MEASURING VOLUNTARY COUGH

AND ITS RELATIONSHIP TO THE PERCEPTION OF VOICE

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Abstract

Cough is a motor act of the laryngeal and respiratory systems. Features of coughing have been considered in the examination of respiratory, swallowing and voice disorders. Although some voice disorders have been linked to excessive coughing, the precise relationship between cough and voice remains unknown. The present study examined the acoustic features of cough across sex and age; and its relationship to the perception of voice production. A total of 30 cough samples and 30 voice samples were collected from 15 healthy females and 15 healthy males; ranging from young age (17-25 years old), middle-aged (30-45 years old) and older-age (60 years old & above). Coughs containing three distinct phases were submitted to an acoustic analysis of the long-term average spectrum (LTAS) and cough duration. Both cough and voice samples were examined perceptually by a group of 20 speech-language pathologists. Results found a distinct three-phase pattern of cough that was remarkably stable across sex and age. Significant differences were found in the duration of each phase of cough. Perception of cough was not significantly related to acoustic features of cough. Perceptual judgment of sex was comparable for both cough and voice samples. However, the accuracy of age recognition was higher for voice samples compared to cough samples. In addition, voice was judged to be healthier and stronger than cough. Overall, the results partially support the previous acoustic findings on cough. A strong relationship between the acoustics of cough and the perception of cough was not evident. Listeners judged voice differently from cough, except for sex recognition. The clinical implications of the findings are discussed.

Introduction

Definition of Cough and Voice

Cough has been routinely described as a three-phase expulsive motor act consisting of inspiratory effort (inspiratory phase); continued by a forced expiratory effort initially against a closed glottis (compressive phase); and finally followed by an active glottal opening and rapid expiratory flow (expulsive phase) (Fontana 2008). Coughing is a crucial function performed by the laryngeal and respiratory systems, which enables an individual to clear the airway of foreign material and secretions, and prevent aspiration of food and liquid (Hadjikoutis, Wiles & Eccles, 1999). Production of cough usually involves development of subglottic pressure beneath adducted false and true vocal folds, followed by a 'blast' of air. It is usually evoked by sensory stimulation to cough receptors in the epithelium that line the respiratory tract from the larynx to the lungs (Spinney, 2002). This sensory information is transmitted to centers in the brainstem through the afferent limb of the vagus nerve, and elicits the cough via the efferent limb of the vagus nerve that innervates the larynx and respiratory muscles (Hadjikoutis et al., 1999). Studies have shown that the regulation and modulation of cough is under a high level of cerebral control (Fong et al., 2004; Mazzone et al., 2007). Davenport (2008) described this central control as the concept of Urge-to-Cough, a component of brain functioning that mediates a cognitive response to cough stimuli. He suggested that an individual can reliably perceive an impending need to cough and quantify this as an estimate of their Urge-to-Cough.

Unlike cough, the production of voice does not involve adduction of the false vocal folds. Rather, voice production involves development of subglottic pressure beneath adducted true vocal folds. The ensuing 'blast' of air initiates vocal fold vibration and hence forms a basic sound known as phonation. This sound travels along the vocal tract, which is transformed by the filtering properties of the speech articulators. The frequency of vocal fold closing and opening determines the fundamental frequency (F0) (or voice pitch), while subglottal pressure, glottal resistance and amplitude of vocal fold displacement influences voice intensity (or loudness). Sataloff (2005) highlighted the involvement of the cerebral cortex in the planning of voice production. This information is transmitted to the brainstem and spinal cord before reaching the structures involved in voice production, namely the laryngeal, thoracic, abdominal musculature, vocal tract resonators and articulators. Voice provides richness in communication and carries more than verbal information. Voice may provide information regarding the speaker's emotional state (Spreckelmeyer et al., 2009), affective state, and identity (Belin, Fectau & Bedard, 2004).

Past Research on Cough

Cough has been implied to be useful in identifying the presence of respiratory disease. Hirtum and Berckmans (2002) examined the F0 of cough in healthy and respiratory infected groups, human and pig. They found acoustic differences in the cough of healthy and respiratory infected subjects, suggesting that features of cough can provide insight as to the physical condition of the respiratory system. Their study was based on examination of the F0 of cough produced by humans and pigs separated into healthy and respiratory-infected groups. The F0 of the cough in the healthy groups was higher compared to the infected groups. This finding was later supported by Ferrari et al. (2008) who studied the acoustic differences in cough sounds from the infected lungs of pigs compared to the cough of healthy pigs, induced by inhalation of citric acid. The healthy pigs were found to have a significantly higher peak frequency and shorter duration of cough compared to the infected pigs. They proposed that the respiratory system acts as the source of cough sounds, thus alteration in an infected lung leads to different sound emissions.

Pirila and Soviraji (1989) determined whether various types of pulmonary disease share similar acoustic and dynamic features of cough. Spontaneous cough samples were collected from 31 patients with different types of respiratory pathology, namely asthma, acute and chronic bronchitis, tracheobronchial collapse and pulmonary fibrosis. They performed a spectral analysis of the cough sounds and evaluated cough expiratory airflow. They identified significant differences in the flow dynamics and sound spectra of cough in asthmatic patients compared to the other groups. Asthmatic patients showed a significantly lower peak expiratory flow during cough, marked longer duration of the first cough sounds and a significant downward shift in the high frequency components of cough sounds compared to the other groups. The findings were marginal between the other groups.

Smith et al. (2006) attempted to identify the descriptions used by healthcare professionals when listening to cough and their ability to diagnose a pulmonary disease condition. They collected nine cough sounds randomly in patients with various pulmonary diseases and categorized them as: (a) cough alone, (b) cough with mucus, (c) cough with wheeze, or (d) cough with mucus and wheeze. They also performed an acoustic analysis of the cough sounds. The cough sounds were presented to listeners who were asked to describe the cough and determine the underlying diagnosis. Results of the acoustic analysis indicated that a majority of the cough sounds had three distinct phases. The coughs with mucus had a significantly longer second phase and total length of cough duration compared to other types of cough. The listeners were able to identify coughs with or without mucus but were unable to identify wheeze in cough and provide an accurate diagnosis. This reinforces the notion that there are unique features of cough sounds and acoustic features of cough have the potential to be used in clinical practice.

Murty, Lancaster and Kelly (1991) assessed the effects of a paralyzed vocal fold on the intensity of coughing. They compared the airflow of voluntary cough in patients with vocal fold palsy to a healthy group. All patients in the study had a paralyzed fold in the lateral position. They found no significant difference between the two groups in peak airflow. However, patients with vocal fold palsy required a significantly longer time to reach peak airflow. The researchers highlighted that testing airflow in voluntary cough has the potential to be used in detecting the presence of vocal fold palsy and monitoring subsequent recovery.

Yet, use of airflow measures could not identify the laterality and position of the lesion. It is not known if the findings of this study could be replicated in patients with vocal fold palsy due to motor lesions and the impact of compensatory mechanisms in a paralyzed vocal fold to a cough.

Murty, Smith and Lancaster (1991) evaluated the impact of the absence of a larynx on cough intensity. They evaluated the cough airflow in laryngectomees compared to healthy subjects. The laryngectomees had significantly longer duration in achieving peak airflow of cough compared to the healthy subjects. However, no significant difference was found in peak airflow between groups. This study showed that the larynx is not essential for the production of cough. Nevertheless, the expiratory and accessory muscles could develop compensatory strategies to produce cough in this population, which was not explored in this study.

The speech-language pathology profession is known to use cough as a means of managing patients with dysphagia. Pitts et al. (2008) compared voluntary cough in Parkinson’s patients who had no evidence of aspiration/penetration with thin liquid detected from videofluoroscopy (VFSS) to another group of Parkinson’s patients with positive findings. Based on measurement of airflow during voluntary cough, a significantly longer time to initiate and achieve the peak of expiratory phase was observed in those patients with aspiration/penetration. These patients also showed difficulty eliciting a voluntary cough. A direct relationship between penetration and aspiration scores and voluntary cough parameters was discovered, reflecting that the ability to cough voluntarily is related to the degree of airway protection.

Hammond et al. (2009) evaluated voluntary cough as a potential tool to examine swallowing function and to predict risk of aspiration in patients with ischemic stroke. A total of 96 patients with acute stroke, at different brain locations, were recruited in this study. Clinical swallowing assessment, VFSS, flexible endoscopic examination for swallowing (FEES), and measurement of aerodynamic and sound pressure level of cough were completed.

Patients with a high risk of aspiration were found to have lower inspiration phase volume, lower inspiration peak airflow, lower sound pressure level, lower expiration phase peak airflow, lower volume acceleration, and higher expulsive phase rise times than non-aspirating patients. Among these parameters, expulsive phase peak airflow, expulsive phase rise time and volume acceleration carried good diagnostic accuracy. Only inspiratory phase duration and glottic closure phase duration were found to have poor diagnostic accuracy for identifying those patients at high aspiration risk. This study demonstrated a significant relationship between the amount of airflow generated during coughing and the risk of aspiration. The Pitts et al. (2008) and Hammond et al. (2009) investigations highlight the potential use of cough in increasing the accuracy of clinical swallowing examination to determine the risk of aspiration in neurogenic dysphagia.

Weir et al. (2009) identified various signs and symptoms in predicting “oropharyngeal aspiration (OPA)” or swallowing dysfunction in children and young adults through a retrospective review of medical files. This review included results from VFSS evaluation with liquid and puree food, as well as clinical signs and symptoms associated with OPA during feeding. They found 11 clinical markers associated with OPA which included, (1) cough response occurring during the clinical feeding evaluation once ingestion had commenced, (2) wheeze, (3) stridor, (4) throat clearing, (5) gagging, (6) choking, (7) desaturations and apnoeas during feeding, (8) wet or gurgly voice, (9) wet or gurgly breathing, (10) laboured breathing during feeding, and (11) increased, sharp temperature (38.5%) during a 24-h period following oral intake. They evaluated the relationship between OPA, laryngeal penetration and pharyngeal residue to the clinical markers. This relationship was then evaluated according to the child’s age and neurological status. They found that cough, wet voice and wet breathing provided the most significant indication of aspiration among children and young adults with oropharyngeal dysphagia.

Type of Cough

Cough has been classified in a number of ways. These classifications encompass a range of descriptors that are assumed to reflect various health conditions. A summary of the classifications is shown in Table 1. Behavioural aspects of voluntary cough are emphasized in the present research.

Voluntary cough: The term, voluntary cough refers to the self-initiation of cough by an individual. The process of producing a voluntary cough involves a build-up of subglottal pressure, followed by a deliberate release of this air pressure to produce an acoustically audible cough (Pitts et al., 2008). Past research has evaluated the production of voluntary cough for various aims. Olia, Sestini and Vagliasindi (2000) examined voluntary cough to identify the acoustic patterns of cough in a healthy population; while Pitts et al. (2008) evaluated it to determine the relationship of voluntary cough production to the risk of aspiration/penetration in Parkinson's disease. Voluntary cough is also applied in compensatory swallowing strategy to increase safety with oral intake in patients with dysphagia, specifically with delayed pharyngeal swallow. One example is supraglottic swallow. In this technique, patients are required to take a deep breath and hold it while swallowing simultaneously. Following the swallow, patients are required to cough or clear their throat before breathing again. This technique was found useful in improving laryngeal elevation for swallowing, but difficult in severe swallowing problems, probably due to the lack of endurance and muscle strength (Bulow, Olsson & Ekbery, 2001).

Reflexive cough: Reflexive cough is usually associated with the laryngeal sensitivity to protect the airway from aspiration of food, liquid and secretions. In an experimental setting, a reflexive cough is commonly induced through the inhalation of tussive or induced agents such as citric acid. Measuring cough reflex sensitivity allows efficacy of pharmacological and other interventions evaluated in clinical cough research (Dicpinigaitis, 2007). Both voluntary and

Table 1: Cough classification. Taken from Chung et al. (2009)

CLASSIFICATION	DEFINITION	EXAMPLE
Behavioural	The manner or associated situation in which the cough is elicited.	Voluntary cough, reflexive cough, induced cough, mainly during the day or at night, on lying down.
Pathology	The perceptual evaluation of cough to make a medical diagnosis.	Dry, bovine, whooping, moist, throat irritation.
Duration	The perceptual judgment of the overall length of cough.	Acute, subacute, chronic.
Effect	The perceptual inference of impact of cough to an individual's health and quality of life.	Urinary incontinence, pain/distress, social embarrassment, rib fracture.
Grade	The perceptual evaluation of cough sensitivity to elicit an involuntary cough.	Normal (eutussia), Sensitized (hypertussia), Desensitized (hypotussia), pathological (dystussia), absent (atussia).

reflexive cough generate high expiratory airflow that will dislodge and eject foreign material from the pulmonary system. It is presumed that voluntary and reflexive cough share similar muscles and structures for the generation of a cough. However, Lasserson et al. (2006) found physiological differences in cough airflow and organization of motor activation in the two types of cough. The airflow for voluntary cough was found to have higher peak airflow and longer duration compared to reflexive cough. Elicitation of voluntary cough results in a gradual sequential onset of expiratory and accessory muscle activation. The sequential activation was assumed to result in the correspondingly higher airflow and longer cough duration. In contrast, reflexive cough involved simultaneous onset of those muscles. Simultaneous onset resulted in decreased peak airflow and shorter cough duration. Uichiro et al. (1995) examined cough reflex among healthy volunteers aged 20 to 78 years-old, induced with citric acid. He found that all participants demonstrated cough at a similar threshold regardless of age. They suggested that a cough reflex does not decrease with the advancement of age.

Acoustic Analysis of Cough

The production of cough results in the generation of an acoustic signal. Thorpe et al. (2001) highlighted that cough leads to air turbulence that carries a broadband noisy character. The particular acoustic features of a cough depend on the velocity of airflow, dimensions of the vocal tract and airway, and location of sound generated. Morice et al. (2007) stated that although many forms of acoustic (cough) waveforms exist, there are three main acoustic patterns of cough that have been described in the literature. These three patterns are illustrated in Figure 1-3. The first pattern is the three-phase cough that was described earlier. This is the type of cough most often reported in the literature. The second type of cough is a two-phase cough. The third type of cough is a “peal” cough Korpas, Sadlonova and Vrabec (1996) described the differences between the source of each phase of cough and factors that affect their productions. These factors are summarized in Table 2.

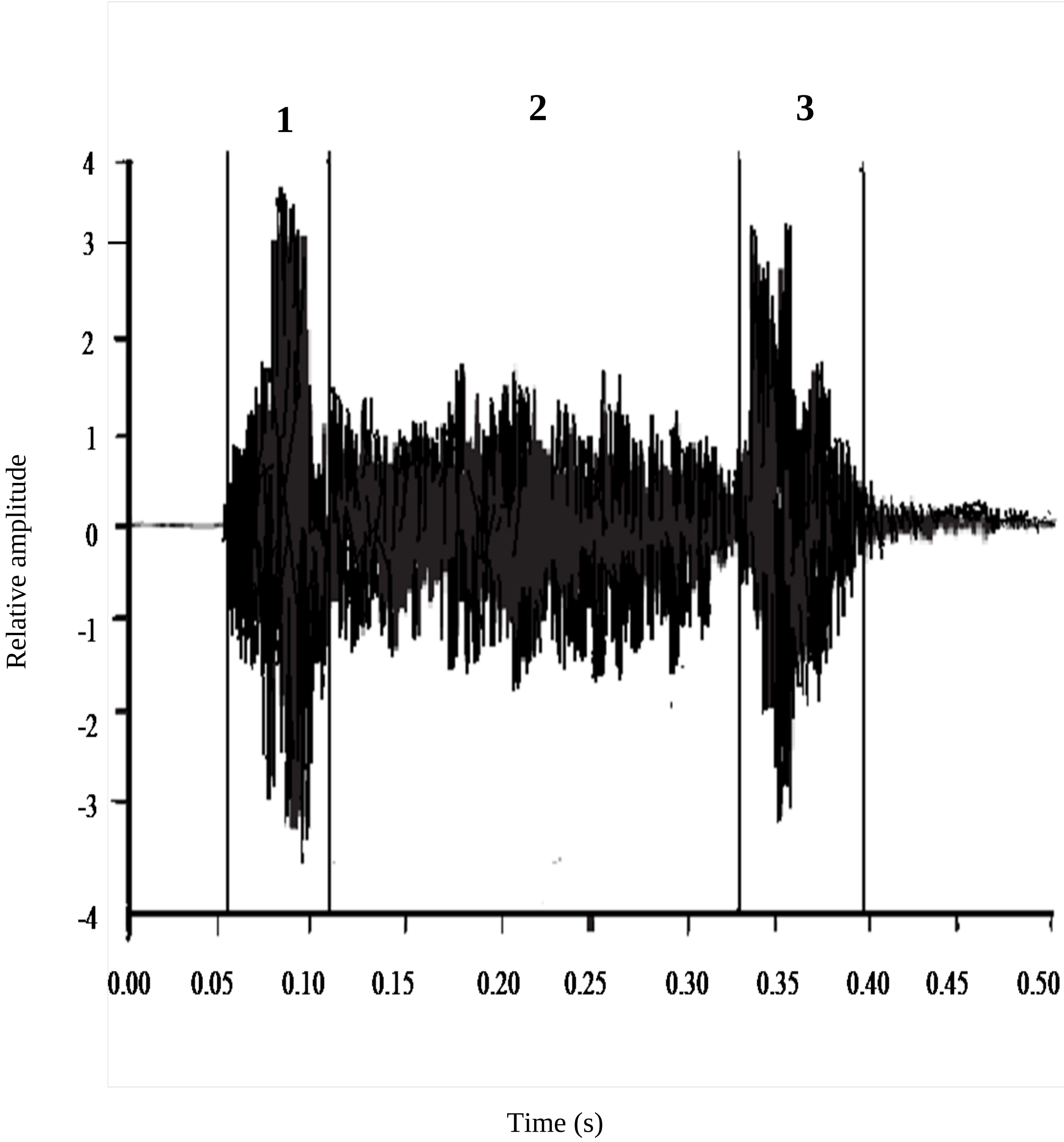

Figure 1: Three-phase cough sound; (1) explosive phase, (2) intermediate phase, (3) voiced phase (Taken from Morice et al., 2007). Note the distinct peaks in amplitude found for the first and third phases.

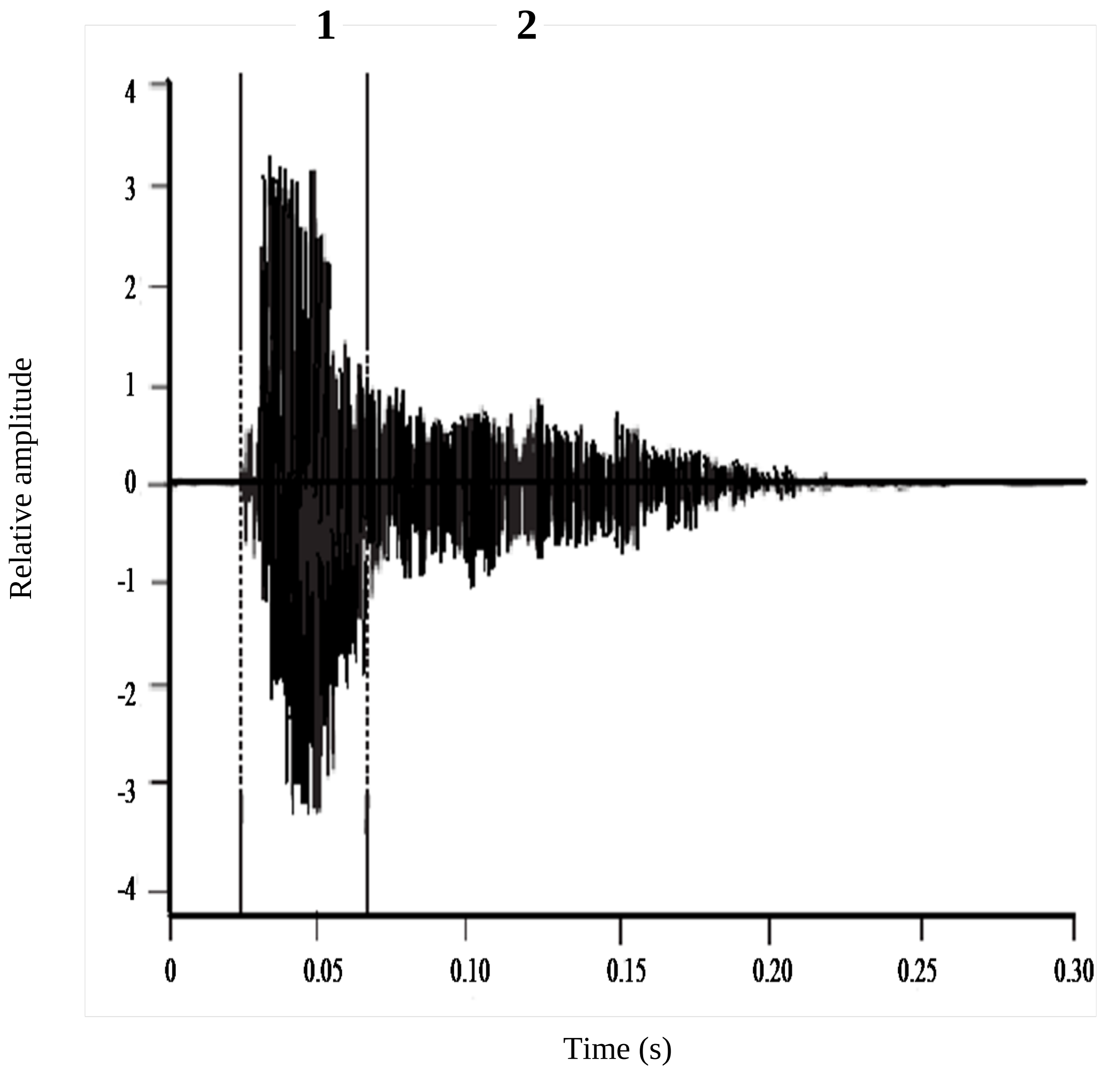

Figure 2: Two-phase cough sound; (1) explosive phase, (2) intermediate phase (Taken from Morice et al., 2007).

