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ORIGINAL ARTICLE

Effects of inhaled corticosteroids on voice production in healthy adults

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Abstract

The isolated effects of inhaled corticosteroids (ICS) on voice production were examined in 30 healthy adults with no known pre-existing airway disease. All participants followed a daily ICS treatment regime of 500 µg in the morning and evening over a 6-day period. Sustained vowels and connected speech samples were audio recorded before, during, and after the ICS regime. Each participant's audio recorded samples were acoustically analysed. Results revealed that ICS has a short-term detrimental effect on various acoustic properties of voice. These effects were more evident in connected speech compared to isolated vowel productions. All acoustic parameters returned to normalcy after discontinuing the ICS. The study provides insight as to the influence of ICS on healthy voice production.

Key words: *Acoustic analysis, asthma, inhaled corticosteroids, voice*

Introduction

New Zealand has one of the highest prevalence rates of asthma in the world, occurring in about 15% to 20% of children and adults and affecting at least 600,000 people. Asthma is the third highest-ranking specific cause of long-term disability in New Zealand (1). This has subsequently resulted in the widespread use of inhaled corticosteroids (ICS) which serve to suppress the asthmatic inflammatory response. Use of ICS is the most potent and reliable of the available agents among the anti-inflammatory drugs and has assumed a major role in the management of asthma (2). Rodrigo (3) surveyed published randomized clinical trials completed during the period of 1996 to 2006 and concluded that the effects of ICS were evident as early as 30 min to 2 h following inhalation. These rapid effects were found to affect airway smooth muscle tone, particularly mucosal blood flow (4).

Patients with persistent acute asthmatic symptoms need to use high doses of ICS for long periods (5). Local side-effects of ICS include throat irritation due to oropharyngeal deposition, oropharyngeal

candidiasis, and hoarse voice (6–8). A variety of studies have been undertaken to examine the influence of ICS on voice production among people with asthma (9–13). For example, Williamson et al. (13) assessed the prevalence of throat and voice symptoms in asthmatic patients compared to a non-asthmatic (control) group. A total of 255 out-patients from Scotland using ICS (the average dose used was 800–1000 µg) and 100 controls were surveyed. Among the patients, 147 (58%) reported dysphonia or throat symptoms compared to 13% of the control group. More women than men reported having throat or voice symptoms. Dysphonia was more prevalent in patients using higher doses of ICS. Gallivan et al. (9) examined 38 patients from the USA with voice complaints associated with the use of ICS. Hoarseness and dysphonia were the primary patient complaints. Upon videostroboscopic evaluation, the researchers found that ICS patients exhibited vocal fold abnormalities like abnormal mucosal wave symmetry/periodicity and supraglottic hyperactivity. Most recently, Erickson and Sivasankar (14) investigated the effects

of ICS on voice production in a group of 'vocally healthy' individuals with asthma from the USA. The voice characteristics of the individuals were examined prospectively as they received ICS treatment over two consecutive days. The participants received real ICS treatment, as well as a sham ICS treatment in a counterbalanced order. The researchers found that ICS treatment increased phonatory threshold pressure (PTP) immediately following ICS inhalation and this persisted for 2 hours; yet no such change was observed for the sham treatment. Perceived phonatory effort ratings were not significantly correlated with PTP.

The clinical evidence for the adverse phonatory effects of ICS treatment would seem to suggest a trade-off between controlling the symptoms of asthma and maintaining normal vocal functioning. However, it is important to recognize that individuals with asthma present with a wide range of co-morbidity factors such as chronic cough and coexisting allergic rhinitis, paranasal sinus disease, gastro-esophageal reflux, and psychological dysfunctioning which may confound the effects of ICS on voice production (15,16). Therefore, the precise effects of ICS on healthy voice production have yet to be clearly examined. An ideal approach to determining the effects of ICS on voice production would be to examine a non-clinical population. Therefore, the aim of the present study was to examine the isolated effects of ICS on acoustic features of voice production in healthy adults with no known airway disease. The research questions developed for this study were: 1) Does short-term repeated use of ICS result in change in acoustic parameters of voice production, and 2) is there a sex difference in the effects of ICS on voice production?

