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# Effect of physical exercise on voice in people living with COPD

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## Abstract

Previous research on the effect of exercise on voice has been mainly performed in a healthy population. However, the competition between breathing and speaking might be more pronounced in people with COPD. We aimed to evaluate voice features change in people living with COPD after exercise. A prolonged vowel /a/ and paced reading task were performed before and after an exercise task. In this exploratory study, differences were found in the sustained phonation for shimmer (apq5 and local), vowel duration, F1 frequency, and H1-A3 harmonic difference, when taking sex into account. Also, we saw a trend that voice features change by increasing COPD severity for HNR (mean) in the sustained phonation, and in the forced reading task for F2 frequency, H1-A3 harmonic difference (mean) and Hammarberg index. More research is needed using voice recordings from a larger sample size to confirm these findings, and possibly implement this in an exacerbation model using voice.

**Index Terms**: COPD, pathological voice, pathological speech, acoustic features, acoutistic analysis

## 1. Introduction

Physical stress is known to affect different aspects of one's voice. During a physical task, breathing frequency, heart rate, and tidal volume increase, and are prioritized above speech production. While attempting to produce speech during exercise, there is a conflict between the voice production system and increased respiration, influencing airflow and voice stability. In addition, exercise-induced muscle fatigue can impact the respiratory and laryngeal muscles, potentially causing vocal strain or breathlessness [1, 2]. Multiple acoustic features change during a physical task. For example, the mean fundamental frequency (F0) increases with physical task stress in 60% of the healthy speakers [3]. Other acoustic features that change during exercise are jitter, shimmer, HNR, and fundamental frequency [4]. Furthermore, difficulties in speech production and its associated acoustic parameters are strongly correlated with the difficulty of the exercise task [3, 5]. Most research has been conducted on a healthy, young and fit population, whereas more than half of the adults globally have an underlying chronic disease [6]. Such chronic diseases, particularly respiratory conditions, might affect voice during exercise differently than in a young and healthy population such as previously studied.

Chronic Obstructive Pulmonary Disease (COPD) is the most common chronic respiratory disease in the world, and is estimated to currently affect 12.6% of the people aged 40 years and older worldwide [7]. In addition, it is the eighth leading cause of poor health [8]. COPD is characterized by chronic, often progressive, airflow limitation causing symptoms such as dyspnea, chronic cough, sputum, and tiredness. This patient population is known for its gradual loss of exercise capacity due to a complex interplay of symptoms, ventilatory impairments, gas exchange limitations and impact on the (respiratory) muscles [9]. Apart from peripheral muscle loss [2], COPD can also affect the respiratory muscles, including the diaphragm and intercostal muscles [10]. A common cause of dyspnea and functional limitation in people with COPD is dynamic hyperinflation. Dynamic hyperinflation is caused by expiratory flow limitation: due to a shortened exhalation period during exercise, complete exhalation is prevented, resulting in air trapping and thus symptoms of dyspnea [11]. Additionally, people living with COPD are at risk for experiencing acute disease worsening, defined as exacerbations. These are pivotal moments in the disease trajectory, as they are associated with a lower quality of life and higher mortality [9].

Since COPD affects multiple aspects of the respiratory system and exercise capacity, it could also affect the speech production system. Previous research on voice in people living with COPD has shown a change in maximum phonation time, shimmer, formants, jitter, and Harmonics-to-Noise-Ratio (HNR) compared to healthy controls [12], but this has not been studied yet after exercise. What has been shown is that voice is different during an exacerbation [13]. Since patients have an expiratory flow limitation during exercise similar to an exacerbation, we hypothesized voice features also change in people living with COPD after exercise. Additionally, since the respiratory system in women is smaller, the effect of COPD on speech could be notably different between sexes [14]. Lastly, dysphonia is another often described symptom of the disease [15], and associated with disease severity [16]. Therefore, the current study aims to research changes in these and additional voice features induced by exercise in people living with COPD. Given the comparable effects of exercise and exacerbations on the respiratory system and voice, studying the voice after exercise in people living with COPD may offer a safe and low-cost model for COPD exacerbations.