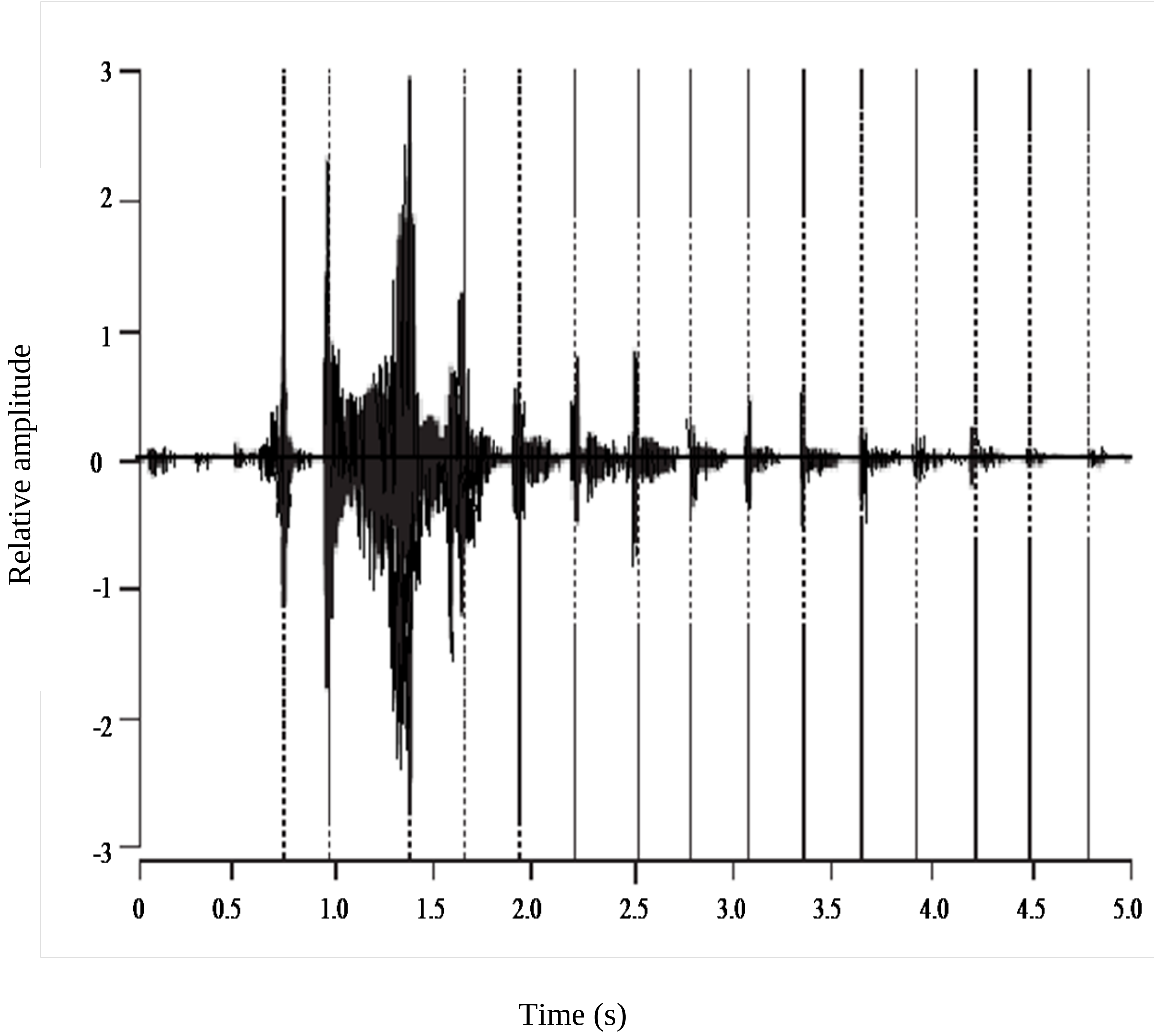

Figure 3: Peal of coughs after a single inspiration with repeated explosive phase (Taken from Morice et al., 2007).

Table 2: Acoustic phases in a three-phase cough and the physiological correlates. Factors that relate to impaired production of each phase are also noted. (Taken from Korpas et al., 1996)

Phase of cough	Physiology of cough	Factors related to impaired production
First phase	Reflects bronchial narrowing and bifurcation, leading to turbulent airflow, which produces vibrations of the airway and the surrounding lung tissues.	Thickening of airway mucosal line, fibrosis or bronchoconstriction.
Second phase	Reflects as egressive airflow from the trachea, as well as the collection of mucus in the trachea.	Quality of the mucous in the trachea.
Final phase	Reflects vocal fold adduction at the end of the second phase of cough. This feature of cough is not present in isolated cough.	Laryngeal inflammation or other pathological process in the laryngeal area.

Doherty et al. (1997) studied the acoustic patterns of involuntary cough in healthy adults and found that a majority of the participants produced a three-phase cough. The first phase was indicated as the first peak amplitude of cough. The second phase of the cough involved noisy airflow. The final phase of the cough was found to have second distinct peak amplitude. In some cases, a cough consisted of only the first and second phase. Thorpe, Toop and Dawson (1992) interpreted the first phase as indicative of sudden, transient glottal opening. The second or middle phase reflected an interval of steady-state airflow with the glottis wide open. The final phase reflected airflow that is arrested by the closing of the glottis in preparation for an ensuing cough. The final phase is only apparent during sequential coughing, compared to the production of a single, isolated cough.

Olia et al. (2000) compared acoustic features of voluntary cough between healthy males and females. They evaluated the total length of cough, length of each phase of cough and the level of spectral energy in each phase of cough. They found that females had a significantly longer duration in the first phase of cough compared to males. There was no sex difference in the length of the second and third phases of cough. Males showed a lower loudness level of the first phase of cough than females. Males also showed a low frequency energy concentration in the second phase of cough, as opposed to the females who showed a concentration of energy in the high frequency region. Titze (1994) stated that adult males have thicker and longer thyroarytenoid muscles (i.e., vocal folds), which allows the glottis to be more rectangular-shaped, and thus more of the entire body of the vocal fold is set into vibration, with greater overall amplitude. The result is a richer timbre of voice. However, it is not known as to how differences in vocal fold configuration influence the acoustics of cough in both sexes.

Hashimoto et al. (2003) demonstrated the effect of the rheological properties of airway mucus to cough sound production. Their study was based on examination of voluntary cough and sputum from patients with chronic productive cough. They found a significantly longer duration of the second phase of the cough in a mucosal airway and marked relationship between the ciliary transportability (i.e., velocity at which sputum is cleared by movement of the cilia) and yield value (i.e., measurement of the plasticity of the sputum), and the second phase of cough. They suggested that patients prolong the second phase of coughing for an effective expectoration of airway mucus. This study supports the earlier work of Murata et al. (1998) who attempted to differentiate productive and non-productive cough acoustically. They analyzed productive and non-productive coughs from patients with chronic bronchitis. Participants with productive cough were found to have a significantly longer duration in phase two of cough, compared to those with a non-productive cough. Non-productive cough was also found to have a longer duration in phase two of cough, although the length was shorter than the productive cough. No difference was found in the first and third phases of cough across participants. Both studies demonstrated the influence of change in airway configuration on the generation of cough.

Bianchi and Baiardi (2008) compared cough peak airflow in healthy children between the ages of 4 to 18 years. All participants were instructed to cough following maximum inspiration. They found that the youngest children demonstrated lower cough peak airflow compared to older children. Children achieved minimum cough peak airflow similar to healthy adults by the age of 12-13 years. Sataloff and Linville (2006) reported that at 5-years of age, the larynx descends to about the level of C5-C6 (cervical vertebra), compared to the C3 level at birth. The larynx continues to descend to about the C6-C7 level between the ages of 15 and 20-years. It is assumed that the developmental changes in the airway across age could contribute to variation in cough airflow, although this influence was not elaborated in this study.

Martinek, Tatar and Javorka (2008) evaluated voluntary cough sounds and non-cough sounds (i.e., speech) for application in ambulatory cough monitoring systems. Based on spectral and non-linear analyses of speech and voluntary cough samples collected from a healthy population, they found that both sounds were significantly different in length. Cough sounds were also found to have marked irregularity and an unpredictable signal compared to voice. The distinguishing acoustic features carried by both sounds were assumed to be related to differences in underlying physiological mechanisms.

Cough in the Management of Voice Disorders

Cough has long been associated as part of voice management protocols. Examination of an individual’s coughing behaviour is often considered during routine assessment of vocal functioning. Individuals who engage in excessive coughing and throat-clearing behaviours may vocally abuse their voice (Sataloff, 2005). Both behaviours may present as a symptom of Gastro-Oesophageal Reflux Disease (GORD), a medical condition that has been found to contribute to voice disorders (Rammage, Morrison & Nichol, 2001; Garrett & Cohen, 2008). On the other hand, asking a patient to deliberately cough as sharp as possible can provide information on vocal fold adduction, particularly in patients suspected of unilateral or bilateral vocal fold paralysis (Aronson, 1990). However, in cases of thyroid and parathyroid post-surgery, Hanna and Brooker (2008) found that perceptual voice and cough assessment provided inadequate markers to identify the presence of vocal fold palsy in this population. Kocak et al. (1999) proposed that visualization of the vocal folds via videostroboscopy is required for accurate diagnosis of vocal fold palsy. Nevertheless, perceptual evaluation of voluntary cough is still recommended in clinical dysphagia management as a means of judging the adequacy of vocal fold movement (Schulze-Delrieu & Miller, 2003).

In patients with persistent cough, ‘silent cough’ is offered as an alternative behaviour as part of the vocal hygiene program. With this technique, the patient is taught to cough without any sound by using abdominal support. This technique is considered less traumatic to the vocal folds and helps to blow mucus off the vocal folds (Heuer et al., 2006; Sataloff, 2006). Patients with psychogenic dysphonia usually present with an incomplete adduction of the vocal folds, and a high pitched, breathy falsetto voice. Cough serves as a manoeuvre to create strong vocal fold opposition and is useful to elicit voice in psychogenic dysphonia (Baker, 1998; Ramig & Verdolini, 1998). The cough sound could be gradually shaped into speech (Rosen et al., 2006).

On the other hand, cough is also applied in therapy with mutational falsetto or puberphonia. Dagli et al. (2008) reported that the use of vegetative voice, including cough and yawn, in conjunction with laryngeal manipulation, helps this population in getting a sense of a low pitched voice. However, cognitive tasks and intrinsic motivation are required to ensure this 'new voice' is used consistently.

Cough and voice are two key functions performed by the larynx (Widdicombe, Fontana & Gibson, 2009). Therefore, it is presumed that any incident that impacts laryngeal function can influence both of these functions. An example is by Vertigan et al (2007), who investigated the perceptual voice characteristics in individuals with chronic cough (CC) and paradoxical vocal fold movement (PVFM), and attempted to determine whether voice disorders are a common feature in these conditions. They also compared the perceptual voice attributes in CC and PVFM to individuals with muscle tension dysphonia (MTD) and healthy controls. The perceptual judgment was made by two experienced speech-language pathologists and was based on audio recording of voice samples collected from the participants in the above groups. Perceptual analysis showed significant differences between groups for the voice parameters of breathy, strain, rough, phonation break and monotone. Specifically, breathiness was found to be significantly higher in participants of the pathological groups than the healthy group. Strain and roughness was found to be significantly higher in participants with CC alone, combined PVFM and CC, as well as MTD. The combined PVFM and CC group also presented with a significantly higher phonatory break compared to the group with CC alone and the healthy group. Monotone was perceived in the group with CC alone and the group with combined PVFM and CC, in comparison to the healthy group. The group with combined PVFM and CC was also perceived to have monotone more often than the group with MTD. This study revealed a remarkable prevalence of perceptual voice disorders in CC and PVFM.

The role of speech-language pathologists in the management of CC further highlights the relationship between cough and voice. Vertigan et al. (2008) evaluated the changes in voice among individuals with CC who received the Speech Pathology Intervention Program for Chronic Cough (SPEICH-C), in comparison to a control group who received Healthy Lifestyle Education (HLE). Using a randomized controlled trial, participants were divided into two groups, each receiving one form of therapy. The SPEICH-C's group received education on the nature of cough, strategies to control cough, psychoeducational counselling, and vocal hygiene education to reduce laryngeal irritation. The HLE's group consisted of four components of healthy lifestyle education, which were relaxation, stress management, exercise and diet. Each session lasted for 30 minutes and was provided by a speech-language pathologist with experience in voice disorders. Outcome measurements were based on evaluation of voice samples before and after the treatment programs. Perceptual voice analysis showed significant improvement in the following voice parameters, (1) breathiness, (2) roughness, (3) strenuous, and (4) glottal fry quality following the SPEICH-C treatment program compared to HLE program. The overall voice quality was also found to improve significantly among participants in the SPEICH-C treatment program. No difference in pitch and loudness perceived from both groups following completion of treatment was found. Acoustic analyses found participants in the SPEICH-C program to show longer maximum phonation time, and a reduction in jitter and harmonic-to-noise ratio in comparison to the HLE program. However, the differences were not statistically significant. Analysis of F0 in connected speech, as well as closed phase of vocal fold vibration from electroglottographic measurement, did not show a difference between pre- and post-treatment in both groups. Although perceptual voice analysis revealed a significant clinical impact of behavioural treatment of CC on voice production, it is not known whether voice disorders in CC are integral to that disorder or a separate underlying process. The change in cough behaviour was also not discussed in this study.

Statement of the Problem

Past research has demonstrated that analysis of cough sound provides insight to different respiratory and swallowing functions. Although voice disorders have been described as a result of excessive cough and vice versa, the precise relationship between cough and voice production remains unknown. As cough and voice production share similar anatomical structures and nervous system innervations, but carry unique acoustic features relative to vocal fold vibration, it is presumed that acoustic features of cough may have potential in the diagnosis of voice problems. Yet, there are few detailed acoustics studies which attempt to evaluate the vocal fold vibratory behavior encompassing cough production. Such information is vital if cough production is to be used as a tool for the evaluation of suspected voice problems. Therefore, the primary purpose of the present study was to perform a detailed acoustic assessment of cough production. A secondary purpose was to explore possible relationships between the perception of cough and the perception of voice. This research attempted to answer the following questions:

Question 1: Are acoustic features of voluntary cough similar to past reports for voluntary cough?

Question 2: Do acoustic features of voluntary cough correlate with perceptual classifications of cough?

Question 3: Do perceptual judgments of cough differ from the perceptual judgments of voice?

Methodology

Participants

This study consisted of two phases of data collection. The initial phase involved obtaining cough and voice samples from a group of healthy adult participants. The second phase involved obtaining perceptual judgments of the same cough and voice samples from a group of experienced listeners.

Participants for Voice and Cough Samples. A total of 30 (15 males & 15 females) were recruited for this study. They were subdivided into three groups (10 participants per group), according to their chronological age with an equal number of males and females. The *young* group was defined as those within the age range of 17-25 years. The *middle-aged* group were those within the age range of 30-45 years. The *older-aged* group were those beyond the age of 60 years. The mean age of the *young* group was 20-years for the males and 22-years for the females. The mean age of the *middle-aged* group was 34-years for the males and 36-years for the females.[1] The mean age for the *older-aged* group was 73-years for the males and 63-years for the females**.** All participants were recruited from the student and staff population at the University of Canterbury. Based on personal report, each participant, (1) had no history of respiratory disease, (2) was a non-smoker, (3) had no upper respiratory tract infection in the four weeks prior to the cough and voice collection, (4) spoke English as their primary language to minimize the influence of accent on the perceptual phase of the study, and (5) had no speech abnormalities including those affecting articulation, resonance and fluency. This final inclusion criterion was determined through clinical examination of oral-motor function and speech by the researcher who is a speech-language pathologist.

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[1] It is debateable that the 30-45 year-old age group reflects “middle age.” However, due to the exploratory nature of this research, there was an attempt to broadly sample age periods covering adulthood. The middle age group was the approximate midpoint of the range of participants sampled in the present study.

Listeners for Perceptual Judgment: Perceptual analysis of cough and voice samples was completed by 20 experienced listeners. All listeners held a degree in speech-language pathology. None of the listeners reported that their current case load was confined to patients with a voice disorder. The judges consisted of 29 females and 1 male and ranged in age from 25 to 47 years.

Data Collection

Cough and Voice Samples. A combination of cough and voice samples were collected from each participant. The cough samples were based on deliberate, voluntary generation of cough. Each participant was instructed to produce three coughing episodes. A coughing episode was defined as a string of three successive voluntary coughs. The researcher demonstrated the production of a coughing episode for each participant prior to data collection. A coughing episode commenced immediately following maximum inhalation. Participants were seated at a table and positioned approximately 30 cm away from a table-top microphone. They were required to cough directly into the microphone.

In addition to collection of the three coughing episodes, a sample of each participant's voice was obtained. The voice sample was based on oral reading of the first 100-words of the Rainbow Passage (Fairbanks, 1960). The participants were allowed to pre-read the passage prior to oral reading. The microphone remained positioned at approximately 30 cm from the mouth. The cough and voice signals were audio-recorded and transferred directly into a desktop computer using specially designed speech analysis software (KAY CSL Model 4300B). All recordings were completed in a quiet room to avoid extraneous noise. The order of data collection was randomized across participants.

Perceptual Judgment. The 20 speech-language pathologists recruited for the perceptual judgments were required to evaluate the cough and voice samples collected across the young, middle, and older age groups. One complete coughing episode and the middle sentence from the Rainbow Passage ("*The rainbow is a division of white light into many beautiful colours*.") was extracted from the original cough/voice database and served as the data corpus for the perceptual judgments. Custom-made software was designed for the perceptual judgments. Each listener was seated in front of a laptop computer which displayed the instructions for the perceptual judgments (see Figure 4). Prior to beginning the task, each listener was allowed to listen to two cough samples and two voice samples for practice. These samples were selected randomly among all samples collected and were not included as part of the perceptual study. Following the practice session, the listeners were presented the cough and voice samples randomly via headphones. Upon listening to each sample, listeners were asked to rate each cough and voice sample on the parameters of (1) strength, (2) healthiness, (3) sex, and (4) age. The strength and healthiness parameters were judged on a continuum scale from 1-10 (1 for unhealthy/weak voice or cough and 10 for healthy/strong voice or cough). For judgment of sex and age, listeners were asked to determine whether each cough and voice sample was produced by a young, middle-aged or older-aged male/female. Listeners were allowed a 5-minute break as they required, avoiding the effect of fatigue that might influence their evaluations. Listeners could also repeat each sample as many times as they wished throughout judging each sample. In addition, the listeners were able to modify the volume of the samples throughout the task, to ensure an adequate loudness level. All judgments were recorded and tabulated by the custom-made software as displayed in Figure 5.