Method

Participants

Thirty healthy young adults (15 females and 15 males) were recruited for the study. The participants ranged in age from 18 to 30 years, with an average age of 24 years. All participants were non-smokers with no history of speech, language, or voice disorder. Each participant's voice quality was judged to be normal based on an auditory-perceptual evaluation by a certified speech-language pathologist with 25 years of clinical experience. An auditory-perceptual judgement of voice quality is a standard approach taken by voice clinicians to define the presence or absence of a voice disorder (17). None of the participants had a history of asthma, respiratory illness, hospital admission, or inhaler use within the past 3 months. The participants were recruited from the University of Canterbury student population. This study received ethical approval from the New

Zealand Ministry of Health, as well as the University of Canterbury Human Ethics Committee.

Data collection

The data collection involved a combination of voice audio recordings and ICS administration. The samples were collected for each participant over a consecutive 6-day period. All participants were asked to refrain from engaging in any vocally abusive behaviour during the period of data collection. All data collection took place within a sound-treated laboratory at the Department of Communication Disorders, University of Canterbury, Christchurch, New Zealand. The time-line of data collection is illustrated in Figure 1 and described in detail below.

Day 1 (morning):

Audio recording. Prior to ICS use, each participant's voice was audio recorded. This sample was termed the *Pre-ICS* sample. This sample served as a baseline of normal voice production which was to be compared to later recordings. Each participant was seated in front of a tabletop microphone that was placed at a distance of 20 cm from the mouth of the participant. The participant was asked to sustain the vowels /i/ (as in 'he'), /a/ (as in 'hah'), and /u/ (as in 'who') for 5 seconds each. Three samples of each vowel were collected. Upon completion of the vowel prolongation task, a connected speech sample was collected from each participant based on oral reading of 'The Rainbow Passage' (18). Audio recordings were collected using a condenser microphone (DSE-PC) connected directly to a laptop computer and sampled at 20 kHz. Each audio recording session lasted approximately 10 minutes. Prior to recording each vowel and oral reading samples, the first author (R.S.) modelled these various samples to each participant. The participants were allowed to practise these vowel/reading productions until they signalled to the researcher that they were ready to be audio recorded.

ICS administration. Upon completion of the baseline vocal tasks, the participant was asked to inhale 500 µg of corticosteroid, fluticasone propionate (FP). The FP was suspended chlorofluorocarbon (CFC)-free hydrofluoroalkane (HFA) propelled. The participant was provided with a spacer attached to a metered-dose inhaler (MDI). The dose chosen was 500 µg, which is the maximum dose of FP that can be prescribed as a single dose (19). All participants received training in the use of the MDI. Prior to inhalation of FP, the participant was asked to exhale fully and place the mouthpiece of the spacer in their mouth. The participant released 250 µg of FP into

the spacing chamber by pressing the MDI once. When the chamber was filled with FP the participant was asked to take five tidal breaths so as to ensure inhalation of the steroid. This process was repeated so that the total dose administered was 500 µg of FP. The participant was provided with cold water for rinsing his/her mouth upon completion of the ICS administration. All morning doses of ICS were taken under supervision during the period of 9–10 a.m.

Audio recording. One hour after the morning ICS administration, each participant returned to the laboratory for a second audio recording of their voice. This recording was termed *ICS-1*. Based on the recent work of Erickson and Sivasankar (14), as well as Rodrigo's (3) evidence-based review of past research examining the rapid impact of ICS on asthmatic patients, we selected a 1-hour lapse between ICS and audio recording to examine the effects of ICS on the vocal apparatus, as well as the cumulative effects over a 6-day period.

Day 1 (evening):

Audio recording and supervision of ICS administration was performed in the evening between the approximate hours of 4–6 p.m. The first task involved ICS administration, with the second task being the audio recording.

ICS administration. The identical procedures used in the morning were used in the evening session. In total, the participant was asked to inhale a 500 µg dose of FP.

Audio recording. One hour after the evening ICS administration, each participant returned to the laboratory for a second audio recording of their voice.

The same procedures used for the morning audio recording were used for the evening recording (i.e. vowel prolongations and oral reading of 'The Rainbow Passage'). This recording was termed *ICS-2*.

