Voice modulation, self-perception and motor branch of the superior laryngeal nerve

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ABSTRACT

Objectives: Vocal morbidity resulting from damage to the motor branch of the superior laryngeal nerve (SLN) after endocrine surgery is well known, but diagnosis is often delayed . The present study aimed to quantify these vocal changes acoustically (main objective), and correlate this with the vocal complaints of patients with suspected SLN motor impairment (secondary objective). **Material and methods:** 30 female patients with suspected injury of the SLN cricothyroid branch (CT-) were compared to 30 patients without postoperative vocal impairment (CT+) and to 30 control subjects. Mean, minimal and maximal fundamental frequencies (F0mean, F0min, F0max) and vocal range were measured on /e/ (French e-acute), sirens (glissandi), a reading text, and minimal intonation pairs. Subjective vocal impairment was evaluated on the Voice Handicap Index (VHI).

Results: A lowering of F0mean associated with vocal range reduction by one fifth (in the reading text) seemed to be specific to CT- patients. Production of questions was affected, with differences in melodic curve and attack. Thyroidectomy within 2 months in itself (without suspected SLN cricothyroid branch injury) also affected these parameters, but to a lesser degree. CT- patients reported greater voice impairment than CT+ patients or controls ($p=0.0004$).

Conclusion: Alterations in speech intonation, quantified on minimal pair test, and self-assessed vocal handicap (VHI) are tools that can easily be used in daily practice to screen for SLN motor branch lesion.

Key-words: thyroidectomy, motor branch of the superior laryngeal nerve, Voice Handicap Index (VHI), vocal modulation, acoustic parameters

INTRODUCTION

Variability in the course of the superior laryngeal nerve (SLN) motor branch, its small size and proximity to the superior end of the thyroid lead to 1-14% rates of injury following thyroidectomy [1]. Despite all efforts to standardize intraoperative location of this nerve, there is no consensus as to the need to locate it or to surgical technique [1, 2].

Injury to the external branch (cricothyroid muscle motor branch) leads to voice fatigue, lowering of the fundamental frequency and difficulty in vocal modulation [2]. The parameters in question, concerning vocal control, are involved in prosody modulation and thus the pragmatic aspect of oral communication and especially intonation effects as in a polar (yes/no) question (with rising intonation) versus an affirmation (falling intonation).

Diagnosis is difficult, based on morphological, functional signs or objective electromyography (EMG) [4]. EMG is the most effective means of diagnosing SLN lesions, but is not easily accessible and is invasive and difficult to interpret, limiting application in clinical practice [4, 5]. Multiparametric acoustic, perceptual and subjective analysis offers an alternative quantification of the problems experienced and assessment of impact on communication. If more clinical instruments were available to practitioners, postoperative management could be anticipated ahead of EMG [5, 6, 7].

The main aim of the present study was to compare acoustic parameters related to patients' vocal complaints between total thyroidectomy patients with and without suspected SLN cricothyroid branch lesion plus a non-operated control group. The secondary objective was to correlate these results with patients' self-assessment.

MATERIAL AND METHODS

Between 2015 and 2017, 3,166 women underwent either total thyroidectomy (n=2,319) or lobo-isthmectomy (n=848) in a single center. Thirty had consulted the same ENTphoniatrician (i.e., standardized examination) with persisting symptoms and agreed to inclusion in the present study. Recruitment was retrospective, based on medical files, following a reference methodology (declaration of conformity and registration with the CNIL data protection commission: n° 2163963 v 0). The external SLN branch lesion was suspected from patients' complaints (voice projection loss, lowered fundamental frequency, vocal fatigue, impossibility of using head voice in glissando) associated with conserved vocal-fold abduction-adduction (ruling out recurrent nerve palsy on systematic flexible endoscopy) and absence of anteroposterior vocal-fold elongation (cricothyroid muscle contraction deficit). Laryngeal sensitivity was systematically tested on endoscopy: no cases of sensory deficit were found. Presenting symptoms at inclusion consisted in persistence of the vocal symptoms underling the ENT consultation. Subjects who had recovered vocal function were excluded. EMG was not part of the team's current diagnostic armamentarium, and was not used. The 30 patients, aged 30-90 years, with clinical suspicion of SLN cricothyroid branch lesion (CT-) were compared to 30 patients without suspicion or complaint (CT+) after the same surgery in the same center. Both groups were recorded at 6 weeks to 3 years postoperatively (mean interval: CT+, 6 weeks; CT-, 1 year).