Data Analysis

Acoustic Analysis of Cough. The coughs comprising each coughing episode were analyzed acoustically using dedicated speech analysis software (Kay CSL 4300B). Attempts were made to select one isolated cough from each of the three coughing episodes. A total of 90 coughs samples were examined for acoustic analysis (30 participants x 3 isolated coughs per participant). The temporal and spectral characteristics of each cough were examined. The temporal aspects of the cough were determined by measuring the total duration, as well as the duration of the three phases of each cough. According to Smith and Woodcock (2008), these phases are also known as explosive phase (first phase), intermediate phase (second phase) and

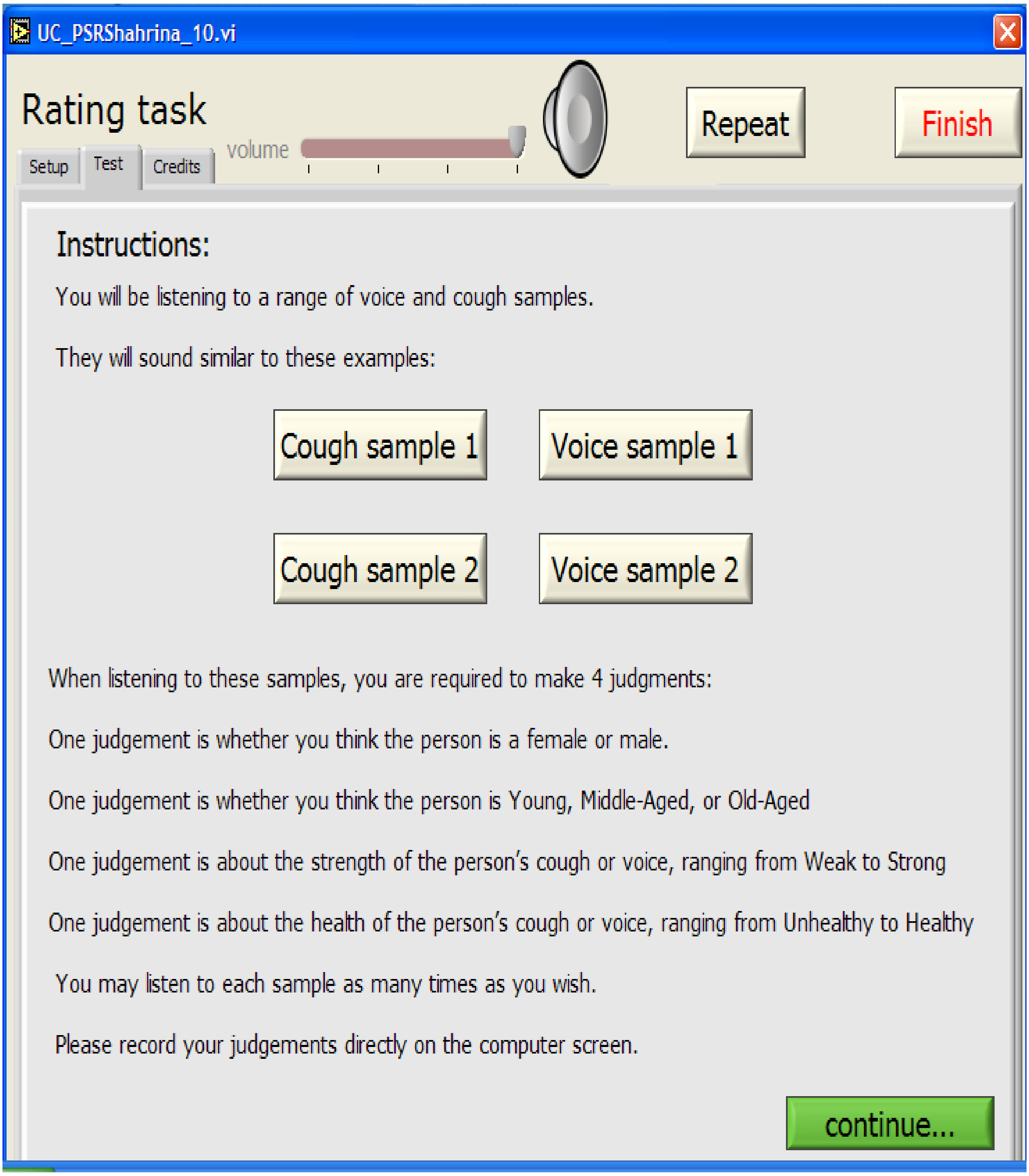

Figure 4: Instructions for the perceptual judgment task as displayed on a computer monitor. The voice and cough samples were included in the instructions for examples and practice.

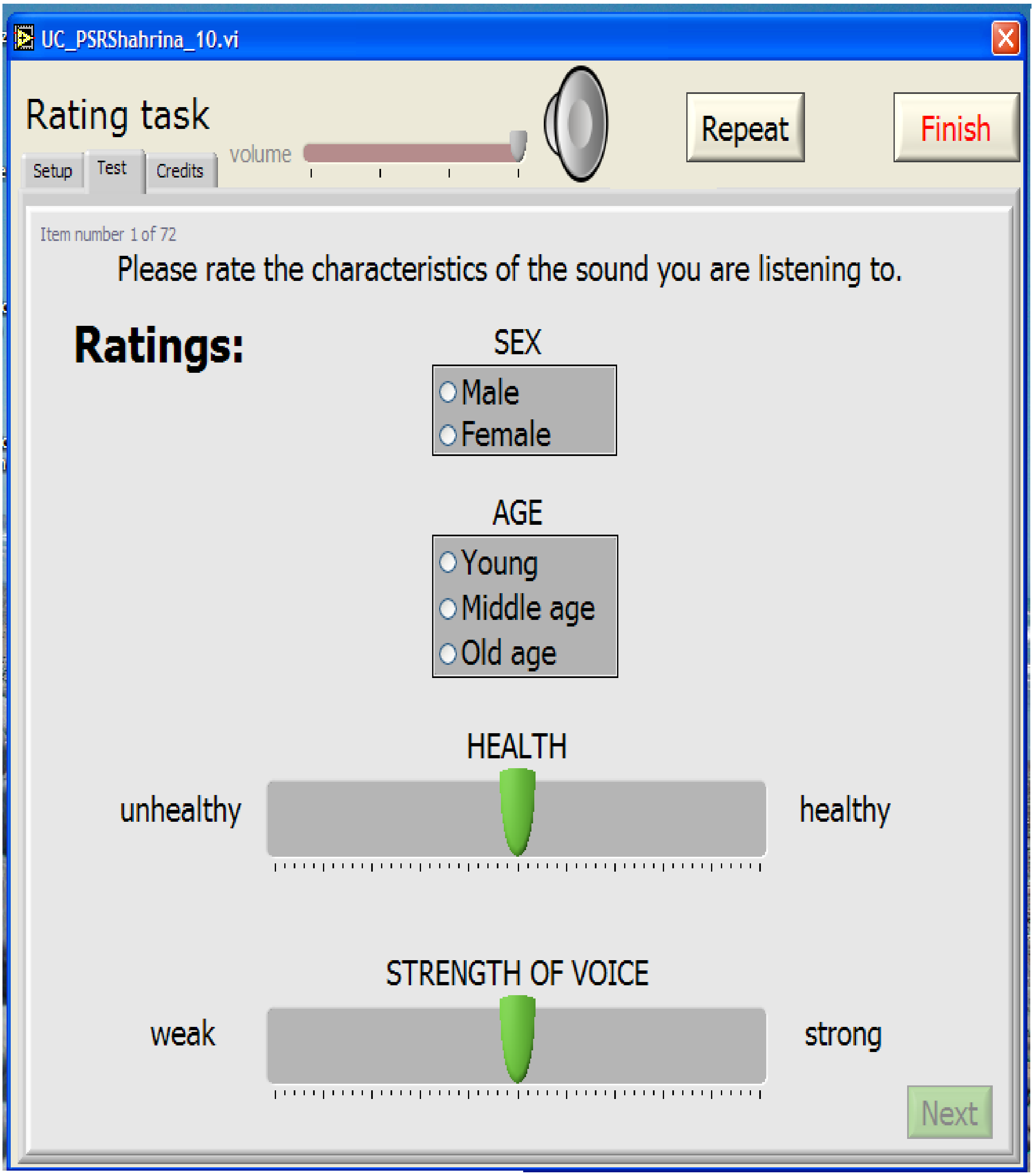

Figure 5: Computer display of the various perceptual judgments made by the listeners. All judgments were directly stored and tabulated by dedicated software. The 'Next' button would only appear after all judgments were made.

voiced phase (third phase). Thorpe et al. (1992) elaborated that the first phase or 'initial burst' corresponds to the glottal opening transient, the second phase or 'middle phase' is related to an interval of steady-state flow with the glottis wide open, and the third phase or 'final burst' is produced as the airflow is arrested by the closing of the glottis. Following the definition established by Thorpe et al. (1992), the three phases were demarcated using a vertical cursor system.

The location of each phase of the cough was based on examination of dual acoustic displays of the amplitude-by-time waveform and the corresponding wideband spectrogram. An example of a typical cough acoustic display is provided in Figure 6. Onset of the first phase (P1) was defined as the initial increase in amplitude from the baseline signal. P1 was also characterized by periodicity as shown in the corresponding spectrogram. The offset of P1 served as the onset of the second phase (P2), which was indicated by a decrease in amplitude and presence of aperiodicty. The offset of P2 served as the onset of the third phase (P3). P3 was indicated by a sudden increase in amplitude of the waveform, as well as the appearance of vocal periodicity. The offset of P3 was indicated as a return to baseline.

The spectral characteristics of each cough were determined using a long-time average spectrum (LTAS) analysis. An LTAS analysis provides a representation of vocal fold behaviour and is based on a continuous sample of a phonatory behaviour (Lofqvist & Mandersson, 1987). The characteristics of the vocal tract (e.g., shape & size) are averaged-out in LTAS analysis, leaving a representation of vocal fold vibratory behaviour. Using LTAS to analyze cough in this study is a novel approach, however, it carries potential in learning cough in relation to vocal fold behaviour. The LTAS analysis of each cough involved placing a pair of vertical cursors at the onset and offset of each cough. Each LTAS display was created through an averaging of individual Fast Fourier Transform (FFT) computations performed every 23 ms across the entire cough sample. Based on this demarcation, the speech analysis software automatically calculated the corresponding spectrum. An example of a typical LTAS display is shown in Figure 7.

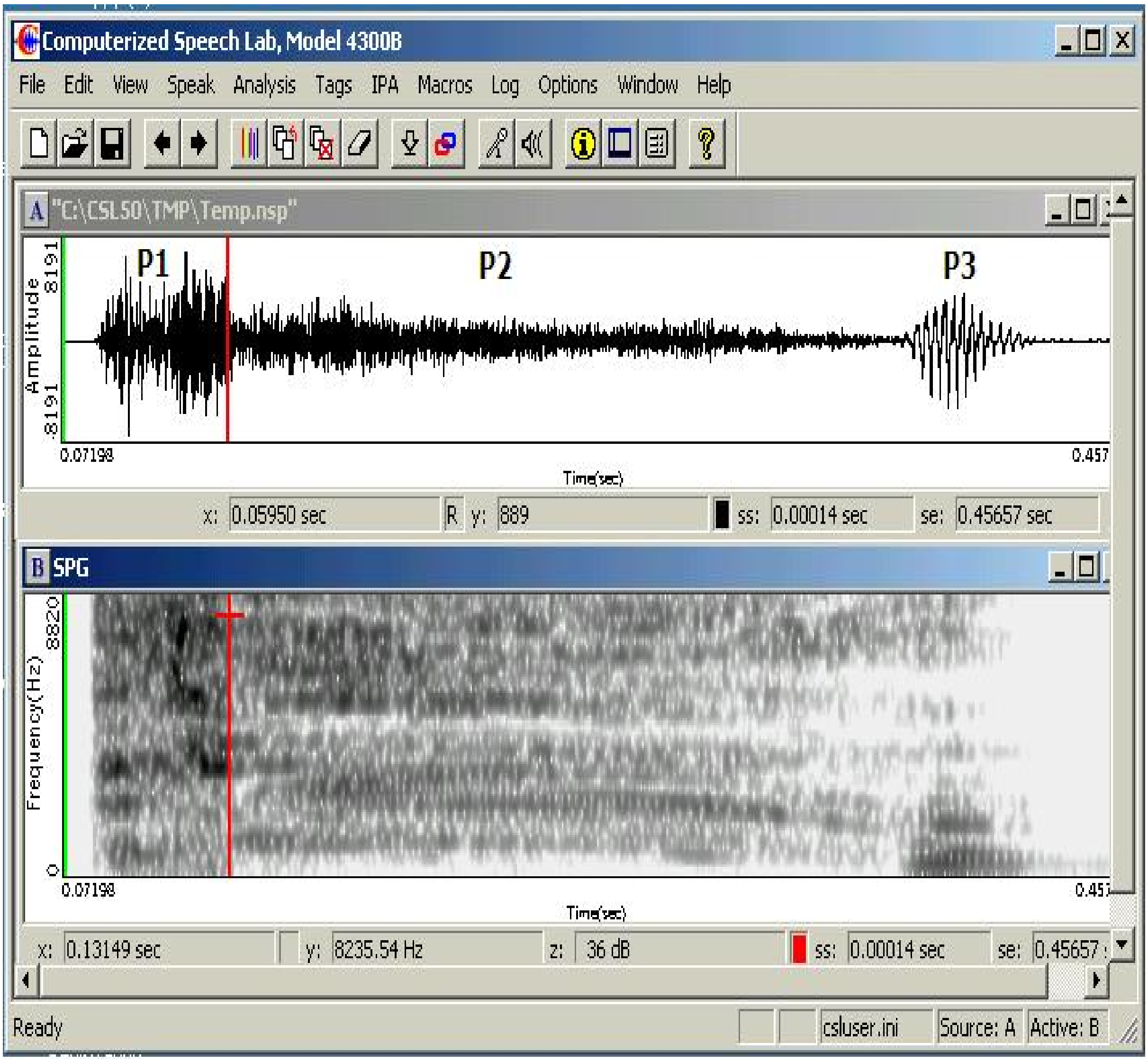

Figure 6: Acoustic display of (a) a typical three-phase of cough, and (b) its corresponding spectrogram. The offset of P1 and onset of P2 is marked by a cursor shown in both screens.

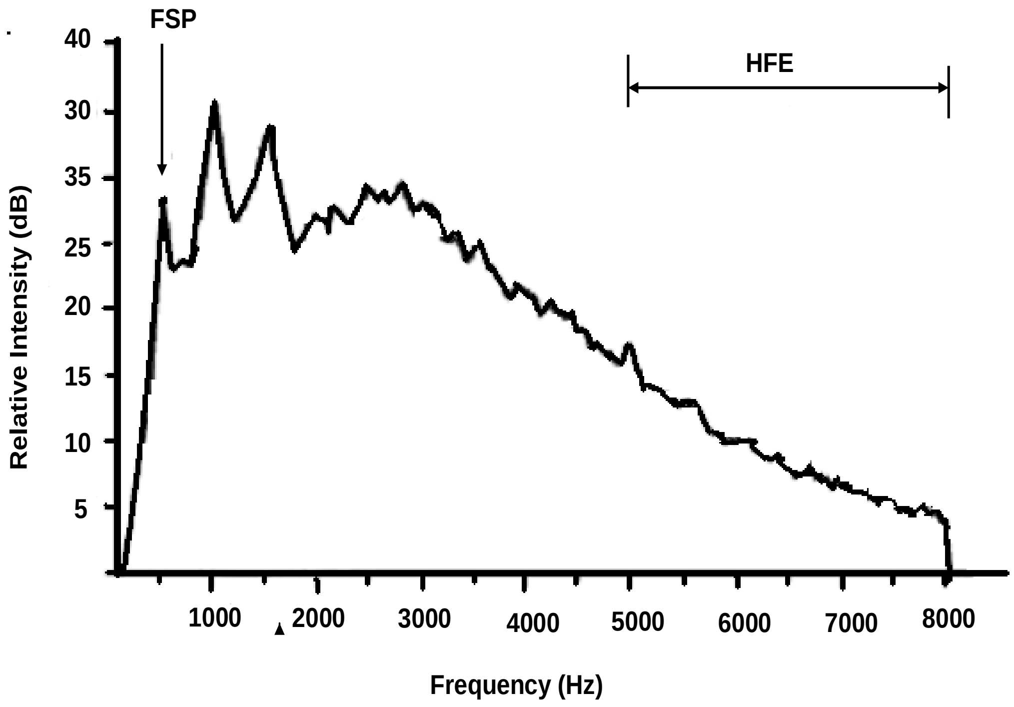

Figure 7: Display of a typical long time average spectrum (LTAS) taken from Goberman and Robb (1999). In this example, the location of the first spectral peak (FSP) is shown at approximately at 500 Hz. The location of high frequency energy (HFE) is also demarcated.

Three measures of cough LTAS were calculated:

(i) First Spectral Peak (FSP) – defined as the frequency value (Hz) associated with the first amplitude peak across the LTAS display (Goberman & Robb, 1999). FSP is assumed to provide a representation of the average F0 across the phonatory sample (Fuller & Horii, 1988) and is related to vocal fold stiffness.

(ii) Spectral tilt (ST) – defined as the ratio of energy (sum of amplitudes) between 0-1000 Hz and 1000-5000 Hz (Goberman & Robb, 1999). ST represents how quickly the amplitudes of the harmonics decline (Lofqvist & Mandersson, 1987) and is related to the adduction behaviour of the vocal folds.

(iii) High Frequency Energy (HFE) – defined as the total measured energy (sum of amplitudes) from 5000 Hz to 8000 Hz (Goberman & Robb, 1999), reflecting the presence of noise elements during phonation.

Perceptual Analysis. The perceptual judgments of cough and voice made by each of the listeners were organized according to each participant. The number of correct judgments of sex and age were determined for each listener. Judgments of health and strength of both cough and voice samples were compared for each participant group (young, middle-aged, older-age), as well as across the group of experienced listeners.

Reliability Assessment

To assess the reliability of acoustic measurement, intrajudge and interjudge reliability were performed. Intrajudge reliability for measures of cough duration were performed by remeasuring 9 samples (10%) of the original samples. The difference between the original and remeasured samples was determined. Results of the intrajudge assessment indicated as average remeasurement of 3 ms for overall cough duration. The average remeasurment difference for cough phase duration was 4 ms, 3 ms, and 2 ms for P1, P2, and P3, respectively.

Interjudge reliability was established by having another individual, who is experienced with acoustic analysis, measure the same (10%) samples. Results of the interjudge assessments indicated an average measurement difference of 4 ms for overall cough duration (range 0 ms – 5 ms). The correlation between the original total duration measurement and the measurement from the second judge was $r = .99$ ($p < .05$). The average measurement difference for P1 was 3 ms (range 0 ms – 3 ms). The correlation between the original P1 measurement and the measurement from the second judge was $r = .95$ ($p < .05$). The average measurement difference for P2 was 2 ms (range 0 ms – 7 ms). The correlation between the original P2 measurement and the measurement from the second judge was $r = .99$ ($p < .05$). The average measurement difference for P3 was 2 ms (range 0 ms – 6 ms). The correlation between the original P3 measurement and the measurement from the second judge was $r = .97$ ($p < .05$).

To assess the reliability for the perceptual task, each listener had to re-judge 13 randomly selected samples (18%) of the total data set played at the end of the original listening task. Comparison of the original and re-judged samples indicated 100% agreement for judgment of sex of voice samples, and 97% agreement for judgment of sex of cough samples. Comparison of the original and re-judged samples indicated 85% agreement for judgment of age of voice samples, and 64% agreement for judgment of age of cough samples. The original judgments related to strength of voice and strength of cough (based on a 10-point scale) compared to the re-judged samples indicated average difference scores of 1.13 and 1.56, respectively. The original judgments related to health of voice and health of cough (based on a 10-point scale) compared to the re-judged samples indicated average difference scores of 0.91 and 1.45, respectively.