Days 2–4:

On the second, third, and fourth days of the study, each participant received the same doses of ICS during the morning and evening sessions. No audio recordings were collected on these days.

Day 5 (morning and evening):

On the morning of the fifth day of data collection, each participant received the same amount of ICS similar to the previous four days. On the evening of the fifth day, audio recordings and ICS administration were carried out. One hour after the evening session of ICS administration, each participant returned to the laboratory for another audio recording of their voice. This recording was termed *ICS-3*.

Day 6 (morning):

On the morning of the sixth day, only an audio recording (i.e. vowel prolongations and 'Rainbow Passage') of each participant's voice was collected. This sample was termed *Post-ICS* and was used as a comparison to all previous samples to assess the cumulative effects of ICS administration over the 6-day period.

Acoustic analysis

Each participant's audio recorded samples were submitted to acoustic analysis using a commercially

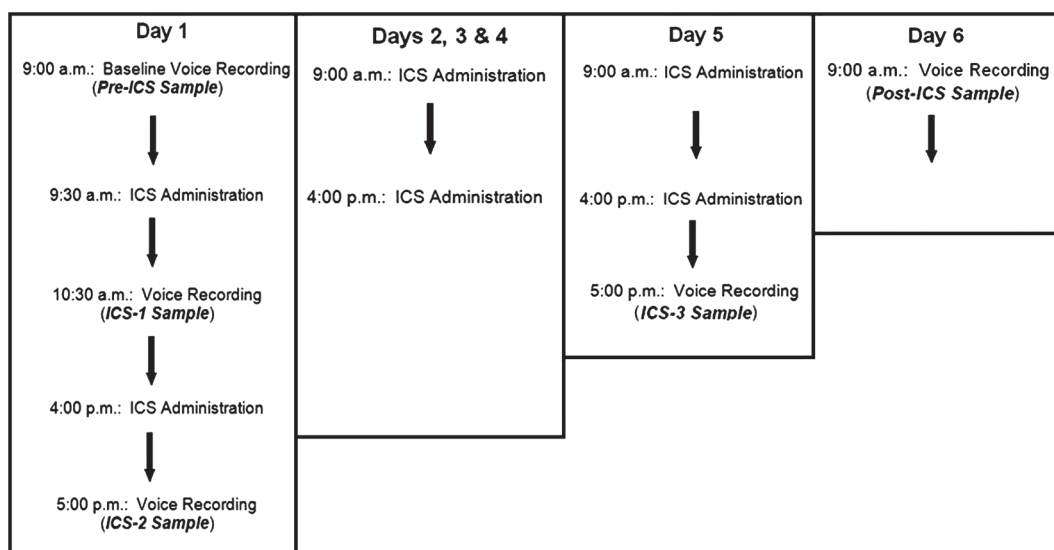


Figure 1. Illustration of the method of voice recording and administration of inhaled corticosteroids (ICS) across a six-day period.

available speech analysis system (CSL 4300B, Kay Elemetrics, Lincoln Park, NJ, USA). Specific acoustic measures were chosen that were assumed to be appropriate to capture changes in voice production associated with sustained vowel production and connected speech production. The following acoustic measurements were made:

(1) *Vocal fundamental frequency (F_0)*. Each sustained vowel was displayed on a computer monitor as an amplitude-by-time waveform. The F_0 of each vowel was determined by positioning a 50 ms window at the mid-point of each vowel. This section was then transformed into a power spectrum providing a cascading display of harmonics. A cursor was placed at the first harmonic peak of the display to determine F_0 . For each recording session, the second rendition of each repeated vowel production was measured. In total, one production of each of the three vowels (/i, u, a/) was measured for each recording session (Pre-ICS, ICS-1, ICS-2, ICS-3, and Post-ICS). While there are numerous acoustic measures available to estimate vocal fold vibratory behaviour (e.g. shimmer, jitter), the selection of average F_0 was based on parsimony. We were interested in using a common and relatively straightforward methodology that would be familiar to most voice clinicians.