The CT- and CT+ groups were age-matched to 30 controls (C): CT-, 56±10years; CT+, 52±12 years; C, 58±11 years. Exclusion criteria in each group comprised non-French speaker, poor reading level, professional singer, any autoimmune, neurologic or cognitive pathology or hearing loss, and, for controls, vocal complaint at time of recording. Two control subjects were thus excluded.

To address the main endpoint, subjects were recorded on a 20 min protocol drawn up by the team based on the Committee on Phoniatrics guidelines [8]. Classic vocal assessment tests comprising sustained /a/, reading ("La poupée rouge", a consensus text by Pierre Gripari), /e/ (French "e-acute"), and siren (glissando) analyzed the fundamental (or mean usual fundamental) frequency (F0: Hz) and assessed vocal range in Hz as minimum-to-maximum frequency difference (ΔF0max-F0min) and in semi-tones (F0 range). Other tests specific to vocal modulation comprised Delattre's dialogue with the 10 French intonations, and reading sentences taken from a French speech pathology protocol (minimal intonation pairs) [9, 10]. The same parameters (F0 and vocal range) were collected and analyzed by manual cutting and labeling in meaning groups called "prosodic words". Then, computerized analysis of speech signals in affirmation and in polar question was performed using a script of Praat's software application [11], as recommended in the literature, grouping intonation modalities according to templates related to change in fundamental frequency over time [3, 9]. For example, in the polar yes/no question "*C'est bien toi?*" (meaning "Is that you?"), *"C'est"* is the first labeled prosodic word, *"bien"* is the second, and *"toi"* is the last.

For the second endpoint, vocal self-assessment used the Voice Handicap Index 30 (VHI). [12].

Analysis of variance (ANOVA) on JMP Trial 14 software, followed by post-hoc tests, assessed pairwise intergroup differences. Pearson correlations were calculated between acoustic and self-assessment scores. The significance threshold was set at $p<0.005$ [13, 14].

RESULTS

Acoustic assessment (main endpoint)

Acoustic scores were significantly lower in CT- than controls (C) for the reading text: F0mean, $F_{(1,56)}=1.47$, $p<0.0001$); F0max, $F_{(1,56)}=1.54$, $p<0.0001$); ΔF0max-F0min, ($F_{(1,56)}=1.47$, $p<0.0001$). Range was one fifth shorter: $F_{(1,56)}=1.89$, $p<0.0001$ (Table 1).

Results were comparable for range ($F_{(1,56)}=1.14$; $p=0.001$) and F0max in glissando ($F_{(1,56)}=1.12$; $p<0.0001$) (Table 2), although mean values in controls did not exceed 466Hz (B-flat 4). There was also a significant difference between CT- and controls for F0max in /e/ ($F_{(1,56)}$=1.58; p<0.0001) (Table 2).

Only F0mean (mean usual fundamental), which tends to be lower in reading, significantly differentiated groups CT- and CT+ (F0mean: $F_{(1,58)}$= 1.33; p=0.0004), while the other acoustic parameters in reading (Table 1) and for /e/ (Table 2) showed only suggestive differences between the 2 groups; there were no significant differences for glissandi.