Statistical Analysis

A series of one-way analysis of variance (ANOVA) tests were performed to examine the difference in the acoustic features of the coughs across age groups. Two-tailed *t*-tests were used to evaluate the difference in the acoustic features of cough according to sex group. A two-way ANOVA was also performed to determine the possible acoustic difference between the three phases of cough as a function of age and sex groupings. Descriptive analyses were also used to evaluate the perceptual judgments of the voice and cough samples in relation to sex, age, healthiness and strength. These were followed by a series of two-way ANOVAs to determine if judgments between the cough and voice samples differed across the age and sex groupings. In addition, correlational analyses were performed to examine the relationship between various acoustic features of cough and qualitative judgments of cough and voice. The ANOVA and *t*-tests were carried out using SPSS 15.0 and the correlational analyses were performed using Pearson product-moment correlation coefficients – Free Statistics Software (http://www.wessa.net/corr.wasp).

Results

The results are presented in three sections. The first section contains numerical data relating to the acoustic analysis of cough. The second section contains the results of a detailed correlational analysis between acoustic of cough and perceptual features of cough. The third section reports the perceptual analysis of cough and voice.

Acoustic Analysis of Cough

Total Duration. The durational features of the entire cough, as well as cough phases are shown in Table 3 according to age group and Table 4 according to sex grouping. The mean values for each sex and age group were based on an average of the median values for each participant taken from the three individual coughs. Across the age groups, the average overall duration of coughs ranged from 293 ms (middle-aged) to 306 ms (older-age). A one-way ANOVA was performed to determine whether the total duration of cough differed significantly across age groups. The test was non-significant [F (2, 27) = .101, p = .90]. Across the sex groups, the average overall duration of coughs was 307 ms for males and 293 ms for females. A two-tailed t-test was performed to determine whether total cough duration differed between groups. The test was non-significant [t (28) = .59, p = .56].

Duration of Phase 1. Results of the durational analysis of Phase 1 (P1) are provided in Table 3 according to age and Table 4 according to sex. The mean values for each sex and age group were based on an average of the median value for each participant. The average duration of P1 was 42 ms for both young and older-age groups, and 38 ms for the middle-aged group. Result of a one-way ANOVA indicated no significant differences in PI according to age group [F (2, 27) = .614, p = .54]. Across the sex groups, the average duration of P1 was 38 ms for males and 42 ms for females. Result of a two-tailed t-test, indicated no significant differences in P1 according to sex [t (28) = 1.11, p = .92]

Participants	Total Duration (s)	Duration of first phase (P1) (s)	Duration of second phase (P2) (s)	Duration of third phase (P3) (s)
Young group				
MY1	0.319	0.036	0.251	0.035
MY2	0.260	0.035	0.174	0.036
MY3	0.411	0.041	0.319	0.050
MY4	0.265	0.035	0.178	0.070
MY5	0.290	0.034	0.204	0.055
FY1	0.343	0.040	0.279	0.028
FY2	0.295	0.043	0.195	0.062
FY3	0.318	0.062	0.159	0.058
FY4	0.306	0.058	0.208	0.040
FY5	0.213	0.033	0.150	0.033
Mean	0.302	0.042	0.212	0.048
Standard Deviation	0.0530	0.0102	0.0549	0.0131
Middle-aged group				
MM1	0.377	0.041	0.194	0.142
MM2	0.269	0.042	0.189	0.037
MM3	0.296	0.032	0.204	0.063
MM4	0.314	0.029	0.230	0.048
MM5	0.281	0.032	0.178	0.068
FM1	0.323	0.032	0.257	0.034
FM2	0.269	0.042	0.181	0.084
FM3	0.224	0.039	0.146	0.042
FM4	0.275	0.032	0.186	0.044
FM5	0.299	0.054	0.185	0.061
Mean	0.293	0.038	0.195	0.062
Standard Deviation	0.0406	0.0076	0.0303	0.0321
Older-aged group				
MO1	0.253	0.031	0.154	0.035
MO2	0.241	0.036	0.123	0.081
MO3	0.210	0.034	0.094	0.084
MO4	0.542	0.065	0.427	0.050
MO5	0.282	0.052	0.178	0.035
FO1	0.322	0.048	0.232	0.047
FO2	0.380	0.044	0.287	0.045
FO3	0.316	0.037	0.222	0.057
FO4	0.255	0.039	0.196	0.041
FO5	0.258	0.030	0.180	0.041
Mean	0.306	0.042	0.209	0.052
Standard Deviation	0.0962	0.0109	0.0942	0.0176

Table 3: Total cough duration and duration of each cough phase. The data are presented according to age group. Participant sex is noted as M = male and F = female. Participant age is noted as Y = young, M = middle-aged and O = older-aged.

Participants	Total Duration (s)	Duration of first phase (P1) (s)	Duration of second phase (P2) (s)	Duration of third phase (P3) (s)
Male group				
MY1	0.319	0.036	0.251	0.035
MY2	0.260	0.035	0.174	0.036
MY3	0.411	0.041	0.319	0.050
MY4	0.265	0.035	0.178	0.070
MY5	0.290	0.034	0.204	0.055
MM1	0.377	0.041	0.194	0.142
MM2	0.269	0.042	0.189	0.037
MM3	0.296	0.032	0.204	0.063
MM4	0.314	0.029	0.230	0.048
MM5	0.281	0.032	0.178	0.068
MO1	0.253	0.031	0.154	0.035
MO2	0.241	0.036	0.123	0.081
MO3	0.210	0.034	0.094	0.084
MO4	0.542	0.065	0.427	0.050
MO5	0.282	0.052	0.178	0.035
Mean	0.307	0.038	0.206	0.059
Standard Deviation	0.0824	0.0093	0.0803	0.0284
Female group				
FY1	0.343	0.040	0.279	0.028
FY2	0.295	0.043	0.195	0.062
FY3	0.318	0.062	0.159	0.058
FY4	0.306	0.058	0.208	0.040
FY5	0.213	0.033	0.150	0.033
FM1	0.323	0.032	0.257	0.034
FM2	0.269	0.042	0.181	0.084
FM3	0.224	0.039	0.146	0.042
FM4	0.275	0.032	0.186	0.044
FM5	0.299	0.054	0.185	0.061
FO1	0.322	0.048	0.232	0.047
FO2	0.380	0.044	0.287	0.045
FO3	0.316	0.037	0.222	0.057
FO4	0.255	0.039	0.196	0.041
FO5	0.258	0.030	0.180	0.041
Mean	0.293	0.042	0.204	0.048
Standard Deviation	0.0446	0.0097	0.0437	0.0136

Table 4: Total cough duration and duration of each cough phase. The data are presented according to sex group. Participant sex is noted as M = male and F = female. Participant age is noted as Y = young, M = middle-aged and O = older-aged.

Duration of Phase 2. The results of the durational analysis of Phase 2 (P2) according to age and sex are shown in Table 3 and Table 4, respectively. Across the age groups, the average duration of P2 ranged from 195 ms (middle-aged) to 212 ms (young). A one-way ANOVA was performed to determine whether the duration of P2 of the cough differed significantly across age groups. The test was non-significant [F (2, 27) = .191, p = .82]. The average duration of P2 was 206 ms for males and 204 ms for females. Results of a two-tailed t-test indicated no significant differences in P2 between groups [t (28) = .09, p = .92].

Duration of Phase 3. Results of the durational analysis of Phase 3 (P3) for age and sex are listed in Table 3 and Table 4, respectively. The average duration of P3 ranged from 46 ms (young) to 62 ms (middle-aged). A one-way ANOVA was performed to determine whether the duration of P3 of the cough differed significantly across age groups. The test was non-significant [F (2, 27) = 1.24, p = .30]. The average duration of P3 was 59 ms for males and 48 ms for females. Results indicated no differences in the duration of P3 between sexes [t (28) = 1.39, p = .17].

Phase Differences. In order to determine whether the three-phases comprising a cough differed significantly across age groups, a two-way ANOVA was performed. The between-groups factor was age and the within-groups factor was cough phases. Results of the test between ages was not significant [F (2, 27) = .03, p = .968]. There was no significant age-by-phase interaction [F (2, 27) = 1.83, p = .179]. There was a significant difference in the duration between each of the phases [F (1, 27) = 9.14, p = .005]. Follow-up t-tests identified differences in duration between P1 and P2 (p = .001), P2 and P3 (p = .001), as well as P1 and P3 (p = .005). A two-way ANOVA was also performed to evaluate differences of the 3-phases of cough according to sex. The between group factor was sex and the within group factor was cough phase. Results of the test between sex was not significant [F (1, 28) =.16, p = .69]. The sex-by-phase duration interaction approached significance [F (1, 28) = 3.09, p = .08]. Similar to the analysis for age groups, there were significant differences between phases [F (1, 28) = 9.27,

p = .005]. Post-hoc t-tests identified differences between P1 and P2 (p = .001), P2 and P3 (p = .001), as well as P1 and P3 (p = .005). A display of the phase duration of each phase of cough, as well as the overall cough duration according to age and sex is provided in Figure 8 and Figure 9, respectively.

First Spectral Peak (FSP). Results of the analysis of FSP for the entire cough are provided in Table 5 according the age group and Table 6 according to sex. The mean values for each sex and age group were based on an average of the median value for each participant. The average FSP ranged from 237 Hz (older-age) to 308 Hz (young-age). Results of a one-way ANOVA revealed no significant differences in FSP according to age group [F (2, 27) = 1.31, p = .28]. The average FSP was 293 Hz for males and 262 Hz for females. Results of a two-tailed t-test indicated no significant differences in FSP according to sex [t (28) = .82, p = .41]. A graphic display of the FSP results is provided in Figure 10.

Spectral Tilt (ST). Results of the analysis of ST for the entire cough according to age and sex are listed in Table 5 and Table 6, respectively. The average ST ranged from 0.59 (middle-aged) to 0.64 (older-age). Results of a one-way ANOVA indicated no significant differences in ST according to age group [F (2, 27) = .82, p = .84]. The average ST was 0.60 for males and 0.64 for females. Results of a two-tailed t-test indicated no significant differences in ST according to sex [t (28) = .48, p = .62]. A graphic display of the ST results is provided in Figure 11.

High Frequency Energy (HFE). The results of the analysis of HFE for the entire cough according to age and sex are listed in Table 5 and Table 6, respectively. The average HFE ranged from 213 (older-age) to 312 Hz (middle-aged). A one-way ANOVA analysis revealed no significant difference in HFE according to age group [F (2, 27) = .68, p = .51]. The average HFE was 279 Hz for males and 227 Hz for females. Results of a two-tailed t-test indicated no significant differences in HFE according to sex [t (28) = .72, p = .47]. A graphic display of the HFE results is provided in Figure 12.

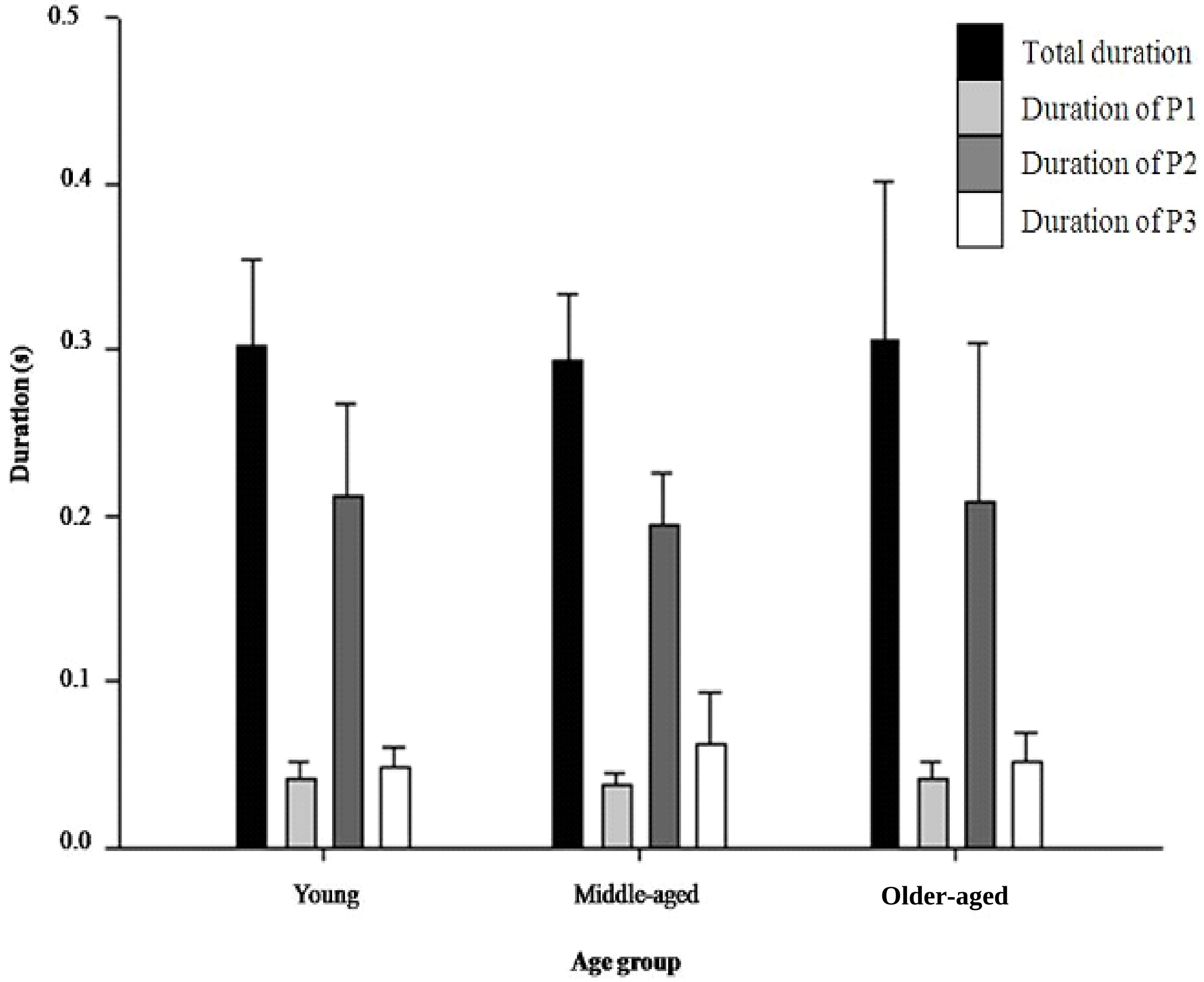

Figure 8: A display of the phase duration of each phase of cough according to age group. The duration of each phase (P1-P3) is also shown.

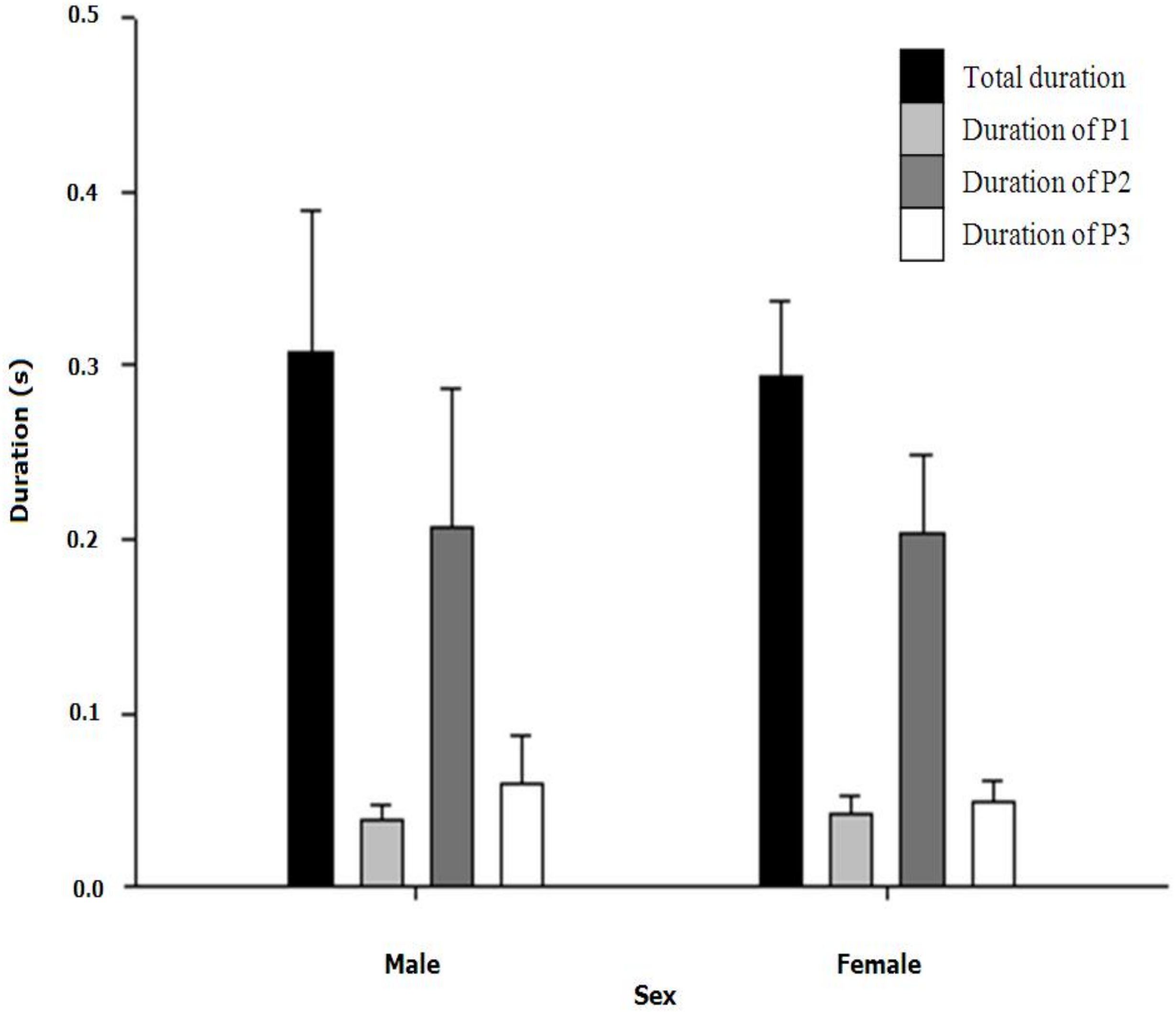

Figure 9: A display of the phase duration of each phase of cough according to sex. The duration of each phase (P1-P3) is also shown.

Participants	FSP (Hz)	ST	HFE (dB)
Young group			
MY1	490.86	0.50	135.01
MY2	195.77	0.66	764.22
MY3	550.26	0.85	26.73
MY4	206.35	0.64	280.51
MY5	248.68	0.65	138.64
FY1	386.24	0.78	305.93
FY2	296.10	0.48	135.79
FY3	249.35	0.55	322.63
FY4	207.79	0.52	142.23
FY5	254.22	0.70	93.61
Mean	308.56	0.63	234.53
Standard Deviation	125.259	0.122	209.749
Middle-aged group			
MM1	343.20	0.39	542.55
MM2	201.06	0.62	300.46
MM3	248.68	0.53	169.82
MM4	513.23	0.67	458.32
MM5	132.28	0.65	90.33
FM1	301.59	0.56	291.90
FM2	253.97	0.42	589.50
FM3	296.30	0.52	225.36
FM4	206.35	0.81	38.81
FM5	380.95	0.81	414.94
Mean	287.76	0.60	312.20
Standard Deviation	107.417	0.144	186.844
Older-aged group			
MO1	338.62	0.71	18.90
MO2	211.64	0.52	173.06
MO3	296.30	0.70	406.03
MO4	211.64	0.49	607.33
MO5	211.64	0.54	81.56
FO1	121.69	0.58	275.57
FO2	216.93	0.37	127.42
FO3	248.68	0.72	90.60
FO4	296.30	0.47	357.83
FO5	216.93	1.34	0.00
Mean	237.04	0.64	213.83
Standard Deviation	61.035	0.270	194.896

Table 5: Long term average spectrum (LTAS) features of coughs, including first spectral peak (FSP), spectral tilt (ST) and high frequency energy (HFE), organized according to age group. Participant sex is noted as M = male and F = female. Participant age is noted as Y = young, M = middle-aged and O = older-aged.