(2) *Formant frequency and formant bandwidth*. To assess whether ICS may have an influence on vocal tract musculature (aside from the vocal folds), the first (F_1) and second (F_2) formant frequencies, as well as the first (BW_1) and second (BW_2) formant frequency bandwidth values were obtained for each sustained vowel. The F_1 and F_2 values provided information regarding the vocal resonance qualities of the vocal tract. The corresponding BW_1 and BW_2 measures provided information regarding the sound absorption qualities of the vocal tract (20,21). Measurement of these formant features was performed by examining the amplitude-by-time waveform and positioning a 50 ms time window at the approximate mid-point of each vowel. This was the same location that was used for determination of vocal F_0 for each vowel. The F_1 and F_2 values were obtained using linear predictive coding (LPC) autocorrelation analysis (36 coefficients). Bandwidths were computed automatically on the LPC spectrum by the CSL software, and numeric results were provided in hertz (Hz).

(3) *Long-time spectral analysis (LTAS)*. Human voice production is assumed to reflect an interaction between a source (i.e. the vocal folds) and a filter. When applied to a connected speech sample, an LTAS analysis (limited to voiced sounds) can serve

to average out the effects of the filter, leaving a representation of the vibratory pattern of the vocal folds (22). In the present study, the LTAS analysis involved examining the spectral characteristics of one phrase of 'The Rainbow Passage': 'The rainbow is a division of bright lights into many beautiful colors.' The amplitude-by-time waveform of the entire 'Rainbow Passage' was displayed on the computer monitor. A pair of vertical cursors was superimposed over the waveform to identify the above phrase. Based on this demarcation, an LTAS display was calculated through an averaging of individual fast Fourier transform (FFT) computations performed every 25 ms across the entire phrase. Once calculated, the LTAS data were stored as a file containing discrete frequency (Hz) values and the corresponding amplitude (dB) values. The following two measurements are commonly reported in an LTAS analysis because of the sensitivity they provide in regard to the estimated vibratory pattern of the vocal folds:

(i) *First spectral peak (FSP)*. This is defined as the frequency value associated with the first amplitude occurring between a rising and subsequently falling amplitude value. The FSP provides an estimate of the average F_0 across the sample (22). However, FSP tends to be slightly lower in frequency compared to F_0 because of the influence of low-frequency energy in the calculation of the LTAS.

(ii) *Spectral tilt (ST)*. This is defined as the ratio of energy (sum of amplitudes) between 0–1000 Hz and 1000–5000 Hz. The ST is a representation of how quickly the amplitudes of the harmonics decline (22). A gradual versus steep ST is indicative of hypo- versus hyper-adductory vocal fold behaviour, respectively.

Measurement reliability

Fifteen per cent of the entire data base of vocal samples was randomly selected across 10% of the participants for the assessment of intra-judge measurement reliability for the acoustic measurements (vocal F_0 , formants/bandwidths, FSP, and ST). A total of 6 participants' data was remeasured for F_0 , LTAS, and formants/bandwidths. The original measurements were compared to the remeasurements. The average remeasurement difference for F_0 was 34 Hz and 12 Hz for females and males, respectively. The average remeasurement difference for F_1 was 24 Hz and 14 Hz for females and males, respectively. The average remeasurement difference for F_2 was 76 Hz and 58 Hz for females and males, respectively. The average remeasurement difference for BW_1 was 16 Hz and 11 Hz for females and males, respectively.

The average remeasurement difference for BW_2 was 35 Hz and 29 Hz for females and males respectively. The average remeasurement difference for FSP was 22 Hz and 12 Hz for females and males, respectively. The average remeasurement difference for ST was 1.1 and 0.8 for females and males, respectively. Collectively these remeasurements are within normal limits for acoustic measurement of voice in women and men (23).

Statistical analysis

A two-way repeated measures analysis of variance (ANOVA) served as the primary statistical procedure to evaluate possible changes in vocal behaviour across the five sampling sessions. The between-groups factor was gender and the within-groups factor was sampling session (time). Separate ANOVAs were performed for each acoustic measure. The factors were fixed with an equal number of observations for each acoustic variable. The residuals of the statistical model were based on the assumption that the data were normally distributed.