Intonation modalities were analyzed on F0 change over time in affirmations and questions. In affirmations, change was broadly similar between the 3 groups. In the question (Table 3), despite the generally lower F0mean in the intonation templates in CT+ and especially CT-, prosodic words differed between the 3 study groups. Figure 1 compares "c'est", "bien" and "toi ?" in the question "*C'est bien toi?*" with ascending intonation. F0mean on the final word ("toi") was significantly lower in CT- ($F_{(1,58)}$=1.41; p=0.0001) and CT+ ($F_{(1,58)}$=1.29; p=0.001) compared to controls. In the middle word ("bien"), on the other hand, F0mean was lower only in CT- (suggestive difference: $F_{(1,58)}$=1.65; p=0.044) (Figure 1 and Table 3).

Except for merely suggestive differences in VHI (p=0.039: see below), F0mean for reading ($F_{(1,56)}$=1.18; p=0.012: Table 1), range in glissandi ($F_{(1,56)}$=1.11; p=0.006) and F0max for /e/ ($F_{(1,56)}$=1.28; p=0.008: Table 2), and non-significant differences in F0min in glissandi ($F_{(1,56)}$=1.05; p=0.33: Table 2) and F0mean in the first ("c'est": ($F_{(1,56)}$=1.12; p=0.48: Table 3) and second ("bien": ($F_{(1,56)}$=1.15; p=0.37) rhythmic groups in the question "C'est bien toi?", all other parameters displayed significant differences between CT+ patients and controls (Tables 1 to 3). Post-hoc comparison between the CT- and CT+ groups versus controls (3rd column from the right and last column in Tables 1 to 3) suggested greater acoustic impairment in CT-.

Subjective assessment (secondary endpoint)

One-factor ANOVA (factor Group) analysis of VHI scores between the 3 groups demonstrated significantly higher scores in CT- compared to CT+ and controls (means: CT-, 24.71; CT+, 11.19; C, 6.4; $F_{(2,85)}=8.7$; p=0.0004: Figure 2, left). On contingency analysis, 14% of CT- patients reported moderate (31-60 points) to severe vocal handicap (>61 points), compared to 4% in CT+.

Subjective assessment showed negative correlation with vocal range in CT+ and CT- (CT+: $r_{30}=-0.38$, p=0.033; CT-: $r_{30}=-0.47$, p=0.009; Controls: $r_{28}=0.17$, p=0.25: Figure 2, right).

DISCUSSION

SLN motor branch lesions induce voice fatigue and impair vocal control and modulation. They are a disabling complication of thyroid surgery and are difficult to diagnose and to confirm [4]. Diagnosis is founded on clinical evidence: difficulty in reaching high tones, loss of projection and modulation, and deficient anteroposterior vocal-fold elongation on endoscopy. EMG is the only recognized examination, but wasnot part of our center’s diagnostic armamentarium, being invasive, technically difficult, difficult to interpret and not readily available [4, 5, 15]. We therefore associated flexible nasal endoscopy to a multiparametric analysis of vocal complaints that is easy to implement in everyday practice. The aim was to quantify acoustic impairment and assess the impact on communication so as to improve and accelerate postoperative care. We focused on acoustic parameters and speech prosody in particular (main endpoint), in relation to vocal complaints (secondary endpoint) in 3 groups of subjects.

Group selection was one possible study limitation. Due to the retrospective design, EMG was not performed. At inclusion, it was checked that the CT- patients were still reporting their presenting symptoms: those reporting recovery were excluded. Matching in terms of postsurgical interval was not ideal: CT+ patients were recorded at a mean 6 weeks, compared to 6 months to 2 years in CT-; however, this reinforced the idea of an often definitive lesion and chronic disability. Also, the CT+ group may have included some patients with unilateral SLN lesion and contralateral compensation; on the other hand, vocal results in the control group testified to fairly reliable sampling, with the usual mean fundamental (F0) at 236 Hz, within the literature range of 220-240 Hz in women [16], and comparable vocal range in the neighborhood of 2 octaves. Retesting would have been useful in CT+ to assess regression of the observed changes.

