Immediate Voice Changes Following Low- and High-Water Resistance Phonation in Healthy Adults: An Acoustic and Self-Perception Study☆

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SUMMARY: Purpose. The purpose of this study was to make a comparison between the short-term effects of low- and high-resistance water phonation exercises, adjusted using the DoctorVox® device, on acoustic parameters and voice self-perception in healthy adults.

Method. Forty-seven healthy adults (37 females, 10 males) performed both low- and high-resistance exercises in a comparative experimental design. Low resistance was achieved with 3 cm of water in the DoctorVox® device, whereas high resistance was achieved by adjusting the DC-Valve® to a 3-mm opening at the same water depth. Acoustic voice recordings (fundamental frequency [F0], jitter, shimmer, harmonics-to-noise ratio [HNR], and acoustic voice quality index) and self-perception ratings (voice quality, phonatory comfort, and vocal fatigue) were collected at baseline, immediately post exercise, and 30 minutes post exercise. The analysis employed both parametric and nonparametric statistical tests.

Results. The low-resistance condition resulted in a significant immediately post exercise increase in F0 and HNR, and a significant decrease in jitter; however, these effects largely disappeared by the 30-minute mark. In the high-resistance condition, only HNR demonstrated a significant change over time, but subsequent pairwise comparisons were not significant. The only significant difference between the two conditions was a higher HNR in favor of the high-resistance condition at 30 minutes post exercise. Despite the absence of any significant difference between the conditions in self-perception ratings, participants in both groups exhibited a tendency to report heightened voice quality and comfort, alongside diminished fatigue, subsequent to the exercises.

Conclusion. The findings suggest that low-resistance exercises may produce immediate acoustic trends in specific parameters and may be useful as a voice warm-up in healthy individuals. Although the effects of high-resistance exercises appear more limited, the results suggest a potential trend toward more sustained changes in certain acoustic parameters. This study highlights the importance of individualizing resistance levels in voice therapy based on specific goals and provides foundational data to guide clinical practice.

Keywords: Water resistance– Tubephonation– Voicetherapy.

INTRODUCTION

In recent years, maintaining and enhancing vocal health has increasingly involved the use of targeted vocal exercises. Among these, semioccluded vocal tract exercises (SOVTEs) have emerged as widely adopted techniques in voice therapy. The underlying principle of SOVTEs is to generate resistance by partially occluding the vocal tract, thereby creating a more stable, balanced, and efficient phonatory environment. This, in turn, supports healthier and more economical voice production. [1,2]

SOVTEs encompass a variety of techniques that create mechanical constrictions in different parts of the vocal tract. These include phonation on lip trills, tongue trills, prolonged voiced fricatives, humming, and phonation into tubes with the distal end either in the air or submerged in water. [2,3]

Within this group, tube phonation applications have been of particular interest in recent years. During tube phonation, the vocal tract is narrowed using various tube types.[4] The distal end of the tube may be positioned either in air, where resistance is primarily generated by the semiocclusion itself, or submerged in water, where additional resistance is created through bubbling and pressure oscillations. Devices such as resonance tubes, LaxVox®, and DoctorVox® have been developed specifically for water resistance applications. LaxVox and DoctorVox® commercial devices are specifically designed to provide phonation in water-resistant environments.[1] It has been hypothesized that the bubbles produced during water resistance phonation create low-frequency oral pressure oscillations in the 14–22 Hz frequency range, and that this pressure can have a massage-like effect on the laryngeal and pharyngeal tissue.[5,6] This “massage-like” effect refers to oral pressure oscillations generated by bubbling during water resistance phonation that are transmitted retrogradely within the vocal tract. These oscillations are

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proposed to contribute to increased tissue mobility and reduced phonatory effort, potentially supporting more regular vocal fold vibration and efficient voice production. The frequency produced by the bubbles varies depending on the depth of the water.[6]

There are studies on the effectiveness of voice therapies applied with water resistance phonation in various voice disorders.[7–11] These exercises are used not only in the treatment of voice disorders but also in healthy individuals to warm up the voice, prevent vocal fatigue, and enhance performance.[12–14]