Results

Vocal F_0

The results of the F_0 analysis for each vowel type are listed in Table I. Results of a two-way repeated measures ANOVA for each vowel indicated a significant main effect for gender ($/i/$ $F(1, 128) = 49.46$, $P < 0.001$; $/u/$ $F(1, 28) = 52.14$, $P < 0.001$; $/a/$ $F(1, 28) = 59.75$, $P < 0.001$) with females having a higher F_0 than males. There was no statistically significant main effect for sampling session and no significant session-by-gender interaction. Exposure to ICS had no significant effect on vocal F_0 .

F_1 and F_2 frequency

The results of the F_1 analysis for each vowel type are listed in Table I. Results of a two-way ANOVA for vowels identified a statistically significant main effect for gender ($/i/$ $F(1, 28) = 35.25$, $P < 0.001$; $/a/$ $F(1, 28) = 35.84$, $P < 0.001$) with females having a higher F_1 than males. There was a significant main effect for sampling session ($F(1, 4) = 2.85$, $P < 0.05$).

Table I. Mean fundamental frequency (F_0), first (F_1) and second (F_2) formant frequency, and first (BW_1) and second (BW_2) bandwidth for the vowels $/i/$, $/u/$ and $/a/$. Data are presented for females and males across the five inhaled corticosteroid (ICS) sampling sessions. Standard deviations are in parentheses.

Sampling session	$/i/$ (Hz)		$/u/$ (Hz)		$/a/$ (Hz)	
	Female	Male	Female	Male	Female	Male
F_0						
Pre-ICS	242 (42)	152 (25)	242 (42)	156 (40)	240 (43)	149 (27)
ICS-1	240 (40)	153 (24)	238 (38)	152 (29)	236 (36)	145 (24)
ICS-2	237 (49)	143 (24)	235 (50)	143 (18)	235 (51)	139 (19)
ICS-3	242 (49)	152 (27)	243 (49)	149 (23)	239 (50)	153 (29)
Post-ICS	240 (52)	157 (31)	241 (48)	147 (28)	236 (46)	141 (19)
F_1						
Pre-ICS	324 (42)	249 (31)	345 (56)	347 (181)	810 (115)	578 (144)
ICS-1	316 (34)	241 (22)	329 (47)	289 (64)	805 (166)	582 (110)
ICS-2	333 (46)	272 (82)	345 (49)	321 (124)	858 (122)	529 (149)
ICS-3	327 (38)	250 (28)	344 (45)	354 (181)	836 (129)	615 (156)
Post-ICS	334 (44)	251 (28)	336 (96)	314 (41)	820 (149)	587 (147)
F_2						
Pre-ICS	2542 (530)	2310 (145)	1122 (218)	1092 (546)	1499 (126)	1176 (95)
ICS-1	2553 (421)	2374 (153)	1092 (210)	1067 (583)	1466 (112)	1152 (120)
ICS-2	2579 (380)	2270 (330)	1088 (200)	989 (383)	1499 (136)	1185 (80)
ICS-3	2557 (457)	2364 (140)	1163 (253)	1049 (590)	1484 (136)	1196 (95)
Post-ICS	2574 (514)	2362 (178)	1336 (196)	1314 (441)	1459 (124)	1182 (141)
BW_1						
Pre-ICS	74 (36)	59 (40)	118 (88)	192 (135)	231 (192)	354 (189)
ICS-1	75 (43)	67 (56)	98 (46)	199 (155)	314 (207)	329 (189)
ICS-2	88 (37)	80 (37)	86 (39)	160 (120)	231 (130)	343 (223)
ICS-3	83 (44)	78 (40)	137 (50)	187 (161)	242 (102)	314 (212)
Post-ICS	74 (36)	59 (40)	82 (61)	64 (93)	279 (200)	388 (318)
BW_2						
Pre-ICS	277 (219)	215 (132)	338 (394)	636 (651)	192 (142)	177 (107)
ICS-1	250 (198)	204 (96)	226 (254)	450 (295)	197 (131)	218 (194)
ICS-2	356 (366)	382 (480)	297 (339)	548 (409)	276 (213)	232 (190)
ICS-3	438 (418)	214 (152)	181 (184)	401 (246)	215 (130)	214 (121)
Post-ICS	254 (164)	229 (203)	275 (305)	448 (459)	229 (156)	204 (126)

Follow-up *t* tests indicated that the F_1 for /i/ was significantly lower at ICS-1 compared to Pre-ICS ($P < 0.05$), as well as compared to ICS-2 ($P < 0.05$). There was no session-by-gender interaction for any of the vowel productions.