Participants	FSP (Hz)	ST	HFE (dB)
Male group			
MY1	490.86	0.50	135.01
MY2	195.77	0.66	764.22
MY3	550.26	0.85	26.73
MY4	206.35	0.64	280.51
MY5	248.68	0.65	138.64
MM1	343.20	0.39	542.55
MM2	201.06	0.62	300.46
MM3	248.68	0.53	169.82
MM4	513.23	0.67	458.32
MM5	132.28	0.65	90.33
MO1	338.62	0.71	18.90
MO2	211.64	0.52	173.06
MO3	296.30	0.70	406.03
MO4	211.64	0.49	607.33
MO5	211.64	0.54	81.56
Mean	293.35	0.61	279.56
Standard Deviation	129.139	0.113	228.488
Female group			
FY1	386.24	0.78	305.93
FY2	296.10	0.48	135.79
FY3	249.35	0.55	322.63
FY4	207.79	0.52	142.23
FY5	254.22	0.70	93.61
FM1	301.59	0.56	291.90
FM2	253.97	0.42	589.50
FM3	296.30	0.52	225.36
FM4	206.35	0.81	38.81
FM5	380.95	0.81	414.94
FO1	121.69	0.58	275.57
FO2	216.93	0.37	127.42
FO3	248.68	0.72	90.60
FO4	296.30	0.47	357.83
FO5	216.93	1.34	0.00
Mean	262.23	0.64	227.47
Standard Deviation	68.094	0.239	159.139

Table 6: Long term average spectrum (LTAS) features of coughs, including first spectral peak (FSP), spectral tilt (ST) and high frequency energy (HFE), organized according to sex. Participant sex is noted as M = male and F = female. Participant age is noted as Y = young, M = middle-aged and O = older-aged.

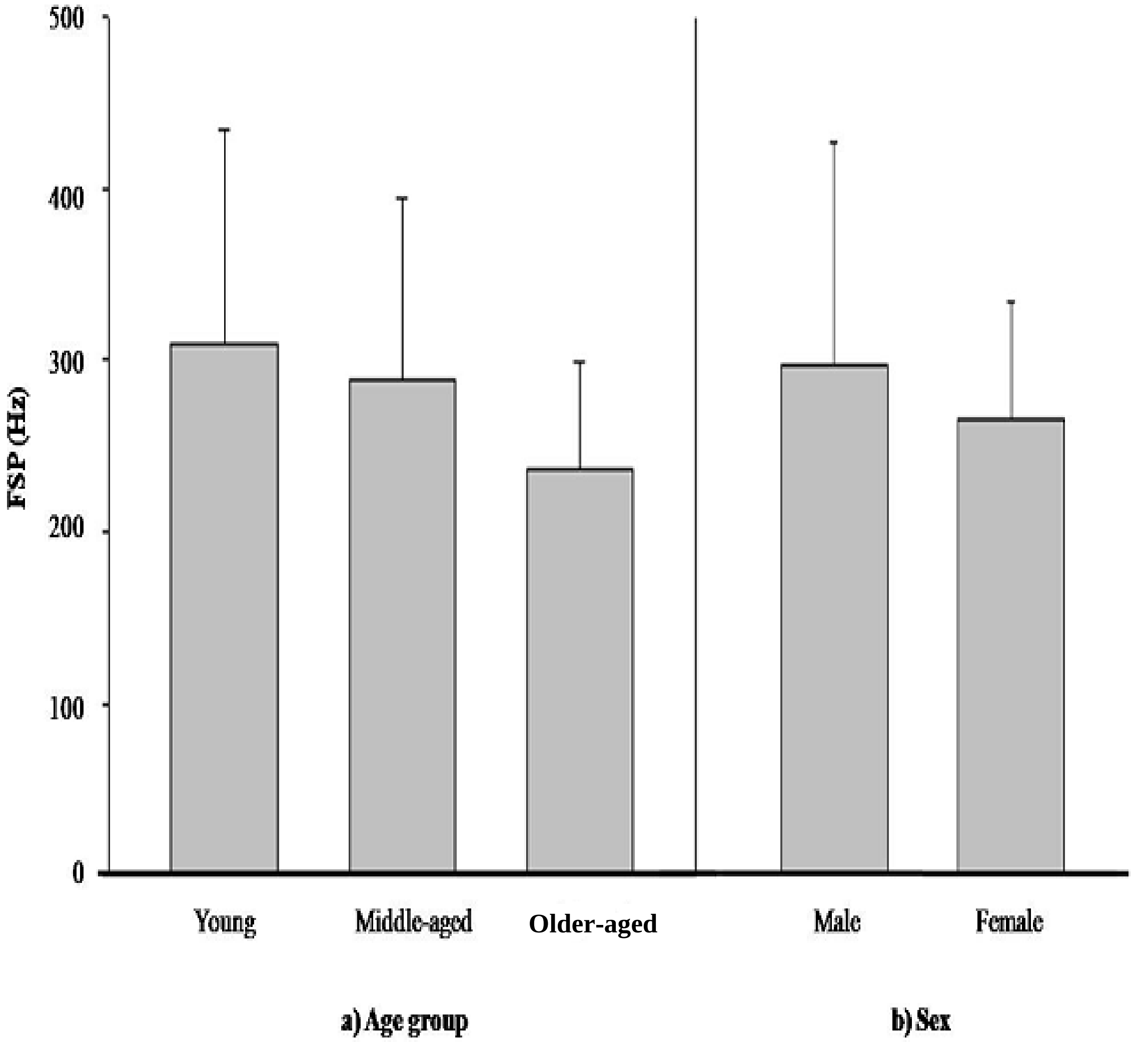

Figure 10: Display of the first spectral peak (FSP) of coughs according to (a) age groups and (b) sex.

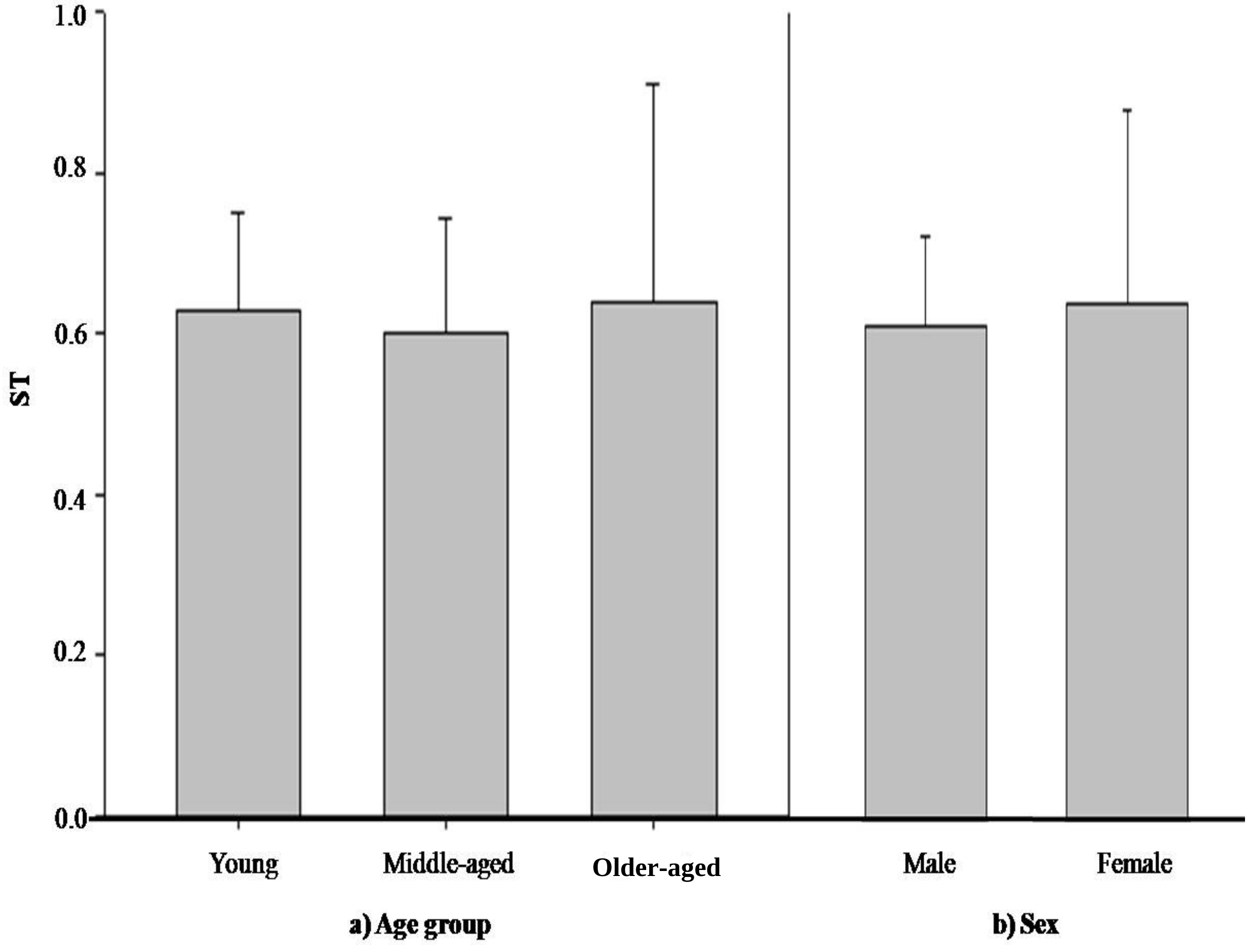

Figure 11: Display of spectral tilt (ST) of coughs according to (a) age groups and (b) sex.

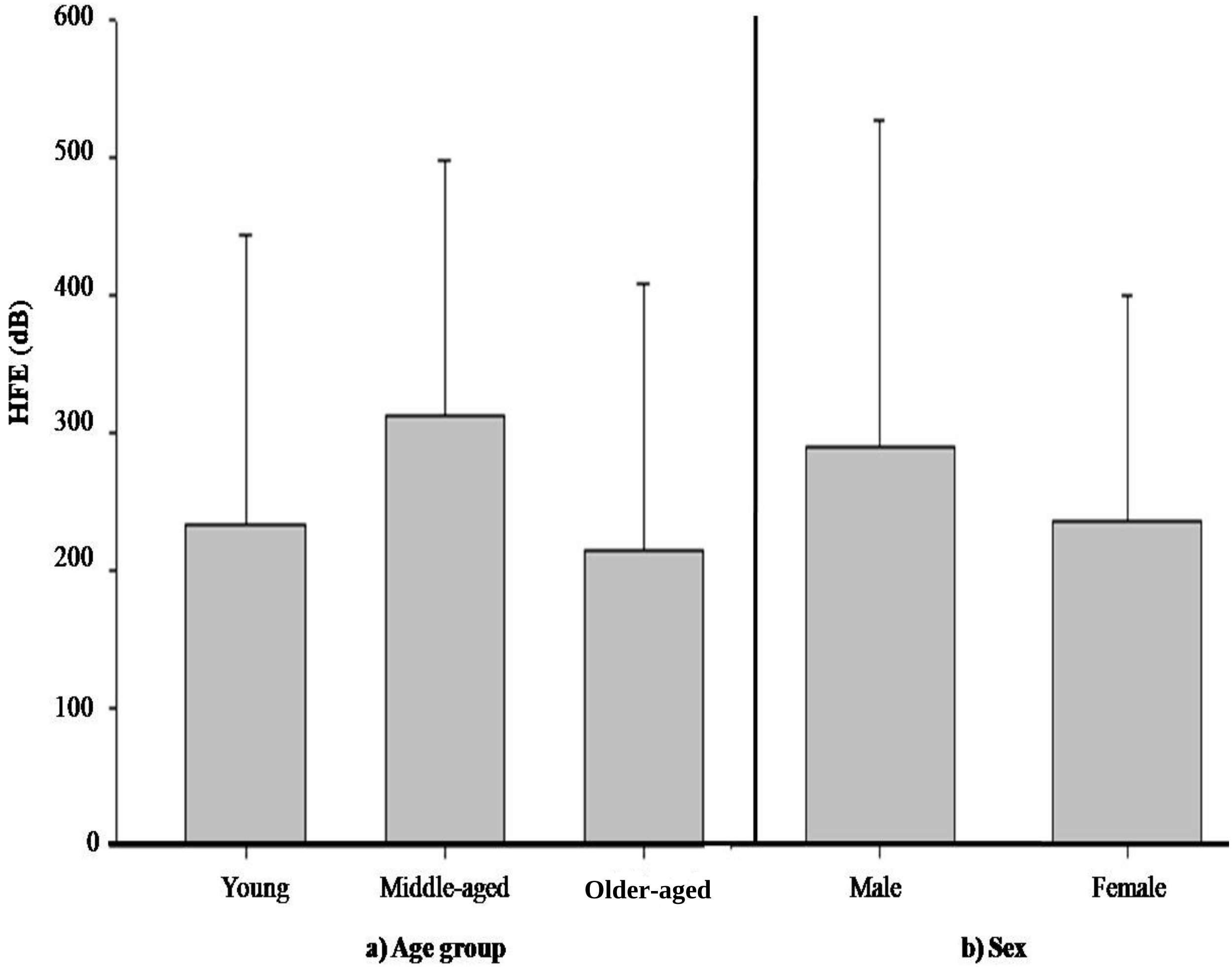

Figure 12: Display of the high frequency energy (HFE) of coughs according to (a) age groups and (b) sex.

Correlation Analysis of Cough and Voice

A series of correlations were calculated to examine possible relationships between acoustic features of cough and perceptual judgments of cough and voice quality. The entire set of correlations is listed in Appendices A-D. Only the major correlations are presented below.

Health of cough and health of voice. Across the age groups, the majority of the voice samples across the three age groups were perceived healthier than the corresponding cough samples. The results are displayed in Figure 13. Across sex, the majority of the voice samples were judged to be healthier than the cough samples. The results are displayed in Figure 14. In addition, the coughs produced by females were generally judged to be healthier than the coughs of males. Despite the observable trends, the relationship between health of cough and health of voice across age and sex groupings only approached significance, $r = .22$ ($p = .12$).

Strength of cough and strength of voice. Across the age groups, the majority of voice samples were perceived stronger than cough samples. The results are displayed in Figure 15. A similar pattern was found when the data were organized according to sex, as displayed in Figure 16. However, the overall correlation between strength of cough and strength of voice was not significant, $r = .16$ ($p = .20$).

Acoustics of cough and perception of cough/voice. Overall, none of the perceptual judgments of cough correlated with any acoustic feature of cough. A number of significant correlations between the perception of voice and the acoustic features of cough were found as a function of age and sex. Specifically, P1 was found to be negatively correlated to the strength and health of the male voice, $r = -.73$ ($p < .05$) and $r = -.52$ ($p < .05$), respectively. A healthy and strong male voice was associated with a short P1 duration. The strength and health of young-aged voice was found to be significantly correlated to P3, $r = .72$ ($p < .05$) and $r = .64$ ($p <.05$), respectively. A healthy and strong young voice was associated with a short P3 duration. In addition, the strength of older-aged voice was found to be significantly correlated to P1, $r = -.66$ ($p < .05$). A strong older-aged voice was associated with a long P1 duration.

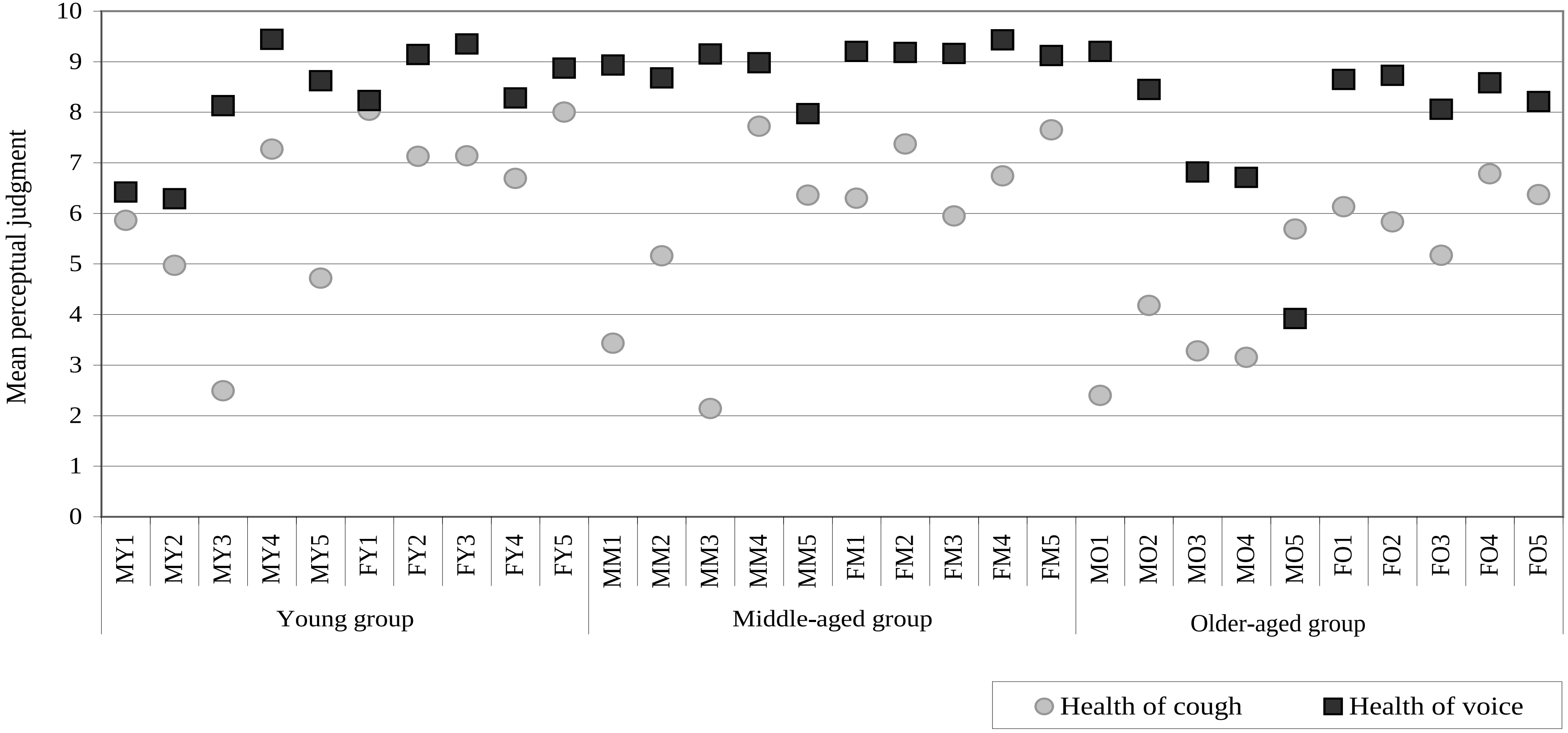

Figure 13: Mean perceptual rating of cough and voice health. Data are presented according to age groups. Participant sex is noted as M = male, F = female. Participant age is noted as Y = young, M = middle-aged and O = older-aged.