Water resistance phonation exercises contribute to voice strengthening and increasing phonatory comfort.[15,16] Research examining the instantaneous physiological and acoustic changes in the voice also emphasizes the effectiveness of these exercises in optimizing phonatory balance and resonance.[3,17,18] The effects of water resistance phonation on voice are strongly influenced by the level of resistance generated during exercise.[19] The level of resistance experienced varies depending on the water depth, the internal diameter of the tube, the length of the tube, and the extent to which the apparatus used (eg, the DoctorVox DC-Valve®) restricts the flow of air.[1,4,20,21] In this context, the air outlet area refers to the distal opening through which exhaled air exits the device after generating bubbles within the water chamber; in the DoctorVox® device, this outlet is regulated by the DC-Valve®, which allows adjustment of the effective opening size and thereby modulates airflow resistance during phonation.

Previous research has generally focused on altering resistance by manipulating water depth or tube diameter. Clinically, the recommended resistance level in treatment varies according to the type of voice disorder. Low-resistance exercises are preferred for hyperfunctional voice disorders, while higher resistance exercises created with a water height of 10–15 cm are commonly used as a clinical heuristic for hypofunctional voice disorders.[18,22,23] High-resistance phonation exercises are also hypothesized, based on physiological principles, to contribute to vocal muscle growth.[1,24]

Water resistance tends to decrease transglottic pressure while increasing subglottic and oral pressures.[25,26] This may reduce vocal fold vibration amplitude, potentially leading to lower impact stress. The hypothesis that lower impact stress exerts a positive effect on voice through reduced phonatory effort is supported by the extant literature.[19,27]

A substantial corpus of literature exists regarding the parameters of voice affected by the SOVTEs. However, the capacity to modify these exercises using different types and apparatus creates the opportunity to investigate the specific effects of the resistance level on the voice. Furthermore, a review of the literature revealed no studies systematically modulating resistance through manipulation of the air outlet area or specifically examining the DoctorVox AIO-Vox®, a prominent commercial device known for offering both ease of use and standardization.

Given the importance of resistance level in shaping therapeutic outcomes, a comprehensive understanding of the effects of exercises on the voice is crucial for personalizing voice rehabilitation. In this context, by manipulating the air outlet area, the present study adopts a distinctive approach compared with previous research and examines the effectiveness of the water resistance exercise principle. Accordingly, it aimed to comparatively assess the effects of low- and high-water resistance phonation exercises performed at a 3-cm water depth, in which high resistance was created by reducing the air outlet area using the DC-Valve® mechanism, on acoustic voice parameters and self-perception of voice in vocally healthy individuals.

MATERIALS AND METHODS

Research design and ethical approval

This study was designed as a prospective, within-subject, comparative experimental study and was approved by the Inonu University Non-Interventional Clinical Research Ethics Committee on 11.03.2025 (Decision No: 2025/7308).

Participants

A total of 47 vocally healthy adults (37 females, 10 males; age range: 18–25 years, mean: 20.8 ± 1.6 years) participated in the study. Participants were undergraduate students recruited on a voluntary basis from the Faculty of Health Sciences and the Faculty of Medicine at İnönü University. All participants were informed about the aims and procedures of the study, and written informed consent was obtained. At baseline, participants completed a Demographic Information Form prepared by the researchers and the voice handicap index-10 (VHI-10) for self-assessment of voice disorders. To ensure a nondysphonic sample, the inclusion criterion was a VHI-10 score below 10, which all participants met. Additional exclusion criteria included a self-reported history of hearing impairment, neurological disorders, prior voice therapy or laryngeal surgery, and current upper respiratory infection at the time of testing. Smoking status was recorded but was not used as an exclusion criterion. Six participants (12.8%) reported current or previous smoking, while the majority of the sample (87.2%) reported no history of smoking. Smoking status was included for descriptive purposes and was not used as a grouping variable in the statistical analyses.