## 2. Methods

### 2.1. Participants

This was a substudy of the ongoing ENBED-study (NL83173.068.22), which is a single-center prospective cross-sectional study recruiting people living with COPD at


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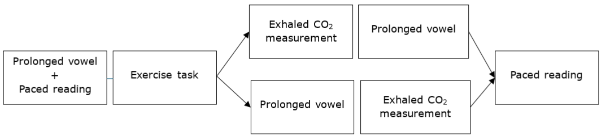


Figure 1: *Study procedures of the exercise tasks*

the outpatient clinic for Respiratory Medicine of Maastricht University Medical Centre, the Netherlands. Participants were included if they were diagnosed with COPD according to the international COPD Gold 2025 guidelines [9] and were able to understand, read and write in Dutch. Participants were excluded when they had an exacerbation of COPD (defined as a worsening of symptoms requiring additional treatment) within 8 weeks before the study, or when participants were diagnosed with comorbidities that could affect their speech, breathing production or coordination, or could affect dyspnea severity.

### 2.2. Study design

After signing informed consent, information regarding the general demographics, medication use, smoking habits, medical history, and pulmonary function tests was collected from electronic patient records. All participants performed a prolonged vowel task (/a/ vowel for as long as possible) and a paced reading at rest. For the paced reading task, participants were asked to read words of colors out loud in a predefined pace (120 words/minute) for 60 seconds. The rationale for the chosen speech tasks was that the sustained vowel /a/ is a frequently used task and enables relatively clear analysis and comparison with existing literature. The paced reading task was hypothesized to enhance the elicited dynamic hyperinflation, which is a specific hallmark of COPD. These voice tasks were followed by an exercise task: 5 times sit to stand from a chair. This physical test is validated for assessing the exercise capacity in people living with COPD, also predictive for the six-minute walking test [17]. As part of the ENBED-protocol, participants were subsequently randomly selected in two study arms, defining the study procedures (see Figure 1). Participants either performed the prolonged vowel /a/ first, followed by the collection of exhaled CO2 for 75 seconds, or vice versa. Both study arms performed the paced reading task afterwards. For the present study, these two arms were combined. All speech data was recorded on an iPad (Mili App, KI:elements) using a Sennheiser PC 5.2 Headset, which was connected via a Jackplug. All assessments were performed in Dutch, and in a quiet room. Voice samples were recorded in linear PCM format (.wav) and sampled to 16 kHz.

### 2.3. Data cleaning

All recordings of the sustained phonation were cleaned manually by listening and trimming silent parts. The paced reading tasks had a fixed length, silent parts were not deleted since these might contain information. Audio recordings were automatically checked for levels of background noise and duration. The most silent voiced parts were compared with the loudest noise part, when there was at least a 30dB difference between them, the audio passed the check. A minimum duration of ten seconds was expected for the prolonged vowel task and a minimum of 60 seconds was expected for the paced reading. The audios that failed these automatic checks, were checked manually.

### 2.4. Feature extraction

Acoustic features were extracted from the paced reading and sustained phonation task using the speech processing pipeline Sigma library by KI:elements. Audio recordings for each task were split into smaller audio parts, so-called bins. The audios were broken into 0.25s and 0.5s parts (4 and 2 bins per second) for the prolonged vowel task and paced reading task respectively. Loudness, signal-to-noise ratio (SNR) and F0 range were then calculated in each bin.