The acoustic parameters impaired in suspected SLN cricothyroid branch lesion impacted prosody: lowered F0mean and F0max and reduction in vocal range by a fifth on reading test in CT- compared to controls. The same acoustic parameters were found to be impaired in previous studies: lower fundamental frequency [17] and reduced speech frequency range [17, 18]. Robinson et al. (2005) reported vocal range on reading to be reduced by 1 half-tone [19]. The present study found a 7 half-tone reduction in range (calculated between F0max and F0min on the reading test). This difference may be due to differences in analysis method, based on F0mean for Robinson et al. (2005) [19] and on F0max-F0min differential in the present study. Likewise, range and F0max for /e/ and glissandi differed between CT- and controls, even though the mean differential did not exceed 466Hz in controls (B-flat 4). This may have been due to difficulty in understanding the instructions for sirens (glissandi), which consisted not in an acoustic example to be reproduced but in a diagram showing a rise then a fall from low to high then high to low note;

the idea was to avoid influencing the subjects by mimicry, but may have induced a different bias.

However, some of the above parameters turned out not to be specific to suspected SLN cricothyroid branch lesion: only lower F0mean on reading significantly differentiated the CT- and CT+ groups at 6 weeks postoperatively (p=0.004), while the other acoustic parameters, in reading (Table 1) or for /e/ (Table 2), showed only suggestive differences, and non-significant differences for sirens (glissandi). These findings agreed with several reports of impairment in certain parameters, including fundamental frequency, up to 2 months postoperatively [18, 20, 21]. Even with a longer interval to testing in CT-, there were signs of greater impairment in VHI and F0 range than in CT+, despite a shorter postoperative interval. CT+ performances were significantly poorer than for controls, but with smaller differences (cf. post-hoc comparisons of CT- and CT+ versus controls: Tables 1 to 3).

Concerning impact on prosody, control subject intonation curves were comparable to those in the literature [3], and there were no profiles not matching French prosody among the patients. In affirmations, data were comparable between groups. This modality involves less modulation. In questions, while F0 showed ascension, as would be expected in a question, the organization of prosodic words was different in CT-: F0 ascension between the first and second prosodic words was clear in CT+ and controls, but much less in CT- (Figure 1). CT- patients sought to emphasize the final ascension in the polar question, which they found difficult to achieve, and therefore limited their F0 ascension from the first to the second prosodic word, to be sure that the ascension between the second and the third would be sufficiently contrasted.

In addition to acoustic parameters, VHI was able to differentiate between patients with and without suspected postoperative SLN cricothyroid branch lesion, and only CT- patients showed negative correlation with reduced vocal range. According to the literature, thyroid surgery impacts VHI at 6 weeks, as in the study by Stojadinovic (2002) [21], despite absence of spontaneous complaint. To the best of our knowledge, there have been no studies of subjective voice handicap using the VHI-30 in French-speaking patients with suspected SLN cricothyroid branch injury. However, Lifante et al. (2009 [22]), comparing 22 patients with external SLN branch monitoring during thyroidectomy versus 25 without, found that the latter had a median VHI-30 score that was significantly higher 3 months postoperatively than preoperatively.

CONCLUSION

Assessment of vocal range in reading a text and a minimal intonation pairs test correlated to self-assessed voice handicap seemed to be reliable and clinically reproducible tools for anticipating postoperative management following SLN cricothyroid branch lesion. Earlier diagnosis could avoid socio-occupational impact and maladapted vocal compensation. Difficulties in vocal modulation and intonation impact communication pragmatics, with incomprehension on the part of interlocuters: questions understood to be affirmations, drop in intensity misinterpreted…

Future studies need to confirm the relevance of the tests used here, by correlation with EMG. This might enable EMG to be forgone in future.

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Figure 1: Mean (+), median, 1st and 3rd quartiles of mean fundamental frequency on the words "c'est", "bien" and "toi" in the question "C'est bien toi?" per group (intra-group comparison, for each word), with (gray) and without (white) suspicion of SLN cricothyroid branch lesion and controls (light gray). **significant ($p<0.005$); *suggestive ($0.005<p<0.05$); NS: non-significant ($p>0.05$).