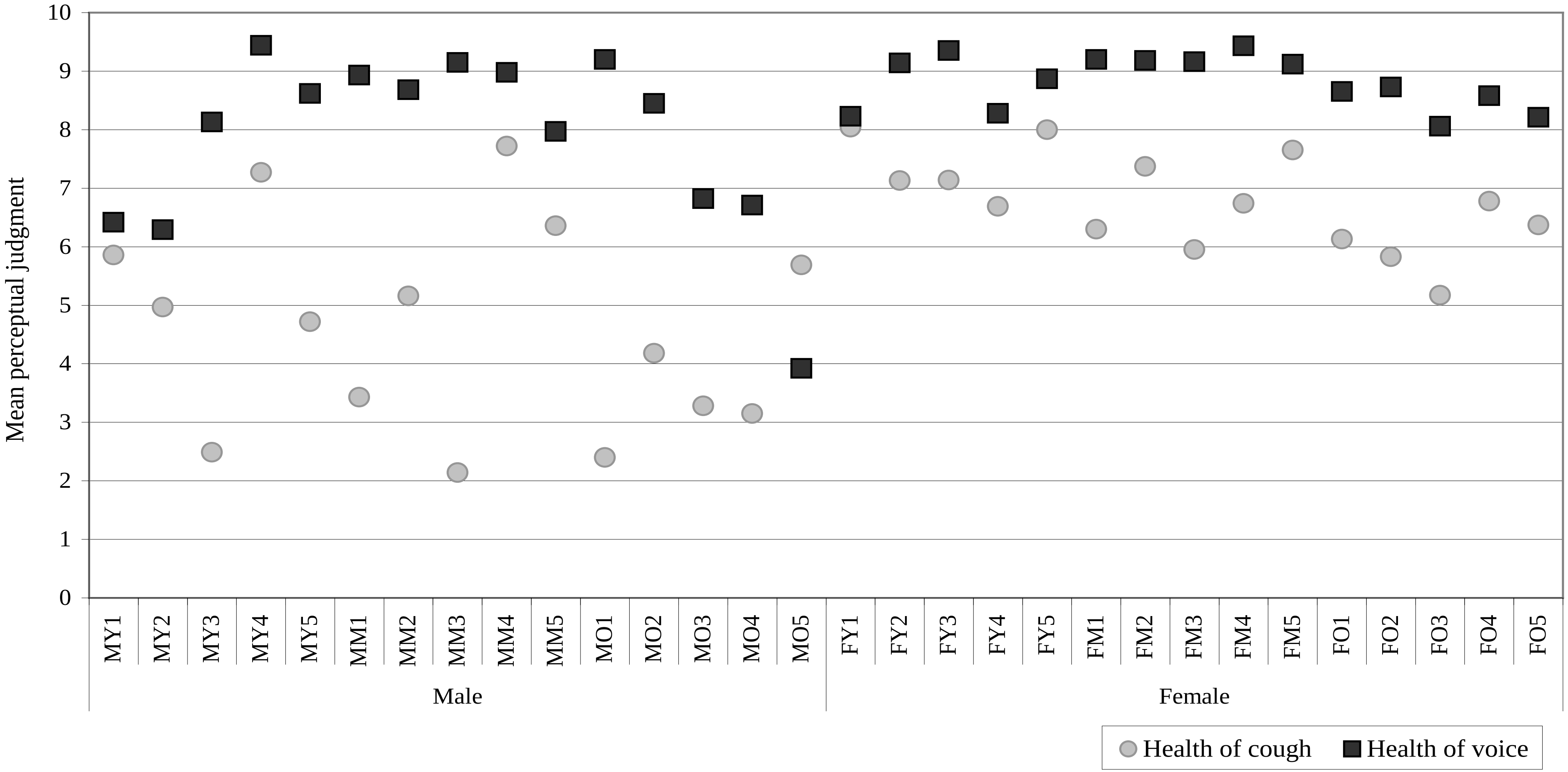

Figure 14: Mean perceptual rating of cough and voice health. Data are presented according to sex. Participant sex is noted as M = male, F = female. Participant age is noted as Y = young, M = middle-aged and O = older-aged.

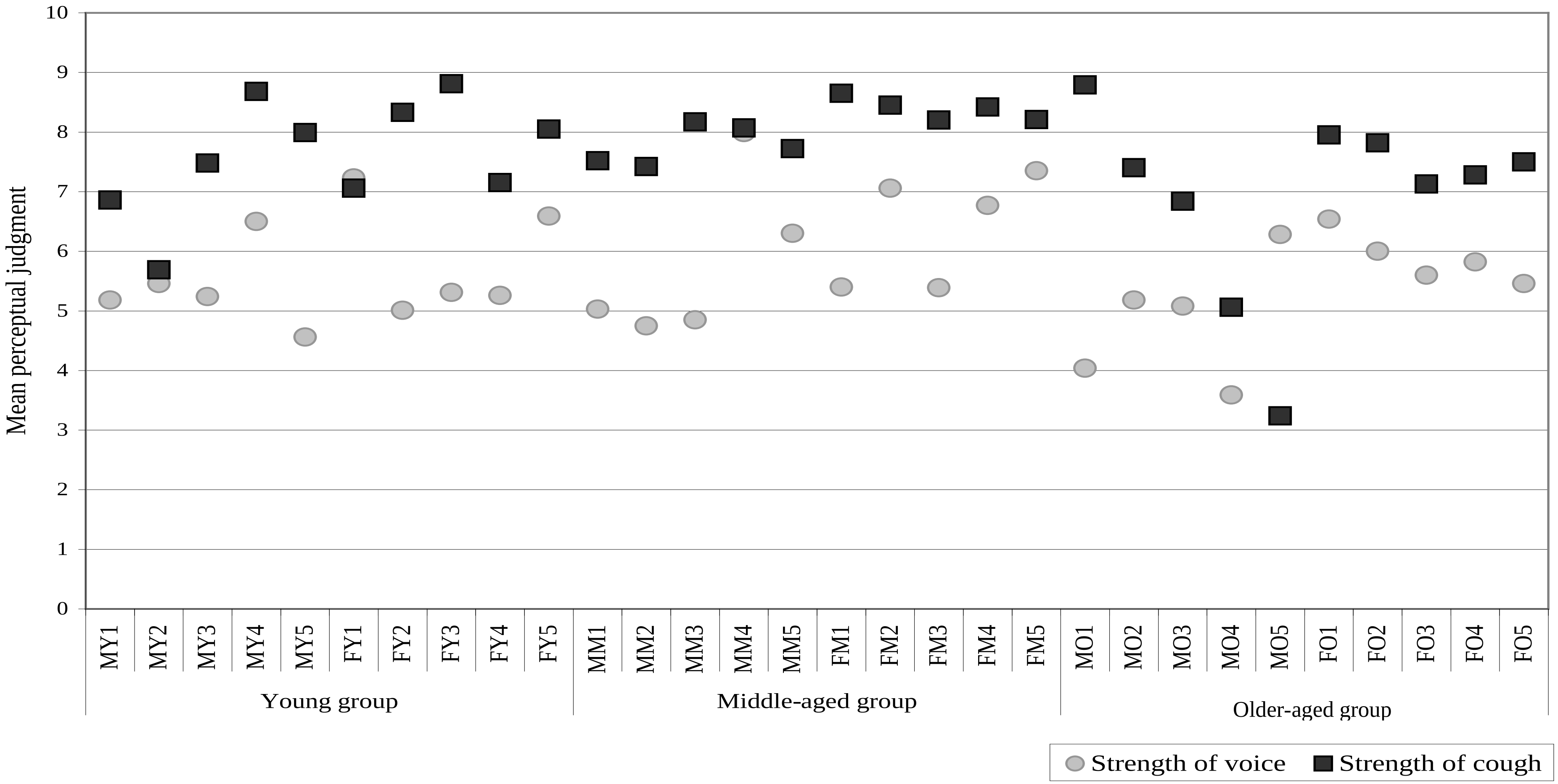

Figure 15: Mean perceptual rating of cough and voice strength. Data are presented according to age group. Participant sex is noted as M = male, F = female. Participant age is noted as Y = young, M = middle-aged and O = older-aged.

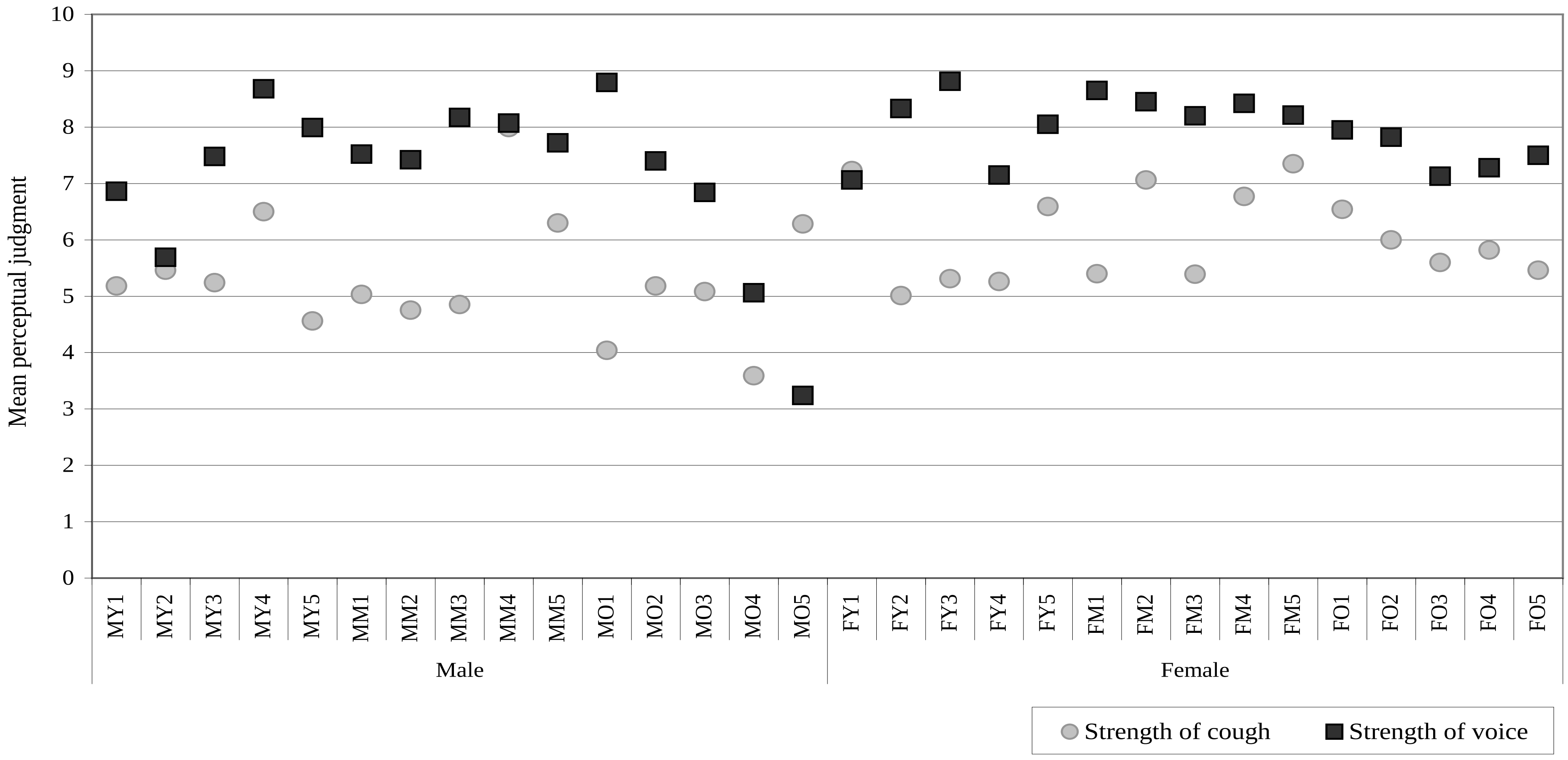

Figure 16: Mean perceptual rating of cough and voice strength. Data are presented according to sex. Participant sex is noted as M = male, F = female. Participant age is noted as Y = young, M = middle-aged and O = older-aged.

Perceptual Analysis of Cough and Voice

Judgment of Sex. The overall perceptual judgments for sex across the cough and voice samples are listed in Table 7 according to age group and Table 8 according to sex. Across the age and sex groupings, the total number of correct judgments for sex of cough ranged from 14 to 20 (i.e., out of 20 judgments in total) with a mean of 19.5 correct judgments (SD = 1.3). The total correct judgments for sex of voice across the groupings ranged from 19 to 20, with a mean of 19.9 (SD = 0.31). A two-way ANOVA was performed to evaluate the listeners' judgments of sex of cough and voice samples according to age of participants. The within-groups factor was age of participant and the between-groups factors were cough/voice samples. There was no significant main effect for age [F (2, 18) = 2.74, p = .13]. There was also no significant main effect for cough/voice samples [F (1, 9) = 1.67, p = .20], indicating that listeners were able to judge the sex of cough and voice equally across age groups. There was no significant interaction between age and judgment of sex [F (2, 18) = 2.14, p = .18].

A two-way ANOVA was also performed to examine if the judgments of sex of cough/voice samples differed across sex. There was no significant main effect for sex [F (1, 14) = 1.58, p = .23]. In addition, there was no significant main effect for cough/voice samples [F (1, 14) = 1.97, p = .18], indicating that listeners were able to judge the sex of cough and voice equally across sex groups. There was no significant interaction between sex and judgment of sex [F (1, 14) = 1.97, p = .18].

Judgment of Age. The overall perceptual judgments for age across the cough and voice samples are included in Table 7 according to age group and Table 8 according to sex. The total number of correct judgments for age of cough ranged from 0 to 19 with a mean of 11.2 correct judgments (SD = 4.7). The total correct judgments for age of voice ranged from 9 to 20, with a mean of 15.5 (SD = 3.04). A two-way ANOVA was performed to evaluate the listeners' judgments of age of cough and voice samples according to age of participants. The within-group

Participants	Total correct judgment of sex		Total correct judgment of age	
	Cough	Voice	Cough	Voice
Young group	-	-		
MY1	20	20	12	12
MY2	20	20	7	18
MY3	16	20	2	11
MY4	20	20	8	13
MY5	14	20	4	17
FY1	20	20	16	19
FY2	20	20	15	18
FY3	19	19	10	19
FY4	20	20	15	19
FY5	20	20	19	11
Middle-aged group				
MM1	20	20	9	13
MM2	20	20	11	16
MM3	20	20	10	13
MM4	20	20	16	15
MM5	20	20	13	15
FM1	20	20	9	13
FM2	20	20	11	16
FM3	20	20	10	13
FM4	20	20	16	15
FM5	20	20	13	15
Older-aged group				
MO1	20	20	19	9
MO2	20	20	13	12
MO3	20	19	15	17
MO4	20	20	14	20
MO5	19	20	11	20
FO1	20	20	5	14
FO2	20	20	17	18
FO3	19	19	8	18
FO4	20	20	0	18
FO5	20	20	8	19

Table 7: Correct judgment of sex and age from the cough and voice samples. Participants sex is noted as M = male, F= female. Participant age is noted as Y = young, M = middle-aged and O = older-aged. The maximum correct judgment was 20.

Participants	Total correct judgment of sex		Total correct judgment of age	
	Cough	Voice	Cough	Voice
Male group	-	-		
MY1	20	20	12	12
MY2	20	20	7	18
MY3	16	20	2	11
MY4	20	20	8	13
MY5	14	20	4	17
MM1	20	20	9	13
MM2	20	20	11	16
MM3	20	20	10	13
MM4	20	20	16	15
MM5	20	20	13	15
MO1	20	20	19	9
MO2	20	20	13	12
MO3	20	19	15	17
MO4	20	20	14	20
MO5	19	20	11	20
Female group				
FY1	20	20	16	19
FY2	20	20	15	18
FY3	19	19	10	19
FY4	20	20	15	19
FY5	20	20	19	11
FM1	20	20	9	13
FM2	20	20	11	16
FM3	20	20	10	13
FM4	20	20	16	15
FM5	20	20	13	15
FO1	20	20	5	14
FO2	20	20	17	18
FO3	19	19	8	18
FO4	20	20	0	18
FO5	20	20	8	19

Table 8: Correct judgment of sex and age from the cough and voice samples. Participants sex is noted as M = male, F= female. Participant age is noted as Y = young, M = middle-aged and O = older-aged. The maximum correct judgment was 20.

factor was age of participant and the between-groups factors were cough/voice samples. There was no significant main effect for sex [F (2, 18) = .07, p = .94]. There was a significant main effect for cough/voice samples [F (1, 9) = 13.08, p = .005], indicating that across age groups, age of voice was more accurately judged compared to age of cough. There was no significant interaction between age and judgment of age [F (2, 18) = 1.04, p = .36].

A two-way ANOVA was performed to examine if the judgments of age of cough/voice samples differed across sex. There was no significant main effect for sex [F (1, 14) = .87, p = .37]. There was a significant main effect for cough/voice samples [F (1, 14) = 14.98, p = .002], indicating that across sex groups, age of voice was more accurately judged compared to age of cough. There was no significant interaction between sex and judgment of age [F (1, 14) = 1.04, p = .67].

Judgment of Health. The overall perceptual judgments for health of the cough and voice samples are listed in Table 9 according to age group and Table 10 according to sex. The judgment for health of cough across the age and sex groupings ranged from 2.14 to 8.04 (based on a scale of 1-10) with mean rating of 5.67 (SD = 1.75). The judgments for health of voice ranged from 3.92 to 9.44 with mean rating of 8.33 (SD = 1.21). A two-way ANOVA was performed to evaluate the listeners' judgments of health of cough and voice samples according to age of participants. There was a significant main effect for age [F (2, 18) = 8.05, p = .003]. Follow up t-tests identified a significant difference between the middle-age and older-age group [t (9) = 2.42, p = .02], and between the young age and older-age group [t (9) = 2.94, p = .04], indicating that the older-age participants were judged to have the unhealthiest voice and cough samples. There was also a significant main effect for cough/voice samples [F (1, 9) = 41.88, p < .001], indicating that voice samples were judged to be significantly healthier than the cough samples across age groups. In contrast, there was no significant interaction between age and judgment of health [F (2, 18) = 1.04, p = .10].

Participants	Health					
	Cough			Voice		
	Mean	Range	SD	Mean	Range	SD
Young group						
MY1	5.86	2.22 – 9.89	2.67	6.42	0.88 – 10.00	3.28
MY2	4.97	0.80 – 9.03	2.54	6.29	0.14 – 10.00	3.26
MY3	2.49	0.14 – 7.83	1.77	8.13	2.31 – 10.00	2.09
MY4	7.27	1.25 – 9.77	2.17	9.44	8.43 – 10.00	0.52
MY5	4.72	0.85 – 9.46	2.96	8.62	4.16 – 10.00	1.56
FY1	8.04	2.48 – 10.00	2.11	8.23	3.13 – 10.00	2.15
FY2	7.13	1.45 – 10.00	2.77	9.14	2.99 – 10.00	1.53
FY3	7.14	3.50 – 10.00	2.13	9.35	7.35 – 10.00	0.72
FY4	6.69	2.05 – 8.97	2.28	8.28	2.99 – 10.00	1.69
FY5	8.00	3.87 – 10.00	1.76	8.87	2.99 – 10.00	1.60
Mean	6.23			8.28		
SD	1.74			1.11		
Middle-aged group						
MM1	3.43	0.88 – 6.98	1.78	8.93	7.35 – 10.00	0.87
MM2	5.16	0.00 – 8.69	2.38	8.68	3.99 – 10.00	1.43
MM3	2.14	0.23 – 7.98	1.78	9.15	7.35 – 10.00	0.80
MM4	7.72	3.13 – 10.00	2.02	8.98	6.55 – 10.00	1.08
MM5	6.36	1.11 – 9.63	2.52	7.97	0.00 – 10.00	2.55
FM1	6.30	1.17 – 9.03	2.28	9.20	7.21 – 10.00	0.83
FM2	7.37	1.88 – 10.00	2.40	9.18	7.09 – 10.00	0.90
FM3	5.95	2.02 – 9.72	2.54	9.16	7.72 – 10.00	0.73
FM4	6.74	1.11 – 9.72	2.78	9.43	7.61 – 10.00	0.57
FM5	7.65	0.97 – 10.00	2.21	9.12	6.67 – 10.00	0.91
Mean	5.88			8.98		
SD	1.84			0.41		
Older-aged group						
MO1	2.40	0.00 – 7.18	1.86	9.20	7.58 – 10.00	0.78
MO2	4.18	0.20 – 8.80	2.74	8.45	4.13 – 9.91	1.48
MO3	3.28	0.85 – 6.95	1.90	6.82	2.99 – 10.00	2.40
MO4	3.15	0.68 – 8.06	2.26	6.71	1.20 – 10.00	3.05
MO5	5.69	0.40 – 9.00	2.87	3.92	0.17 – 8.86	2.98
FO1	6.13	2.02 – 9.29	2.37	8.65	6.95 – 10.00	1.08
FO2	5.83	1.82 – 9.43	2.56	8.73	6.04 – 10.00	0.92
FO3	5.17	0.00 – 8.89	2.75	8.06	5.73 – 10.00	1.21
FO4	6.78	0.68 – 10.00	2.61	8.58	4.90 – 10.00	1.39
FO5	6.37	2.65 – 10.00	2.24	8.21	2.96 – 10.00	1.81
Mean	4.90			7.73		
SD	1.54			1.56		

Table 9: Perceptual judgments of health across cough and voice samples based on a scale of 1 to 10. The data are presented according to age group. Participant sex is noted as M = male, F= female. Participant age is noted as Y = young, M = middle-aged and O = older-aged.