### 2.5. Data analysis

Due to the relatively small sample size compared to the possible number of extracted features, a feature selection was performed a priori based on previous research, presumed clinical relevance, and by limiting the number of feature derivatives (e.g. only the mean value of F1 frequency). From each feature, the mean value was selected to minimize the effect of outliers. A full list of extracted features can be found in the supplementary material.[1] To calculate the effect size caused by the exercise task, the post-exercise mean value of each selected feature was subtracted from the mean value before exercise. Since this field of research is novel and clinical, interpretable findings are preferred over black-box methods. Therefore, we used a MANOVA to investigate the relationship between the different voice features and exercise. Before analysis, data were checked for the assumptions, and checked for outliers (defined as 4SD) but no data were excluded from analysis since no value exceeded this threshold. Different clinical features were analyzed as covariates in MANOVA. These included age, sex, BMI, (inhaled) corticosteroid usage, smoking status, and COPD-severity (using the GOLD guideline staging) [9]. Since there was a time difference between the exercise task and the execution of the sustained vowel, the two arms were tested for group differences before further analysis. In case of no difference, both arms were analyzed simultaneously. Given that the respiratory system is significantly built different between men and women [14], we performed a post hoc analysis evaluating the effect of exercise in voice features accounting for sex, irrespective of the primary analysis. All data were analyzed using IBM SPSS Statistics 28.0.1.0. All p-values were corrected for multiple testing, using the false discovery rate method.

### 2.6. Ethical approval

This prospective, single-center study was approved by the medical-ethical committee azM/UM in 2023 (WMO statement NL83173.038.22). All patients provided written informed consent before study information was obtained. The study complied with the Declaration of Helsinki. The protocol for the ENBED-study was published in a public library [18].

## 3. Results

In total, the voices of 51 people with COPD were recorded; 24 men (47%) and 27 women (53%) with a median age of 67.7 years (SD 4.56). All participants were current or former smokers. Patients characteristics of the study population are depicted in Table 1.

[1] `https://github.com/Loes5307/Interspeech25Lauren/blob/main/All_Features.pdf`

| | | Male (n=24) | Female (n=27) |
|---|---|---|---|
| Age (median, SD) | | 68 (9) | 68 (8) |
| BMI (median, SD) | | 26.1 (4.2) | 24.8 (4.9) |
| Smoking status | Current | 22 | 21 |
| | Former | 2 | 6 |
| GOLD severity | 1 | 3 | 4 |
| | 2 | 7 | 10 |
| | 3 | 9 | 9 |
| | 4 | 5 | 4 |
| (inhaled) corticosteroid usage | Yes | 16 | 16 |
| | No | 8 | 11 |
| CAT-score (median,SD) | | 20 (7.06) | 23 (6.7) |
| FEV1 %pred (median, SD) | | 49 (23) | 51 (18) |
| FEV1 L (median, SD) | | 1.49 (0.81) | 1.16 (0.53) |

Table 1: *Patient characteristics*

| | Men Before (mean, IQR) | After (mean, IQR) | Women Before (mean, IQR) | After (mean, IQR) |
|---|---|---|---|---|
| Shimmer (apq5) | 3.46% (1.72;2.98) | 4.55% (2.39;6.65) | 3.22% (1.69;3.78) | 3.34% (1.81;5.03) |
| Shimmer (local) | 5.77% (3.13;8.31) | 7.61% (3.86;11.16) | 5.39% (2.93;6.08) | 5.63% (3.26;8.48) |
| Vowel duration | 14.27s (8.91;19.81) | 11.45s (8.81;14.19) | 11.87s (7.22;16.32) | 10.50s (6.35;14.05) |
| F1 Frequency (mean) | 688.91Hz (632.73;759,45) | 723.56Hz (643.66;787.68) | 729.60Hz (670.07;774.60) | 746.97 (680.20;823.80) |
| H1-A3 harmonic difference (mean) | 17.11 (-22.50;-12.47) | -14.01 (-19.20;-10.11) | -16.83 (-22.53;-10.46) | -16.06 (-20.88;-11.66) |

Table 2: *Speech features that are statistically significant when accounting for sex in the sustained phonation task /a/ (all p-values <0.05)*

### 3.1. Sustained phonation task

No statistical significance was found for the difference in voice features in the sustained phonation /a/ before and after exercise (MANOVA, p=0.055), see table 4. Also, no significant effects were seen for the covariates sex (0.170), BMI (p=0.244), and (inhaled) corticosteroid usage (p=0.466). There was a significant difference between the two arms in the smokers and non-smokers group. The groups did not have enough power to be analyzed separately and were therefore not further investigated.