Results of the F_2 analysis are also listed in Table I. A two-way ANOVA identified a statistically significant main effect for gender (/i/ $F(1, 28) = 5.45$, $P < 0.05$; /a/ $F(1, 28) = 71.9$, $P < 0.001$). There was no statistically significant main effect for sampling session and no significant session-by-gender interaction for any of the vowel productions. Exposure to ICS had no significant effect on the F_2 frequency of the three vowels.

BW₁ and BW₂

The results of the BW_1 and BW_2 analysis for each vowel type are listed in Table I. A two-way ANOVA identified a statistically significant main effect for gender ($F(1, 28) = 5.38$, $P < 0.05$) with males having a larger BW_1 and BW_2 for production of /u/. There was no significant main effect for sampling session and no significant session-by-gender interaction for any of the vowel productions. The collective results for BW_1 and BW_2 indicated no significant effects resulting from exposure to ICS.

FSP and ST

The results of the FSP analysis for 'The Rainbow Passage' are listed in Table II. Results of a two-way ANOVA identified a statistically significant main effect for gender ($F(1, 28) = 26.29$, $P < 0.001$) with females exhibiting a higher FSP than males. The main effect for sampling session approached significance ($F(1, 4) = 2.61$, $P < 0.06$). Follow-up *t* tests identified a significantly higher FSP at ICS-3

compared to ICS-2 ($P < 0.05$). There was no significant session-by-gender interaction.

The results for ST are listed in Table II. A two-way ANOVA identified a statistically significant main effect for sampling session ($F(1, 4) = 3.5$, $P < 0.05$). Follow-up *t* tests found that ST at ICS-1 was significantly lower compared to Pre-ICS ($P < 0.05$), and that ST at ICS-3 was lower compared to ICS-2 ($P < 0.05$). There was no significant main effect for gender or a session-by-gender interaction.

Discussion

The research questions developed for this study were to determine whether short-term use of ICS would result in a change in acoustic parameters of voice production, and whether a difference was evident between men and women. Not surprisingly, men and women clearly differed in the acoustic parameters of their voice; however, there were no sex differences in the effects of ICS on voice production. When the participants were examined collectively, there were changes in some but not all of the voice parameters as a function of ICS use. A summary of the major findings is provided in Table III. A discussion related to the major findings for each acoustic measure follows.

Vocal F₀

There was no change in F_0 across time, indicating that the use of ICS did not appear to affect the average rate of vocal fold vibration. Three possibilities for the lack of change in F_0 across time are presented. First, it is possible that the lack of change in F_0 is a result of the speech samples measured in the present study. The F_0 analysis was confined to isolated vowel production. Use of a larger and more natural speech sample, such as conversational speech, may have provided a more revealing influence of ICS on vocal fold vibrations. This interpretation needs empirical verification. A second possibility for the lack of change in F_0 across the sampling periods is to consider the pharmacology of ICS. The inhalation of corticosteroids is designed to serve as an anti-inflammatory agent (24). Among the present group of participants there was no pre-existing inflammation of the vocal folds, so it is possible the corticosteroid had no direct effect on the vocal fold musculature (i.e. as inferred by F_0). Finally, it is important to note that past studies among asthmatic patients which have found a change in F_0 have attributed this change to the irritating effects of ICS (7). This irritation results from the use of propellant and lubricant components of ICS preparations. Erickson and Sivasankar (14)

Table II. Mean first spectral peak (FSP) and spectral tilt (ST) during connected speech. Data are presented for females and males across the five inhaled corticosteroid (ICS) sampling sessions. Standard deviations are in parentheses.