Participants	Health					
	Cough			Voice		
	Mean	Range	SD	Mean	Range	SD
Male group						
MY1	5.86	2.22 – 9.89	2.67	6.42	0.88 – 10.00	3.28
MY2	4.97	0.80 – 9.03	2.54	6.29	0.14 – 10.00	3.26
MY3	2.49	0.14 – 7.83	1.77	8.13	2.31 – 10.00	2.09
MY4	7.27	1.25 – 9.77	2.17	9.44	8.43 – 10.00	0.52
MY5	4.72	0.85 – 9.46	2.96	8.62	4.16 – 10.00	1.56
MM1	3.43	0.88 – 6.98	1.78	8.93	7.35 – 10.00	0.87
MM2	5.16	0.00 – 8.69	2.38	8.68	3.99 – 10.00	1.43
MM3	2.14	0.23 – 7.98	1.78	9.15	7.35 – 10.00	0.80
MM4	7.72	3.13 – 10.00	2.02	8.98	6.55 – 10.00	1.08
MM5	6.36	1.11 – 9.63	2.52	7.97	0.00 – 10.00	2.55
MO1	2.40	0.00 – 7.18	1.86	9.20	7.58 – 10.00	0.78
MO2	4.18	0.20 – 8.80	2.74	8.45	4.13 – 9.91	1.48
MO3	3.28	0.85 – 6.95	1.90	6.82	2.99 – 10.00	2.40
MO4	3.15	0.68 – 8.06	2.26	6.71	1.20 – 10.00	3.05
MO5	5.69	0.40 – 9.00	2.87	3.92	0.17 – 8.86	2.98
Mean	4.59			7.85		
SD	1.77			1.52		
Female group						
FY1	8.04	2.48 – 10.00	2.11	8.23	3.13 – 10.00	2.15
FY2	7.13	1.45 – 10.00	2.77	9.14	2.99 – 10.00	1.53
FY3	7.14	3.50 – 10.00	2.13	9.35	7.35 – 10.00	0.72
FY4	6.69	2.05 – 8.97	2.28	8.28	2.99 – 10.00	1.69
FY5	8.00	3.87 – 10.00	1.76	8.87	2.99 – 10.00	1.60
FM1	6.30	1.17 – 9.03	2.28	9.20	7.21 – 10.00	0.83
FM2	7.37	1.88 – 10.00	2.40	9.18	7.09 – 10.00	0.90
FM3	5.95	2.02 – 9.72	2.54	9.16	7.72 – 10.00	0.73
FM4	6.74	1.11 – 9.72	2.78	9.43	7.61 – 10.00	0.57
FM5	7.65	0.97 – 10.00	2.21	9.12	6.67 – 10.00	0.91
FO1	6.13	2.02 – 9.29	2.37	8.65	6.95 – 10.00	1.08
FO2	5.83	1.82 – 9.43	2.56	8.73	6.04 – 10.00	0.92
FO3	5.17	0.00 – 8.89	2.75	8.06	5.73 – 10.00	1.21
FO4	6.78	0.68 – 10.00	2.61	8.58	4.90 – 10.00	1.39
FO5	6.37	2.65 – 10.00	2.24	8.21	2.96 – 10.00	1.81
Mean	6.75			8.81		
SD	0.82			0.46		

Table 10: Perceptual judgments of health across cough and voice samples based on a scale of 1 to 10. The data are presented according to sex. Participant sex is noted as M = male, F= female. Participant age is noted as Y = young, M = middle-aged and O = older-aged.

A two-way ANOVA was also performed to evaluate the role of sex of participants and the health of their voice and cough samples. There was a significant main effect for sex, with females cough/voice judged to be significantly healthier than males [F (1, 14) = 48.47, p < .001]. There was also a significant main effect for voice/cough samples, with the voice samples were judged to be healthier than the cough samples across sex groups [F (1, 14) = 33.93, p < .001]. In addition, there was a significant interaction between sex and voice/cough samples [F (1, 14) = 4.78, p = .05], indicating that there was a reversal in judgment of voice/cough healthiness for some of the participants.

Judgment of Strength. The overall perceptual judgments for the strength of cough and voice samples are listed in Table 11 according to age group and Table 12 according to sex. The judgments for strength of cough ranged from 3.59 to 7.35 across the age and sex with mean rating 5.69 (SD = 1.00). The judgments for strength of voice ranged from 3.24 to 8.81 with mean rating 7.53 (SD = 1.17). A two-way ANOVA was performed to evaluate the listeners' judgments of strength of cough and voice samples according to age of participants. There was a significant main effect for age [F (2, 8) = 4.93, p = .040]. Follow up t-tests identified a significant difference between the young and middle-age group [t (9) = 2.27, p = .05], indicating that the middle-age participants were judged to have stronger voice and cough samples. There was also a significant main effect for cough/voice samples [F (1, 9) = 66.68, p < .001], indicating that voice samples were judged to be significantly stronger than the cough samples across age groups. However, there was no significant interaction between age and judgment of strength [F (2, 18) = .27, p = .77].

A two-way ANOVA was also performed to evaluate the role of sex of participants and the strength of their voice and cough samples. There was a significant main effect for sex, with females cough/voice judged to be significantly stronger than males [F (1, 14) = 51.49, p < .001]. In addition, a significant main effect was found for cough/voice samples [F (1, 14) = 11.45, p = .004], indicating that voice samples were judged to be significantly stronger than the cough

Participants	Strength					
	Cough			Voice		
	Mean	Range	SD	Mean	Range	SD
Young group						
MY1	5.18	1.51 – 9.00	2.26	6.86	2.51 – 10.00	2.14
MY2	5.46	0.43 – 9.15	2.23	5.69	1.11 – 10.00	3.00
MY3	5.24	0.68 – 8.03	2.18	7.48	2.96 – 10.00	1.94
MY4	6.50	2.45 – 9.37	1.88	8.68	5.04 – 10.00	1.17
MY5	4.56	1.88 – 8.06	2.19	7.99	0.91 – 10.00	2.09
FY1	7.23	2.54 – 9.77	2.34	7.06	2.48 – 10.00	2.40
FY2	5.01	1.00 – 7.81	2.23	8.33	3.02 – 10.00	1.72
FY3	5.31	2.11 – 8.97	2.10	8.81	7.24 – 10.00	0.83
FY4	5.26	1.94 – 8.69	1.97	7.15	2.11 – 10.00	2.13
FY5	6.59	2.14 – 10.00	2.21	8.05	1.88 – 10.00	1.80
Mean	5.63			7.61		
SD	0.84			0.96		
Middle-aged group						
MM1	5.03	1.68 – 8.60	2.09	7.52	3.73 – 10.00	1.87
MM2	4.75	1.11 – 7.64	1.85	7.42	2.08 – 10.00	2.33
MM3	4.85	0.14 – 8.86	2.21	8.17	2.31 – 9.60	1.61
MM4	7.99	4.30 – 10.00	1.65	8.07	1.85 – 10.00	2.03
MM5	6.30	3.48 – 9.74	1.96	7.72	0.91 – 10.00	1.99
FM1	5.40	2.02 – 8.97	2.15	8.65	7.41 – 10.00	0.88
FM2	7.06	3.30 – 10.00	2.13	8.45	5.73 – 10.00	1.30
FM3	5.39	1.97 – 9.03	2.29	8.20	5.73 – 10.00	1.19
FM4	6.77	1.99 – 8.95	1.93	8.42	5.04 – 10.00	1.24
FM5	7.35	3.99 – 10.00	1.83	8.21	6.10 – 10.00	1.15
Mean	6.09			8.08		
SD	1.16			0.41		
Older-aged group						
MO1	4.04	0.20 – 7.27	1.92	8.79	6.70 – 10.00	0.95
MO2	5.18	1.88 – 9.23	2.13	7.40	2.91 – 10.00	1.73
MO3	5.08	2.71 – 7.98	1.91	6.84	2.99 – 9.49	1.85
MO4	3.59	0.97 – 8.09	2.05	5.06	0.97 – 9.00	2.78
MO5	6.28	1.51 – 10.00	2.57	3.24	0.40 – 6.84	1.82
FO1	6.54	2.91 – 9.72	1.81	7.95	3.93 – 9.91	1.61
FO2	6.00	2.02 – 9.17	2.14	7.82	3.28 – 10.00	1.67
FO3	5.60	2.22 – 8.29	1.98	7.13	2.96 – 9.17	1.90
FO4	5.82	2.19 – 9.00	2.16	7.28	2.85 – 10.00	1.79
FO5	5.46	1.20 – 8.72	2.18	7.50	3.59 – 10.00	1.81
Mean	5.36			6.90		
SD	0.94			1.60		

Table 11: Perceptual judgments of health across cough and voice samples based on a scale of 1 to 10. The data are presented according to age group. Participant sex is noted as M = male, F= female. Participant age is noted as Y = young, M = middle-aged and O = older-aged.

Participants	Strength					
	Cough			Voice		
	Mean	Range	SD	Mean	Range	SD
<u>Male group</u>						
MY1	5.18	1.51 – 9.00	2.26	6.86	2.51 – 10.00	2.14
MY2	5.46	0.43 – 9.15	2.23	5.69	1.11 – 10.00	3.00
MY3	5.24	0.68 – 8.03	2.18	7.48	2.96 – 10.00	1.94
MY4	6.50	2.45 – 9.37	1.88	8.68	5.04 – 10.00	1.17
MY5	4.56	1.88 – 8.06	2.19	7.99	0.91 – 10.00	2.09
MM1	5.03	1.68 – 8.60	2.09	7.52	3.73 – 10.00	1.87
MM2	4.75	1.11 – 7.64	1.85	7.42	2.08 – 10.00	2.33
MM3	4.85	0.14 – 8.86	2.21	8.17	2.31 – 9.60	1.61
MM4	7.99	4.30 – 10.00	1.65	8.07	1.85 – 10.00	2.03
MM5	6.30	3.48 – 9.74	1.96	7.72	0.91 – 10.00	1.99
MO1	4.04	0.20 – 7.27	1.92	8.79	6.70 – 10.00	0.95
MO2	5.18	1.88 – 9.23	2.13	7.40	2.91 – 10.00	1.73
MO3	5.08	2.71 – 7.98	1.91	6.84	2.99 – 9.49	1.85
MO4	3.59	0.97 – 8.09	2.05	5.06	0.97 – 9.00	2.78
MO5	6.28	1.51 – 10.00	2.57	3.24	0.40 – 6.84	1.82
Mean	5.34			7.13		
SD	1.08			1.47		
<u>Female group</u>						
FY1	7.23	2.54 – 9.77	2.34	7.06	2.48 – 10.00	2.40
FY2	5.01	1.00 – 7.81	2.23	8.33	3.02 – 10.00	1.72
FY3	5.31	2.11 – 8.97	2.10	8.81	7.24 – 10.00	0.83
FY4	5.26	1.94 – 8.69	1.97	7.15	2.11 – 10.00	2.13
FY5	6.59	2.14 – 10.00	2.21	8.05	1.88 – 10.00	1.80
FM1	5.40	2.02 – 8.97	2.15	8.65	7.41 – 10.00	0.88
FM2	7.06	3.30 – 10.00	2.13	8.45	5.73 – 10.00	1.30
FM3	5.39	1.97 – 9.03	2.29	8.20	5.73 – 10.00	1.19
FM4	6.77	1.99 – 8.95	1.93	8.42	5.04 – 10.00	1.24
FM5	7.35	3.99 – 10.00	1.83	8.21	6.10 – 10.00	1.15
FO1	6.54	2.91 – 9.72	1.81	7.95	3.93 – 9.91	1.61
FO2	6.00	2.02 – 9.17	2.14	7.82	3.28 – 10.00	1.67
FO3	5.60	2.22 – 8.29	1.98	7.13	2.96 – 9.17	1.90
FO4	5.82	2.19 – 9.00	2.16	7.28	2.85 – 10.00	1.79
FO5	5.46	1.20 – 8.72	2.18	7.50	3.59 – 10.00	1.81
Mean	6.05			7.93		
SD	0.80			0.58		

Table 12: Perceptual judgments of health across cough and voice samples based on a scale of 1 to 10. The data are presented according to sex. Participant sex is noted as M = male, F= female. Participant age is noted as Y = young, M = middle-aged and O = older-aged.

samples across sex groups. On the other hand, there was no significant interaction between sex and judgment of strength [F (1, 14) = .03, p = 88].

Discussion

The purpose of this study was to describe the acoustic features of voluntary cough and examine the relationship of these features to the perception of voice. A number of research questions were posed to evaluate multiple aspects of cough and voice. The outcome of each question is elaborated below. Following this discussion, a series of limitations to the present study are presented. In addition, the clinical implications of the present study and directions for future research are included.

Question 1: Are acoustic features of voluntary cough similar to past reports for voluntary cough?

Cough Duration. Acoustic analysis of the cough samples obtained in the present study revealed the presence of a three-phase voluntary cough across all participants. The acoustic properties of all cough samples were consistent between men and women, as well as between young, middle and older age groups. These findings are in agreement with past research by Hashimoto et al. (2003), Olia et al. (2000), and Murata et al. (1998) who also found a distinctive three-phase voluntary cough in normal healthy adults. Past studies have explained a three-phase cough as reflecting bronchial narrowing and bifurcation which leads to turbulent airflow. The first phase reflects the vibrations of the airway and the surrounding lung tissues. The second phase reflects egressive airflow from the trachea, as well as the collection of mucus in the trachea. The third phase reflects vocal fold adduction at the end of the second phase (Korpas et al., 1996).

In addition to finding a distinct three-phase cough, there are a number of similarities in the durational composition of the cough phases compared to past studies. The present study found that the duration of the three phases differed significantly according to age group and sex. The longest phase duration was P2, followed by P3, and finally P1. These findings parallel those of Murata et al. (1998) who noted that their group of healthy and non-healthy (i.e., respiratorydiseased) participants produced coughs with a significantly longer P2. The healthy participants also had a longer P3 than P1. In contrast, their non-healthy participants had a longer P1 compared to P3. The researchers attributed the longer P1 to the marked presence of sputum in the airway. Presumably, this necessitated a longer and more forceful onset of cough compared to those produced by healthy participants.

Comparison of the coughs produced by females and males in the present study revealed no significant differences in the overall duration of coughs or between the various phase durations of cough. This finding corresponds somewhat to the results of Olia et al. (2000). These researchers acoustically analyzed the voluntary coughs of 12 healthy males and 12 healthy females. The total duration of cough, as well as the duration of P1, P2 and P3 were measured and examined according to sex. They found that the total duration of cough, as well as the duration of P2 and P3 did not differ significantly different between females and males. However, females were found to have significantly longer P1 duration compared to males. The researchers did not speculate as to the similarities or differences in cough duration found between females and males.

Considering the basic anatomical and physiological differences in male and female vocal anatomy, it is surprising to observe no significant differences in cough duration. The respiratory capacity (i.e., vital capacity) of male adults is 4.8 L compared to the capacity of 3.5 L found in female adults (Raes & Clement, 1996). In addition, the length of the vocal tract in adult males is approximately 17 cm compared to the vocal tract length of 14 to 15 cm found in female adults (Kent, 1997). These combined differences in anatomy would presumably result in durational differences in cough production between sexes. Specifically, a longer cough duration would be expected in men compared to women. The lack of difference in cough duration would indicate that the physiological act of coughing is not entirely dependent upon the anatomical size of the respiratory and vocal tract systems**.** Rather, the act of coughing is a reflection of the anatomy and physiology that is essential to clear the airway.

LTAS. No studies prior to the present one have used LTAS to examine the acoustic features of cough. Such being the case, comparison of the present LTAS results to past cough studies is difficult. Application of LTAS to voice production provides a unique approach to examining the vocal fold vibratory characteristics devoid of supraglottal (i.e., vocal tract) influence. LTAS has been used widely to describe voice production in healthy and impaired (i.e., dysphonic) populations (Master et al., 2008). For example, Dromey (2003) examined whether the overall spectral shape (LTAS) of voice production could differentiate male speakers with hypokinetic dysarthria and healthy male speakers. They found that speakers with dysarthria had a lower spectral mean value (averaged 202 Hz) compared to healthy male speakers (averaged 313 Hz). The lower mean spectral value among the dysarthric speakers was interpreted to reflect weakness in the upper harmonics, with the main acoustic power of voice being concentrated towards the lower frequencies. Healthy speakers have broader energy distributed in the spectrum of voice production.

Linville and Rens (2001) used LTAS to examine dynamic features of voice in young adulthood and old age. The average FSP of elderly female speakers was 412 Hz compared to an FSP of 582 Hz for young female speakers. The average FSP of elderly male speakers was 442 Hz compared to an FSP of 496 Hz for young male speakers. The higher FSP value noted for the young adults was interpreted to reflect greater vocal fold elasticity compared to elderly adults. In a later study, Linville (2002) found that elderly female speakers tended to have an average ST value that was slightly higher compared to young female speakers, 0.93 and 0.90, respectively. They also found that elderly male speakers had an average ST value that was lower than young male speakers, 1.01 and 1.06, respectively. However, the ST values between age groups of males and females did not differ significantly. The lower ST value observed for the female participants was indicative of nominally greater energy in the upper spectral region of the voice. This higher energy was attributed to the gap in vocal fold closure (i.e., glottal chink), that is characteristic of the female voice (Bless & Abbs, 1983).

Finally, LTAS has also been applied to examine infant vocal behaviour (i.e., crying). Goberman and Robb (1999) found that in full term babies, FSP averaged 457 Hz, while ST and HFE averaged 0.29 and 909 Hz, respectively. Preterm babies were found to have an average FSP of 519 Hz, while ST and HFE averaged 0.19 and 909 Hz, respectively. The lower FSP among the full term babies was attributed to greater vocal fold length and mass compared to the preterm babies. The lower ST value among the preterm babies was indicative of a hyperfunctional voice quality. The similar HFE value for both groups was interpreted to reflect an equivalent amount of 'noise' in the cry samples.

In the present study, the FSP characterizing the coughs produced by the participants averaged approximately 278 Hz, while ST and HFE were 0.62 and 254 Hz, respectively. There was no age or sex difference observed for any of the LTAS measures. Assuming FSP provides an approximate indication of vocal F0, it is interesting to note the markedly lower values among the present participants compared to the +400 Hz values reported for healthy adult males and females, as well as infants (Goberman & Robb, 1999; Linville & Reins, 2001). The ST is a reflection of decline in the amplitudes of the harmonics. A high ST reflects hypoadduction of the vocal folds, and a low ST reflects hyperadduction of the vocal folds (Goberman & Robb, 1999). In the present study, the ST was lower than what was found in male and female adults (Linville, 2002) and higher than what was found in infant cry (Goberman & Robb, 1999). The HFE is a reflection of the presence of noise elements during phonation (Goberman & Robb, 1999). In the present study, the HFE was lower than what was found in infant cry.

There is a wealth of past research indicating acoustic differences in the voices of men and women, as well as between young and old (Baken & Orlikoff, 2000). These differences are generally attributable to basic anatomical differences in female and male vocal anatomy. Interestingly, the present study found that LTAS features of voluntary cough did not serve to differentiate speakers according to age and sex. One explanation for the lack of differences in cough LTAS is to consider the behaviour of the laryngeal muscles required for voice production compared to cough production, namely the action of the cricothyroid (CT) muscle. Numusawa et al. (2004) studied the pattern of membrane potential changes in CT motoneurons during breathing, vocalizing, swallowing and coughing in adult cats. All cats were paralyzed to allow identification of CT motoneurons through activation of the superior laryngeal nerve. They found that the control of motoneurons differed as a function of laryngeal activity. The CT motoneuron activity during vocalization was controlled by excitatory inputs, while coughing required inhibitory inputs. Their findings demonstrated that activation of the CT muscle during vocalization and coughing was clearly different and thus indicative of different motor acts. Poletto et al. (2004) examined the corresponding human laryngeal muscle activities during speech and non-speech gestures (i.e., cough & sniff). The muscles examined included the CT, posterior cricoarytenoid (PCA), lateral cricoartenoid (LCA) and thyroarytenoid (TA). Muscle activity was recorded using electromyography (EMG) while a nasoendoscope was used to view vocal fold movement. The TA and LCA muscles were found to significantly contribute to vocal fold closing during the act of coughing. In contrast, the CT and TA muscles were significantly correlated to both opening and closing of the vocal folds during speech. These findings lend further support to the suggestion that laryngeal muscles serve different purposes during the acts of speaking and coughing.