Despite the lack of statistical significance found for the general MANOVA in sex (p = 0.170), the effects of sex on voice were further explored. A significant difference was shown after exercise for shimmer (apq5 and local, p=0.042), vowel duration (mean, p=0.042), F1 frequency (mean, p=0.042), and H1-A3 harmonic difference (mean, p=0.042) when accounting for sex. The effect of exercise was more pronounced in women than in men, with a mean difference in shimmer (apq5) of -1.087% and -0.117% for respectively men and women, and similar results were shown for shimmer (local), showing a small increase in shimmer after exercise for both sexes. Also, the increase in F1 frequency (mean) and H1-A3 harmonic difference (mean) after execise was proportionally larger in men than in women after exercise. The prolonged vowel shortened with 2.8s after exercise in men, while in women this was 1.4s shorter (see Table 2). Lastly, there was no overall statistical difference for the COPD-severity (p=0.154), however a trend was observed for HNR (mean), see Figure 2.

### 3.2. Paced reading task

Similar to the sustained phonation /a/, no statistically significant effects were found for the paced reading task before and after exercise (p=0.446), see table 3. There were no significant effects found for the clinical features age (p=0.989), sex (p=0.371), BMI (p=0.628), smoking status (p=0.291), (inhaled) corticosteroid usage (p=0.228) or COPD-severity (p=0.625).

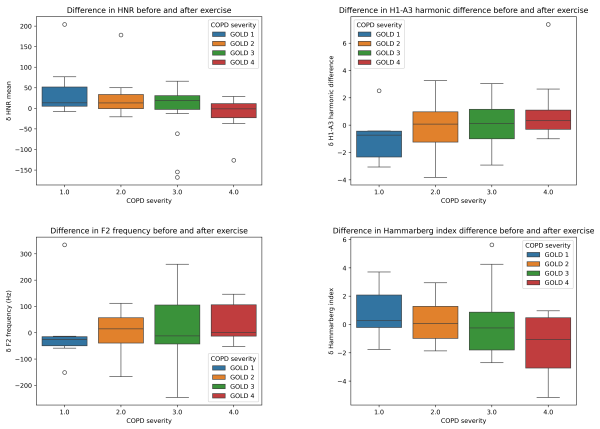


Figure 2: *Difference in voice feature before and after exercise per GOLD stage, LU for HNR (mean) in SpA*, RU delta H1-A3 harmonic difference (mean) PR*, LL delta F2 frequency (mean) in PR* and LR delta Hammarberg index (mean) in PR**
*SpA = sustained phonation /a/ task, PR = paced reading task

| Voice features | Mean | IQR | p-value | adj. p-value |
|---|---|---|---|---|
| Shimmer (local) | 0.0885 | -0.39;0.52 | 0.494 | 0.84 |
| Shimmer (apq5) | 0.0777 | -0.28;0.48 | 0.375 | 0.84 |
| Jitter (local) | 0.0411 | -0.15;-0.20 | 0.388 | 0.84 |
| Jitter (ppq5) | 0.0243 | -0.086;0.098 | 0.360 | 0.84 |
| Pitch (mean) | -0.347 | -7.13;6.47 | 0.820 | 0.88 |
| HNR (mean) | -3.092 | -19.32;7.47 | 0.525 | 0.84 |
| Loudness (mean) | 0.533 | -1.58;3.39 | 0.374 | 0.84 |
| Vocal tremor | 13.888 | -15.64;15.92 | 0.57 | 0.84 |
| F1 frequency (mean) | -1.394 | -22.05;18.43 | 0.778 | 0.88 |
| F2 frequency (mean) | 14.361 | -39.88;64.84 | 0.326 | 0.84 |
| F3 frequency (mean) | -9.308 | -43.70;25.15 | 0.388 | 0.84 |
| H1-A3 Hormonic difference (mean) | -0.0308 | -1.18;1.10 | 0.915 | 0.92 |
| Hammarberg index (mean) | -0.118 | -0.12;0.97 | 0.679 | 0.86 |
| Utterance durations (mean) | 0.00140 | -0.0096;0.011 | 0.598 | 0.84 |