Figure 2: Left: Mean (+), median, 1st and 3rd quartiles for VHI-30 in CT- (suspicion of SLN cricothyroid branch lesion), CT+ (without) and controls; **significant ($p<0.005$); *suggestive ($0.005<p<0.05$); NS: non-significant ($p>0.05$). Right: correlations between vocal range (F0max-F0min differential (Hertz)) and VHI-30 score per group. Full line: regression curve in CT- (r_{30}=-0.47; p=0.009); black dotted line: regression curve in CT+ (r_{30}=-0.38; p=0.033); gray dotted line: regression curve in controls (r_{28}=0.17; p=0.25).

TESTS/PARAMETERS		CT- Mean (SD)	CT+ Mean (SD)	Controls Mean (SD)	*$F_{(2, 85)}$; p-value*	***Post-hoc*** **CT-/ controls**	***Post-hoc*** **CT- / CT+**	***Post-hoc*** **CT+ / controls**
Reading	**F0mean** (Hz)	191 (42)	217 (32)	238 (35)	11.64 p<0.0001	F=1.47 p<0.0001	F=1.33 p=0.004	*F=1.18 p=0.012*
	F0max (Hz)	333 (127)	399 (105)	531 (102)	23.08 p=<0.0001	F=1.54 p<0.0001	*F=1.35 p=0.016*	F=1.56 p<0.0001
	Δ F0max-F0min (Hz)	206 (120)	267 (100)	392 (103)	22.22 p=<0.0001	F=1.47 p<0.0001	*F=1.34 p=0.017*	F=1.45 p<0.0001
	range: semitone	16 (6)	19 (5)	23 (4)	14.99 p=<0.0001	F=1.89 p<0.0001	*F=1.33 p=0.015*	F=1.41 p=0.0003

Table 1: Mean (standard deviation) for intergroup ANOVA comparison in reading. CT-: with suspected postoperative SLN cricothyroid lesion; CT+: without. Gray: significant ($p < 0.005$); italics: suggestive ($0.005 < p < 0.05$).

TESTS/PARAMETERS		**CT- Mean (SD)**	**CT+ Mean (SD)**	**Controls Mean (SD)**	$F_{(2, 85)}$; ***p-value***	***Post-hoc* CT-/ controls**	***Post-hoc* CT- / CT+**	***Post-hoc* CT+ / controls**
SIREN	**F0max** (Hz)	320 (134)	369 (147)	466 (127)	8.52 p=0.0004	F=1.12 p<0.0001	F=1.19 NS p=0.092	F=1.03 p=0.0004
	F0min (Hz)	133 (37)	142 (30)	146 (37)	1.12 p=0.33	F=1 p=0.089	F=1.09 p=0.14	F=1.05 p=0.33
	range: semitone	14 (7)	16 (6)	20 (7)	5.66 p=0.0004	F=1.14 p=0.001	F=1.07 p=0.21	*F=1.11 p=0.006*
/e/ (e-acute)	**F0max** (Hz)	298 (107)	366 (128)	441 (103)	11.51 p<0.0001	F=1.58 p<0.0001	*F=1.24 p=0.014*	*F=1.28 p=0.008*

Table 2: Mean (standard deviation) for intergroup ANOVA comparison in sirens and /e/. CT-: with suspected postoperative SLN cricothyroid lesion; CT+: without. Gray: significant (p < 0.005); italics: suggestive (0.005 < p < 0.05); normal: non-significant (p > 0.05).