The studies profiled above by Numusawa et al. (2004) and Poletto et al. (2004) demonstrate that there is significant CT muscle involvement during the production of speech but not during generation of a cough. The CT muscle has been acknowledged as a vocal fold tensor that contributes to pitch elevation and to vocal fold adduction (Boone, McFarlane & Von Berg, 2005). Inference could be derived from the present study that the features which are often attributed to voice production, namely vocal fold length, size, and mass, are not dominant during the production of cough. Doherty et al. (1997) have likewise suggested that vocal fold vibration is not the predominant mechanism of cough generation. Rather, turbulent airflow and vibration of the airways are the dominant features of cough production.

In summary, the present study demonstrated similarities in the phase duration of cough in comparison to previous studies. Therefore, the first research question can be answered in the affirmative. In addition, the duration of voluntary cough, as well as the LTAS features and cough did not differ significantly between sex and age groups.

Question 2: Do acoustic features of voluntary cough correlate with perceptual classifications of cough?

No studies prior to the present one have examined possible relationships between the auditory perceptual and acoustic features of cough. Such being the case, comparison of the present correlation results to previous studies is difficult. Although clinical decisions in the management of voice disorders often rely heavily on auditory-perceptual judgments, these judgments lack the objectivity found in acoustic measurements (Kent, 1996). Despite the objective nature of acoustic measurements, the ability to accurately determine a direct relationship between acoustic information and perceptual assessments is not always possible (Eadie & Baylor, 2006).

Smith et al. (2006) examined the ability among respiratory healthcare professionals in identifying cough sounds and diagnosing respiratory disease based on the perceptual quality of the cough sounds. Results indicated that these professionals were able to identify wet and dry cough (i.e., coughs with or without mucus) with a high degree of accuracy. Although presence of wheeze in cough can be acoustically identified, participants were not able to perceive the presence of wheeze in cough sounds, nor derive an accurate diagnosis. The researchers also found that respiratory healthcare professionals used a wide range of cough descriptors. The researchers concluded that there was non-uniformity of knowledge among participants about one of the most common symptoms of respiratory disease (i.e., cough). They also proposed that determining the clinical utility of cough sound characteristics is warranted to determine its benefit in patient care. The present study found no strong relationships between the perception of cough and the corresponding acoustics of cough. There are two possibilities explaining this result. First, the similarities in acoustic features of cough across participants may cause difficulty to listeners in identifying a distinct feature that serves to differentiate a healthy cough from a strong cough. A second possibility is that the criteria used to judge a healthy / strong cough may have varied across listeners, as no standard definition was given to listeners on either parameter.

One interesting finding in this study relates to the perceptual classifications of sex and cough. Listeners were able to identify sexual identity of 98% of cough samples. Yet, acoustic features of cough samples were unable to differentiate coughs according to sex. Therefore, it is unlikely that the acoustic analyses used in the present study were sensitive to sex differences of cough. Mullennix et al. (1995) explained that identification of a person's sex does not rely on F0 or formant frequencies in isolation, but on complex auditory information of various acoustic factors such as breathiness, combined with formant frequency and F0. The acoustic analyses used in the present study focused primarily on vocal fold vibratory behaviour and features of duration. Missing from this analysis was a measure of vocal tract resonance. It is possible features such as formant frequency or formant bandwidth may serve to differentiate cough according to sex.

In summary, the present study does not support a strong relationship between acoustics of cough and perception of cough. Yet, the identification of sex from cough samples was high despite of the absence of a clear difference in the acoustics of cough between sexes.

Question 3: Do perceptual judgments of cough differ from the perceptual judgments of voice?

Identification of a person's age and sex from auditory perception of voice samples has been acknowledged in previous studies. Belin et al. (2004) stated that a person's voice carries important and unique identity features and reflects essential laryngeal and vocal tract differences between sex and age groups. The present study sought to determine whether features such as sex and age could likewise be determined from perceptual listening of cough samples.

The percentage of correct judgments for identifying a person's sex from cough samples in the present study was 98%. This result parallels that reported by Smith et al. (2006) who found the percentage of correct judgments of sex from cough samples was 93%. Judgment of sex from voice samples was nearly identical (99%) compared to cough samples. Results of statistical testing found no difference in the judgment of sex from cough and voice samples. Mullennix et al. (1995) explained that identification of a person's sex is possible from voice samples. However, identification of sex does not rely on F0 or formant frequencies in isolation, but on complex auditory information of various acoustic features of voice. Thus, it is likely that the dynamic acoustic features comprising both cough and voice production are sufficient for differentiating sexual identity.

The acoustic parameters of F0 and formant frequency, as well as speaking rate allow for a reasonably good estimation of age from voice samples (Linville, 1996). In the present study, the percentage of correct judgments of age from cough samples was significantly lower than voice samples, 56% and 78% respectively. There are two possible explanations for the disparity in determining a person's age from cough and voice samples. One possibility may be due to the incongruence between acoustic features in cough and voice samples and the chronological age of the participant. For example, the cough samples were likely to contain a large amount of aperiodicity compared to voice samples. The noise associated with coughs may have lowered the precision of judgment. A second possibility is to consider the durational length of cough or voice samples needed to predict age during moments of coughing and speaking. The voice samples used in the present study contained one sentence from the Rainbow Passage that was approximately 5 seconds in length, and consisted of recognizable words. In contrast, the cough samples were approximately 2 seconds in length, and consisted of three rapidly occurring coughs. The length of the samples, as well as the familiarity (or lack of) may have influenced the listeners' ability to determine the age of the participants.

In the present study, voice samples were perceived to be significantly healthier and stronger than cough samples. Several factors may have contributed to this situation. Cough is a physiological phenomenon that typically serves as a defensive reflex within the respiratory tract and is thought to provide an important symptom of many chronic airway diseases (Chung & Widdicombe, 2004). Relatedly, the presence of noise in the production of voice is perceived as an indicator of vocal pathology (Bhuta, Patrick & Garnett, 2004). Although no such noise was evident in the present voice samples, a noise component was found in each of the cough samples. Hence, the generic perception of cough, associated with the presence of noise may have lowered the listeners' perceptual rating of health and strength compared to the perception of voice. The absence of a specific definition of a healthy cough and healthy voice, as well as a strong cough and a strong voice may also have contributed to the present findings. Without a specific "gold standard" model, listeners may have used their own voice as a reference (Morsomme et al., 2001), and similarly could have applied this reference to their evaluation of cough as well. Consequently, the perceptual rating of health and strength of cough and voice in this study could imply that multiple references are used among listeners.

In summary, the present study provides partial support for the suggestion that perceptual judgments of cough differ from perceptual judgments of voice. The identification of sex from cough and voice samples was similar. The perceptions of age, health and strength differed between cough and voice samples.

Clinical Implications

Acoustic features of cough have been found to mark the health status of the respiratory systems in humans (Pirila & Sovijarvi, 1989; Thorpe et al., 1992) and in pigs (Hirtum & Berckmans, 2002). In the management of voice disorders, cough has also been considered as a valuable therapy tool (Baker, 1998; Ramig & Verdolini, 1998; Sataloff, 2006; Heuer et al., 2006; Rosen et al. 2006; Dagli et al., 2008). For example, in the management of puberphonia or mutational falsetto, cough is viewed as a vegetative function that could lower pitch to achieve an appropriate pitch for a male voice (Yu, 2008; Green & Mathieson, 1989). If the patient is beyond puberty, the cough resembles the typical low-pitched, abrupt cough of the adult male (Boone et al., 2005). Hence, it is reasonable to conclude that the frequency (pitch) of cough is one that should be targeted in this population. However, the present study found that the F0 of cough did not differ between men and women. Therefore, caution must be taken that the cough frequency elicited from this population may not serve as a targeted frequency, but rather as a relative reference point in 'shaping' the desired voice.

In the management of conversion aphonia, coughing can be used judiciously in looking for 'normal voicing'. Patient can be directed to cough as a means of achieving voicing (Colton, Casper & Leonard, 2006). The results of the present study tend to support previous results suggesting that the neural control of laryngeal muscles used for voicing may not be the same as those used for coughing. Specifically the role of the CT in coughing has been questioned (Numusawa et al., 2004, Poletto et al., 2004), while there is undeniable recognition that the CT is used for the generation of voice. Further research needs to confirm differences in the laryngeal muscle neural pathways and functions in voicing and coughing to further affirm the application of cough as a tool for voice management (Davis & Flecther, 1996). Therefore, caution is warranted that emphasizing cough to form an appropriate voice can be a great challenge to this population and may not have an automatic effect on voice. In addition, the use of cough to perceptually assess vocal fold adduction as part of an evaluation of voice disorders must also be interpreted with care (Aronson, 1990). The impression of ‘an adequate’ vocal fold function may not reflect ‘an adequate’ voice mechanism. The present study found that the perception of cough was significantly different from the perception of voice, except for sex identification. Hence, any interpretation from the perception of cough might not reflect the voice systems accurately.

Limitations

Statistical power assessment was not performed prior to collecting the participants used in the current study. Therefore, one cannot rule out the possibility that the lack of significant differences in the present study was either due to insufficient statistical power, or due to the nature of acoustic features in cough that are stable across age and sex groups.

The present study applied LTAS and durational analyses of cough. LTAS measured the behaviour of cough occurring at the level of the vocal folds, while duration measured cough associated with respiratory activity. However, formant frequencies also provide valuable information related to the role of the vocal tract in the generation of an acoustic signal (Titze, 1994). The lack of relationship between acoustic features of cough and perceptual judgment of cough and voice may have been due to the focus on duration and F0 exclusively. The analysis of formant frequency, together with LTAS and cough duration would have allowed for a more comprehensive description of cough.

In the present study, participants were directed to inhale deeply 'at their maximum' to initiate each episode of cough. However, no instrument was used to monitor the consistency of the 'deep inhalation' in producing the three cough episodes. Hence, it is arguable that participants may not have inhale at their maximum for all cough episodes. Spirometry allows for measurement of vital capacity (Olia et al., 2000). The use of spirometry would have allowed the researcher to ensure participants generated a cough using equivalent respiratory effort.

Baken and Orlikoff (2000) reported subtle changes in speaking F0 as a function of age. For example, the average F0 in 'young' female voice (age range 20-30) is approximately 224 Hz. The average F0 in 'middle-aged' females (age range 40-49) and 'older-aged' females (age range 65-79 Hz) is 221 Hz and 197 Hz, respectively. The narrow range of age used to define the age groups in the present study may not have allowed the listeners to perceive the slight difference in the acoustics of voice, as well as the acoustics of cough. A wider range of age would potentially highlight the salient acoustic features between the age groups and would allow for a clearer differentiation of the acoustic features of cough and voice.

Finally, Gelfer (1988) attempted to identify the perceptual rating scales for normal voice. She found that listeners demonstrated higher confidence and achieved high interjudge agreement for the dimensions of pitch, loudness and rate of speech. The perceptual ratings used by the listeners to discriminate the disordered voice differed from the voice that was judged as normal. The present study did not provide a standard definition for the perceptual task, specifically for the health and strength parameters. As such, the definition for each parameter varied as demonstrated by a wide range of perceptual judgments made by the listeners. Use of a clear definition of a strong and healthy cough or voice as a 'standard reference' would allow more affirmative and concise perceptual judgments of cough or voice.

Direction for Future Research

The present study incorporated LTAS as a tool to measure cough. A limited relationship was found between the perceptual judgment of voice and the acoustics of cough. Such information does not provide a firm understanding of how the two vocal behaviours may be related. Thus a possible area of research would be to further refine the acoustic measurement of cough. Incorporating different aspects of measuring acoustic features of cough, such as formant frequency, may allow for a better understanding of the relationship between the acoustics of cough and perception of voice.

The F0 of cough has tacitly been viewed as a representation of F0 in males and females voice (Boone et al., 2005). However, the present study identified a comparable F0 in males and females cough, suggesting that the F0 in cough production among this population should be used as reference point, but rather a targeted F0 in voice therapy. Nevertheless, there is insufficient data to verify this notion. Assessing the change of F0 in both cough and voice production in this population before and after treatment could provide evidences to uphold this conception.

There is also a need for systematic studies examining the acoustic features of cough in people with unilateral vocal fold palsy and to track the change in acoustic features of cough following either surgical intervention (i.e., thyroplasty) or voice therapy. Comparison of the acoustic features of cough and multi-dimensional voice measurements should also be considered. Cough has been used to perceptually determine the adequacy of vocal fold adduction in dysphonic voice (Aronson, 1990). However, the clinical value of cough as a means of identifying the potential benefits of thyroplasty or voice therapy in improving voice production is yet unknown. A study such on this may help to determine whether cough carries important value in the diagnosis, treatment and prognosis of voice outcome following surgical or therapeutic intervention among people with unilateral vocal fold palsy.

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APPENDIX A

INSTRUCTIONS FOR COUGH AND VOICE SAMPLES COLLECTION

<u>INSTRUCTION FOR COUGH SAMPLES COLLECTION:</u>

I need you to take a deep breath at your maximum effort and produce 3 coughs continuously. Do this for 3 times. I will provide you with an example.

<u>INSTRUCTION FOR VOICE SAMPLES COLLECTION:</u>

Now you are going to first prolong /a/, /i/ and /u/ and read a paragraph out loud and use your normal manner of speaking. I will provide you with an example.

APPENDIX B

SUMMARY OF CORRELATION ANALYSES BETWEEN THE PERCEPTION OF STRENGTH / HEALTH OF COUGH AND STRENGTH / HEALTH OF VOICE

N.B.: None of the comparisons yielded a significant correlation ($p < .05$).

Aspect	Sub-area	Correlation value	Degrees of freedom
Strength of cough and strength of voice	Overall	0.16	28
	Male	0.06	13
	Female	-0.01	13
	Young	0.02	8
	Middle	0.36	8
	Old	-0.04	8
Health of cough and Health of voice	Overall	0.22	28
	Male	-0.09	13
	Female	0.25	13
	Young	0.41	8
	Middle	0.04	8
	Old	0.02	8

APPENDIX C

SUMMARY OF CORRELATION ANALYSES BETWEEN THE PERCEPTION OF STRENGTH OF COUGH AND ACOUSTIC OF COUGH

N.B.: None of the comparisons yielded a significant correlation ($p < .05$).

Aspect	Sub-area	Correlation value	Degrees of freedom
Strength of cough and ST	Overall	0.16	28
	Male	0.18	13
	Female	0.13	13
	Young	0.45	8
	Middle	0.50	8
	Old	-0.06	8
Strength of cough and FSP	Overall	0.13	28
	Male	0.19	13
	Female	0.23	13
	Young	-0.05	8
	Middle	0.46	8
	Old	-0.48	8
Strength of cough and HFE	Overall	0.09	28
	Male	0.01	13
	Female	0.42	13
	Young	0.14	8
	Middle	0.24	8
	Old	-0.35	8
Strength of cough and total duration	Overall	-0.23	28
	Male	-0.31	13
	Female	0.02	13
	Young	-0.21	8
	Middle	-0.06	8
	Old	-0.36	8
Strength of cough and duration of P1	Overall	-0.14	28
	Male	-0.38	13
	Female	-0.06	13
	Young	-0.23	8
	Middle	0.05	8
	Old	-0.10	8
Strength of cough and duration of P2	Overall	-0.14	28
	Male	-0.25	13
	Female	0.12	13
	Young	0.01	8
	Middle	0.06	8
	Old	-0.28	8
Strength of cough and duration of P3	Overall	-0.07	28
	Male	-0.01	13
	Female	0.11	13
	Young	-0.34	8
	Middle	-0.11	8
	Old	-0.13	8

APPENDIX D

SUMMARY OF CORRELATION ANALYSES BETWEEN THE PERCEPTION OF HEALTH OF COUGH AND ACOUSTIC OF COUGH

N.B.: None of the comparisons yielded a significant correlation ($p < .05$).

Aspect	Sub-area	Correlation value	Degrees of freedom
Health of cough and ST	Overall	0.08	28
	Male	-0.01	13
	Female	0.02	13
	Young	-0.36	8
	Middle	0.50	8
	Old	0.11	8
Health of cough and FSP	Overall	-0.06	28
	Male	-0.06	13
	Female	0.49	13
	Young	-0.46	8
	Middle	0.26	8
	Old	-0.45	8
Health of cough and HFE	Overall	0.03	28
	Male	0.08	13
	Female	0.37	13
	Young	0.05	8
	Middle	0.16	8
	Old	-0.25	8
Health of cough and total duration	Overall	-0.26	28
	Male	-0.26	13
	Female	-0.23	13
	Young	-0.55	8
	Middle	-0.30	8
	Old	-0.13	8
Health of cough and duration of P1	Overall	0.07	28
	Male	-0.20	13
	Female	0.16	13
	Young	0.17	8
	Middle	0.15	8
	Old	-0.02	8
Health of cough and duration of P2	Overall	-0.14	28
	Male	-0.14	13
	Female	-0.27	13
	Young	-0.52	8
	Middle	0.01	8
	Old	0.01	8
Health of cough and duration of P3	Overall	-0.27	28
	Male	-0.01	13
	Female	0.01	13
	Young	-0.09	8
	Middle	-0.38	8
	Old	-0.36	8

APPENDIX E

SUMMARY OF CORRELATION ANALYSES BETWEEN THE PERCEPTION OF STRENGTH OF VOICE AND ACOUSTIC OF COUGH

N.B.: Correlations highlighted in boldface were statistically significant at the $p < .05$ level.

Aspect	Sub-area	Correlation value	Degrees of freedom
Strength of voice and ST	Overall	0.07	28
	Male	0.29	13
	Female	-0.24	13
	Young	-0.17	8
	Middle	0.15	8
	Old	0.20	8
Strength of voice and FSP	Overall	0.11	28
	Male	0.23	13
	Female	-0.03	13
	Young	-0.17	8
	Middle	-0.15	8
	Old	0.21	8
Strength of voice and HFE	Overall	-0.18	28
	Male	-0.26	13
	Female	0.28	13
	Young	-0.51	8
	Middle	-0.08	8
	Old	-0.27	8
Strength of voice and total duration	Overall	-0.13	28
	Male	-0.27	13
	Female	-0.12	13
	Young	-0.09	8
	Middle	-0.22	8
	Old	-0.31	8
Strength of voice and duration of P1	Overall	-0.33	28
	Male	**-0.73**	**13**
	Female	0.10	13
	Young	0.25	8
	Middle	-0.16	8
	Old	**-0.66**	**8**
Strength of voice and duration of P2	Overall	-0.25	28
	Male	-0.24	13
	Female	-0.36	13
	Young	-0.31	8
	Middle	0.28	8
	Old	-0.26	8
Strength of voice and duration of P3	Overall	0.16	28
	Male	0.25	13
	Female	0.39	13
	Young	**0.72**	**8**
	Middle	-0.40	8
	Old	0.10	8

APPENDIX F

SUMMARY OF CORRELATION ANALYSES BETWEEN THE PERCEPTION OF HEALTH OF VOICE AND ACOUSTIC OF COUGH

N.B.: Correlations highlighted in boldface were statistically significant at the $p < .05$ level.

Aspect	Sub-area	Correlation value	Degrees of freedom
Health of voice and ST	Overall	-0.01	28
	Male	0.15	13
	Female	-0.34	13
	Young	-0.01	8
	Middle	0.01	8
	Old	0.10	8
Health of voice and FSP	Overall	0.04	28
	Male	0.12	13
	Female	0.10	13
	Young	-0.32	8
	Middle	0.38	8
	Old	0.14	8
Health of voice and HFE	Overall	-0.09	28
	Male	-0.11	13
	Female	0.32	13
	Young	-0.43	8
	Middle	0.17	8
	Old	-0.16	8
Health of voice and total duration	Overall	-0.26	28
	Male	-0.08	13
	Female	-0.20	13
	Young	-0.10	8
	Middle	-0.02	8
	Old	-0.12	8
Health of voice and duration of P1	Overall	-0.21	28
	Male	**-0.52**	**13**
	Female	0.10	13
	Young	0.31	8
	Middle	0.10	8
	Old	-0.50	8
Health of voice and duration of P2	Overall	-0.14	28
	Male	-0.11	13
	Female	-0.39	13
	Young	-0.30	8
	Middle	0.15	8
	Old	-0.05	8
Health of voice and duration of P3	Overall	-0.19	28
	Male	0.34	13
	Female	0.35	13
	Young	**0.64**	**8**
	Middle	-0.14	8
	Old	0.04	8