Table 3: *Values of difference between before and after exercise in the paced reading task without corrections*

As in the sustained phonation task, a detailed analysis of the features was conducted while accounting for sex; however, no statistically significant features were identified. A trend was seen for GOLD-status and F2 frequency, H1-A3 harmonic difference (mean), and the Hammarberg index, see Figure 2.

## 4. Discussion

This study shows that voice changes during exercise in people living with COPD. When accounting for differences in sex, an effect in the sustained phonation task was observed with a shortened vowel duration, increased shimmer (apq5 and local), increased F1 frequency (mean) and increased H1-A3 harmonic difference (mean) in men and women. Additionally, we showed that the disease severity is likely to play a role. A non-significant trend was seen in the severity of COPD for HNR (mean) in the sustained phonation task, and in the paced reading task, for F2 frequency (mean), H1-A3 harmonic difference (mean), and the hammarberg index (mean).

### 4.1. Possibly relevant voice features in COPD

The shortening of the prolonged vowel after exercise is most likely caused by earlier exhaustion due to the underlying flow limitation. The amount of increase in shimmer (apq5 and local) found in this study is also of importance and could be caused by fluctuations in subglottal pressure after exercise [19]. These results combined suggest that people living with COPD experience increased breathlessness and hoarseness after exercise when accounting for sex [20] and that such differences can be observed using speech.

Differences in the respiratory system between men and women likely explain that we found significant differences in our analysis otherwise not seen in our primary analysis. It is known that women tend to have smaller airway diameters and lower lung volumes which lead to lower maximal flow-volume loops and lower capacity to increase their ventilation during exercise. [14]. The direction of these changes was different than expected. Where we expected that the change in shimmer, vowel duration and F0 differences would have been higher in women, the opposite was observed. Our results suggests that men have higher fluctuations in subglottal pressure in exercise suggesting difficulties with laryngeal muscle control in this population. Notwithstanding the contradictory direction of the results in this study, differences in sex should be evaluated when researching the effect of exercise in voice. The exact mechanisms behind this need to be further researched. Additionally, this might explain the shorter vowel duration at baseline and lower reduction of vowel duration after exercise for women.

Contrary to our expectations, we did not observe an association between disease severity and shimmer. However, in the present study, the threshold in shimmer for pathological speech (3.81%) [20] was not met, which could explain why shimmer was not associated with disease severity.

Speech production was also affected in our study population. For instance, we observed a change in the frequency of the first formant (mean) and H1-A3 harmonic difference (mean) after exercise in the sustained phonation task, which suggests that exercise affects the vowel formation of the participants and confirms the competition between breathing and speaking directly after exercise. We also observed a trend in the severity of COPD with the frequency of the second formant. These trends could be explained by the effects of exhaustion on speech formation.

Additionally, a trend was seen in COPD severity and HNR (mean). HNR is a feature that also seems important for diagnosing pathological voices, as a lower HNR describes more noise and a lower airflow in the energy of vibration of the vocal folds, which could be due to hoarseness [20, 21]. In this population, a decrease in HNR difference was observed for an increasing stage of COPD, that is, the more severely a patient is affected, the lower the difference between HNR before and after exercise. This is contrary to what was expected, since increased airflow limitation is seen in the people with more severe diseases and there an increase in HNR was hypothesized. The observed lower HNR change in severe airway obstruction could possibly be related to the lower baseline HNR in the severely affected participants, resulting in a lower difference after exercise.