Sampling session	Female	Male
FSP		
Pre-ICS	205.1 (44.4)	134.3 (38.5)
ICS-1	192.2 (40.5)	144.4 (47.2)
ICS-2	200.2 (43.1)	127.4 (40.5)
ICS-3	217.4 (42.6)	150.6 (53.0)
Post-ICS	211.7 (43.5)	138.3 (49.7)
ST		
Pre-ICS	4.0 (2.4)	4.0 (3.1)
ICS-1	3.2 (1.6)	3.0 (2.2)
ICS-2	3.9 (2.3)	2.7 (1.8)
ICS-3	2.4 (1.5)	2.4 (2.0)
Post-ICS	3.1 (1.3)	3.1 (2.5)

Table III. Summary of the major findings in the present study for each acoustic feature.

Feature	Result
F_0	Female F_0 was significantly higher than male F_0 for each vowel type ($P < 0.001$). For combined groups, ICS exposure had no significant effect on F_0 for sustained vowel production across sampling sessions.
F_1	Female F_1 was significantly higher than male F_1 for /i/ and /a/ ($P < 0.001$). For combined groups, F_1 for /i/ was significantly lower at ICS-1 compared to Pre-ICS ($P < 0.05$). No other effects were found for ICS across sampling sessions.
F_2	Female F_2 was significantly higher than male F_2 for /i/ and /a/ ($P < 0.05$). For combined groups, ICS exposure had no significant effect on the F_2 of sustained vowels across sampling sessions.
BW_1	Male BW_1 was significantly larger than females for /u/ ($P < 0.05$). For combined groups, ICS exposure had no significant effect on the BW_1 of sustained vowels across sampling session.
BW_2	Male BW_2 was significantly larger than females for /u/ ($P < 0.05$). For combined groups, ICS exposure had no significant effect on the BW_2 of sustained vowels across sampling session.
FSP	Female FSP was significantly higher than male FSP for connected speech ($P < 0.001$). For combined groups, the FSP at ICS-3 was significantly higher than ICS-2 ($P < 0.05$).
ST	Females did not significantly differ from males in ST for connected speech. For combined groups, the ST at ICS-1 was significantly lower than Pre-ICS ($P < 0.05$), and the ST at ICS-3 was significantly lower than ICS-2 ($P < 0.05$).

suggest that these components, when inhaled, adversely affect phonation by increasing vocal fold viscosity. In the present study, non-asthmatic patients were used and this irritation did not appear to affect average vocal fold vibration (i.e. F_0) during sustained vowel production.

F_1 and F_2 frequency

Collectively, the F_1 and F_2 analyses were indicative of minimal changes in vocal tract resonance of isolated vowel production during the course of the 6-day study. The exception was for production of the vowel /i/. Specifically, F_1 frequency was found to be lower between Pre-ICS and ICS-1 sampling points, with a rise in F_1 between ICS-1 and ICS-2. The F_1 frequency at ICS-1 was the lowest frequency value observed across the five sampling points. Interestingly, the unusually low F_1 frequency at ICS-1 was the point at which each participant received their first dose of ICS. The low F_1 frequency would normally suggest that the volume of the pharyngeal cavity was enlarged compared to the sampling periods before and after ICS-1. This enlargement can occur in two ways. First, increased volume could result from an increase in the diameter of the vocal tract area. Assuming that ICS serves as a bronchodilator, it is intriguing to consider that the dilating effects of this steroid could also influence the volume of the pharyngeal cavity, resulting in an increase of vocal tract area (i.e. inferred by lowering of F_1 frequency). A second and perhaps more plausible explanation for the increased volume is that there were subtle changes in vowel articulation. In general, the frequency of F_1 varies with vowel changes involving tongue elevation in the vocal tract, and F_2 varies mostly with vowel changes involving tongue advancement (23,25,26).

Of the vowels examined in the present study, /i/ involves the most advanced (forward) and highest tongue articulation. Consequently, variable vocal tract adjustments for producing the vowel /i/ may have served to lower F_1 frequency at ICS-1.