TESTS/PARAMETERS		CT- Mean (SD)	CT+ Mean (SD)	Controls Mean (SD)	$F_{(2, 85)}$; *p-value*	*Post-hoc* CT-/ controls	*Post-hoc* CT- / CT+	*Post-hoc* CT+ / controls
Minimal intonation pairs (polar question "C'est bien toi?")	F0max (Hz)	252 (69)	279 (59)	337 (88)	10.21 p=0.0001	F=1.61 p<0.0001	F=1.39 NS	F=1.23 p=0.002
	F0mean "c'est" (Hz)	168(37)	177(24)	177(26)	0.96 p=0.39	F=2.07 p=0.13	F=2.29 p=0.13	F=1.1 p=0.48
	F0mean "bien "(Hz)	183(43)	203(33)	200(34)	2.66 p=0.07	*F=1.65 p=0.044*	*F=1.67 p=0.022*	F=1 p=0.37
	F0mean "toi?" (Hz)	232(66)	253(52)	307(79)	9.74 p=0.0001	F=1.41 p=0.0001	F=1.02 p=0.084	F=1.29 p=0.001
	range: semi tone	8 (3)	9 (3)	12 (4)	8.19 p=0.0005	F=2.55 p=0.0001	F=1.06 p=0.17	F=1.6 p=0.003

Table 3: Mean (standard deviation) for intergroup ANOVA comparison in minimal intonation pairs. CT-: with suspected postoperative SLN cricothyroid lesion; CT+: without. Gray: significant ($p < 0.005$); italics: suggestive ($0.005 < p < 0.05$); normal: non-significant ($p > 0.05$).