The changes that we found in the formants during exercise in people with COPD were different than those previously reported in healthy individuals. It is known that F0 changes during exercise [22]. In this study, we measured pitch as a derivative of F0 [4, 23] and found no difference, even when accounting for sex. Given that dynamic hyperflation is an hallmark of COPD, we expected that pitch would be increased. We did observe a change in F1, suggesting there a signal in speech formation, but this was either a weak signal in COPD or our study sample was too small.

| **Voice features** | **Mean (IQR)** | **p-value** | **adj. p-value** |
|---|---|---|---|
| Shimmer (local) | -0.99% (-2.47;0.66) | 0.011 | 0.054 |
| Shimmer (apq5) | -0.57% (-1.57;0.50) | 0.017 | 0.054 |
| Jitter (local) | 0.012% (-0.36;0.32) | 0.72 | 0.772 |
| Pitch (mean) | -1.52Hz (-1.52;5.81) | 0.48 | 0.55 |
| HNR (mean) | 10.76 (-4.64;29.96) | 0.20 | 0.32 |
| Loudness (mean) | 0.91 (-2.33;3.30) | 0.15 | 0.27 |
| Vocal tremor | -7.47 (-12.57;5.96) | 0.026 | 0.069 |
| Vocal duration (mean) | 2.05s (-2.45;5.54) | 0.015 | 0.054 |
| First loudness drop (mean) | 2.31s (-1.35;7.00) | 0.07 | 0.14 |
| Hammarberg index (mean) | 1.13 (-2.25;3.74) | 0.068 | 0.136 |
| F1 Frequency (mean) | -25.5Hz (-25.50;-17.70) | 0.008 | 0.054 |
| F2 Frequency (mean) | -13.95Hz (-13.95;-5.11) | 0.22 | 0.32 |
| F3 Frequency (mean) | 23.58 (-65.56;106.03) | 0.33 | 0.44 |
| H1-A3 harmonic difference (mean) | -1.87 (-6.64;-2.27) | 0.015 | 0.054 |
| Detrended fluctuaction analysis | -0.013 (-0.021;0.021) | 0.36 | 0.44 |

Table 4: *Values of differences between before and after exercise in the sustained phonation /a/ task without corrections*

### 4.2. Strengths and limitations

This study contributes to the existing knowledge on the effect of physical stress in a non-healthy population on acoustic parameters. Given the competition between breathing and speech, studying speech in people in whom breathing is already affected, provides insight into the contribution of respiratory mechanics in this competition. Eventually, a better understanding of the effect of exercise on voice in this patient population, enables further research regarding e.g. home-monitoring and early diagnostics in people living with COPD. Additionally, the first steps are taken to create a non-invasive, accessible, and affordable model of COPD exacerbations using speech. Lastly, the MANOVA test used improves explainability, transparency, and reliability.

Several limitations should be noted. First, we only studied a small sample of individuals and our results should be considered exploratory. Future studies in a larger group of patients with COPD should be undertaken to validate the results of the present study. As a result of the smaller sample size, the power of our study was limited in the ability to find small significant differences and to draw firm conclusions. Another limitation is the lag time between the two arms for performing the sustained phonation after exercise, which possibly results in fewer effects on voice. However, this was checked for in the analysis and not observed.

### 4.3. Conclusion

In our small sample of people living with COPD, we showed statistically and clinically relevant effects of exercise on voice in men and women. In addition, there was a trend suggesting that voice is also affected by COPD disease severity. Shimmer and F1 frequency were identified as possible relevant features for assessing the effect of exercise on voice in people living with COPD. This study is the first, to our knowledge, to address this topic within this population and should encourage more research in the field of speech analysis in people living with COPD. These results can be used for further development of an exacerbation model using voice in people living with COPD.

# 5. Acknowledgments

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