BW_1 and BW_2

There were no statistically significant changes in BW_1 and BW_2 across the ICS sampling intervals. Measures of formant frequency bandwidth were originally selected as a means of estimating sound absorption in the vocal tract. Among asthmatic patients, use of ICS serves to reduce airway mucosal edema and thickening (9). Presumably, this would result in a relaxation of pharyngeal muscles and would result in greater absorption as inferred by an increase in BW_1 and/or BW_2 . In the absence of these pre-existing airway conditions, it appears that the short-term use of ICS had no effect on the sound absorption properties of the vocal tract during isolated vowel production.

FSP and ST

FSP was used as a way of estimating F_0 in a connected speech sample (i.e. 'The Rainbow Passage'). At each sampling period, women had a higher FSP than males, which corresponds to the F_0 results obtained from isolated vowel productions. A significant finding in the present study was that, for the combined groups, FSP was found to change across ICS sampling intervals. Specifically, FSP was found to increase during the evening of day 5 (ICS-3) compared to the evening of day 1 (ICS-2). The increase in FSP at ICS-3 is in agreement with past studies, which attributed an increase in F_0 to the irritating

effects of ICS (7,27). It is of interest to note that FSP was sensitive to ICS sampling intervals, whereas sustained vowel F_0 samples were not. The likely reason for these discrepant findings is due to the amount of speech being sampled to estimate average vocal fold vibration. Measurement of FSP provides a representation of the average F_0 across large connected speech samples, while measurement of F_0 was confined to isolated vowel productions. Connected speech production is a dynamic process that involves rapid and precise regulation of respiratory airflow, laryngeal adjustments, and the supralaryngeal structures (23). Alternatively, isolated vowel production involves a fixed, steady-state form of phonation. Thus, the present findings would appear to indicate that the irritating effects of ICS on voice production were more evident during naturalistic (albeit oral reading) speaking activities compared to production of sustained vowels.

In the present study, ST was measured in a connected speech sample to assess whether ICS might contribute to hypo- or hyper-adductory vocal fold behaviour. The ST was found to be significantly lower following use of ICS in the morning of day 1 (ICS-1) in comparison to Pre-ICS. The ST was also significantly lower at ICS-3 in comparison to ICS-2. These significantly lower ST values at ICS-1 and ICS-3 are reflective of hyper-adductory phonatory behaviour (22). Similar to the results for FSP (particularly as evidenced at the ICS-3 sampling session for both measures) it seems likely that negative ICS effects were discovered because of the nature of the speaking sample. It is also important to note that, for both FSP and ST, the changes observed were short-lived and returned to normal within 24 h (Post-ICS). This finding is agreement with Williamson et al. (13) who argued that dysphonia resulting from ICS use was due to myopathy of laryngeal muscles but the condition was reversible when treatment was withdrawn.

Conclusion

Past research examining the acoustic effects of voice resulting from ICS have focused on patients with a pre-existing airway disease, namely asthma. Most research indicates that the long-term use of ICS has a detrimental effect on voice production (9,11,13,16,28). These findings would suggest a trade-off between controlling the symptoms of asthma and maintaining normal vocal functioning. However, there are several types of asthma (e.g. allergic, exercised-induced, cough-variant), and individuals with asthma present with a wide range of co-morbidity factors. These factors include chronic cough and coexisting allergic rhinitis, which may confound the

effects of ICS on voice production. In the present study, these co-morbidity factors were controlled by examining healthy non-asthmatic men and women. On the basis of using the recommended dosage of 1000 μg FP per day (500 μg in the morning + 500 μg in the evening) (19), effects on voice production were apparent within one week of ICS usage. These effects were most evident during naturalistic speech production compared to sustained vowel production. However, the negative changes in voice reversed to normalcy within one day of discontinuation of ICS use (i.e. at Post-ICS). Although the observed changes were relatively minor, the findings hold clinical relevance because of the apparent impact of ICS on voice production in healthy non-asthmatic men and women.

The results of the present study should serve as the basis for a more detailed long-term evaluation of the effects of ICS on voice production. Future research should consider the introduction of a control (placebo) group, as well as investigating the effects of low and high ICS dosage. Although the present results would seem to suggest that the short-term use of ICS is associated with negative effects on the acoustic properties of voice production, more detailed studies are warranted to validate these findings.

Declaration of interest: The authors report no conflicts of interest.

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