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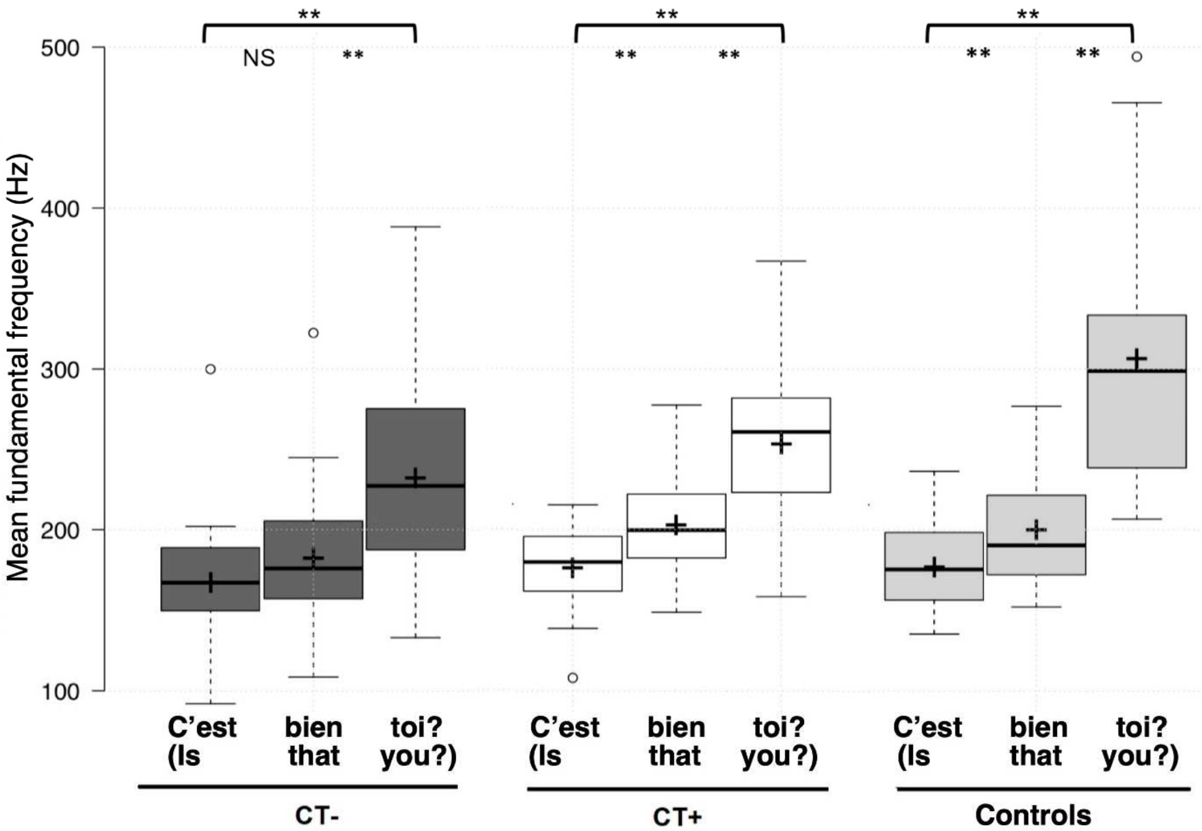
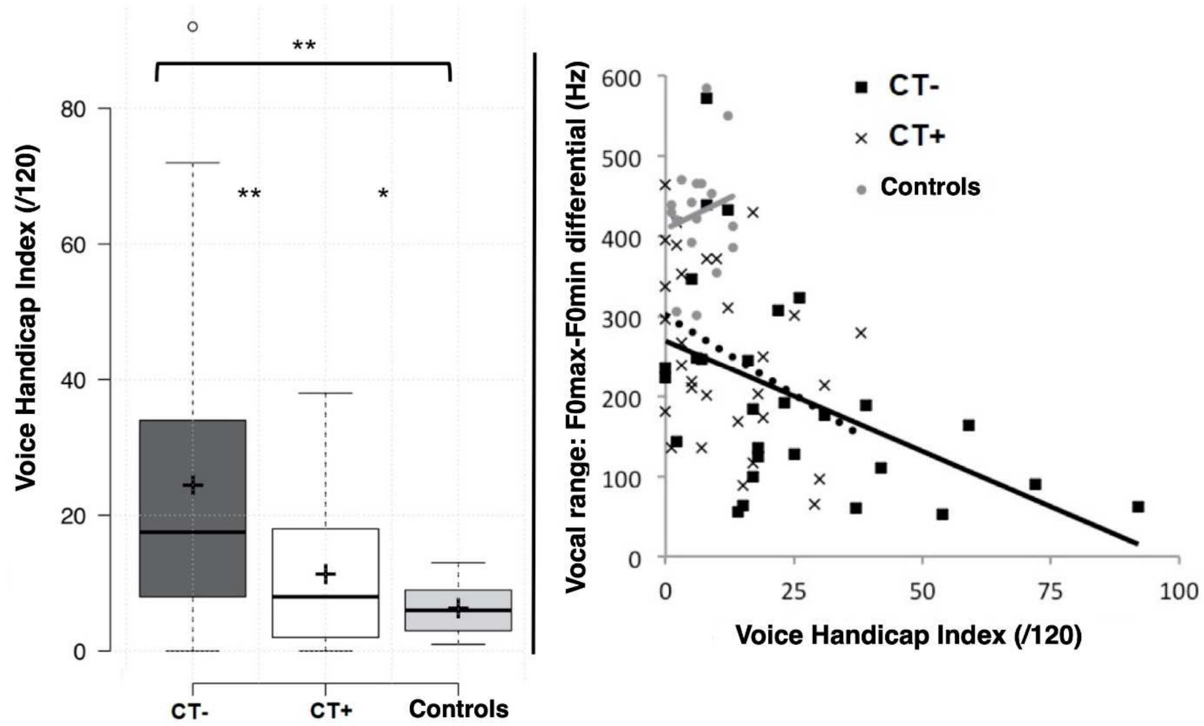


Mean fundamental frequency (Hz)
500
400
300
200
100
**
NS
**
**
**
**
**
**
**
C'est (Is
bien that
toi? you?)
CT-
CT+
Controls



**
Voice Handicap Index (/120)
80
60
40
20
0
**
*
CT-
CT+
Controls
Vocal range: F0max-F0min differential (Hz)
600
500
400
300
200
100
0
0
25
50
75
100
Voice Handicap Index (/120)