample size may yield results that could be statistically generalized to this population. Future studies may include collaborative effort with cardiologists to further investigate heart rate inconsistencies and potential vagal nerve involvement, as was found as incidental findings in this study.

Funding

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Conflict of Interest

The authors declare no competing interests.

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