Acoustic assessment

Acoustic measurements were obtained at three time points for both exercise conditions: pre exercise, immediate post exercise, and 30 minutes post exercise. Participants produced a sustained /a/ phonation for at least 5 seconds and read this Turkish sentence: *“Serüvenim resimde gördüğünüz doğa harikası şu dağ köyünde başladı.”*. The Turkish sentence used for acoustic voice quality index (AVQI) calculation was selected from the phonetically balanced

"Pinokyo Passage," consistent with its use in previous Turkish AVQI validation studies.[31]

Recordings were made in a sound-attenuated audiometric booth (ambient noise level < 30 dB) using a *Shure SM58* microphone and a *Behringer U-Phoria UMC22* audio interface, connected to an *ASUS Vivobook i5* laptop, and captured with the *Audacity* software. The microphone was positioned 10 cm from the participant's mouth at a 45-degree angle during recording, as recommended by Patel et al.[28] All voice samples were analyzed using *PRAAT (v.6.4.23)* software.

As part of the acoustic analysis, fundamental frequency (F0), frequency perturbation (Jitt%), amplitude perturbation (Shimmer%), and harmonics-to-noise ratio (HNR) analyses were performed on the middle 3 s of the prolonged /a/ phonation. The AVQI was calculated from the 3-second segment of the prolonged /a/ phonation and the sentence sample using the modified AVQI plug-in (version 03.01) for *PRAAT*, adapted by Kılıç.[29] AVQI is a multivariate acoustic model that objectively evaluates voice quality using both continuous speech and sustained vowel samples,[30] and its validity and reliability for the Turkish language have been demonstrated.[31] A 20% portion of the voice recordings was reanalyzed by a second rater to assess inter-rater reliability. The Intraclass Correlation Coefficient (ICC) was calculated for each acoustic parameter using a two-way mixed-effects model with an absolute agreement definition.

Self-perception of voice

Immediately after each exercise and again 30 min later, participants compared their voice to the preexercise condition and rated voice quality, phonatory comfort, and vocal fatigue on a five-point Likert scale (ranging from "very much decreased" to "very much increased"). Prior to rating, participants were provided with brief explanations of the terms "voice quality," "phonatory comfort," and "vocal fatigue," and were instructed to base their ratings on their immediate subjective perception relative to their preexercise voice. These data were coded as categorical variables.

Exercise procedure

Participants performed both low- and high-water resistance exercises using the DoctorVox AIO-Vox® device. For the low-resistance condition, the AIO-Vox® chamber was filled with 3 cm of water, whereas for the high-resistance condition, the same water level was maintained but the DC-Valve® adjustment mechanism was set to a 3-mm opening to increase backpressure. In its default configuration, the air outlet of the DoctorVox AIO-Vox® device has a circular opening with an approximate diameter of 11 mm, allowing relatively unrestricted airflow. Adjustment of the DC-Valve® partially occludes this opening, converting it into a narrowed slit-like aperture and thereby increasing airflow resistance during phonation. For the high-resistance condition, the effective outlet width was set to approximately 3 mm by manually adjusting the DC-Valve® mechanism according to the manufacturer's calibrated scale. Participants were not blinded to the resistance condition, as changes in airflow resistance were likely perceptible during phonation; however, they were not provided with explicit information regarding the pressure settings or resistance levels. To eliminate potential order effects, the sequence of low- and high-resistance exercises was determined using simple random allocation over two consecutive days. The one-day interval between sessions was determined a priori and was considered sufficient to minimize carryover effects, based on prior literature indicating that the acoustic effects of water resistance phonation are short-lived and typically dissipate within minutes to hours. Participants were instructed to sustain smooth and comfortable /u/ phonation into the water for five minutes during each exercise session, with a soft voice onset (avoiding hard glottal attacks), maintaining a steady bubbling sound, pausing near the end of each breath, and resuming after inhalation through the nose. They were also instructed not to take breaks or speak during the five-minute exercise. The procedure was demonstrated through modeling, and the first author monitored each session to ensure accurate performance. Pitch and loudness were not strictly controlled and were allowed to vary naturally. Intraoral pressure was not directly measured in the present study; resistance levels were operationally defined based on standardized exercise conditions. The exercise protocol and measurement timing were standardized based on existing clinical practice and prior literature on short-term SOVTE effects, and no formal multiphase pilot testing was conducted.

Statistical analysis

The statistical analysis was conducted using *IBM SPSS* Statistics (Version 22.0). The significance level was set at $P < 0.05$ for all analyses. The normality of the data distribution was assessed using the Shapiro-Wilk test. Parametric or nonparametric statistical tests were selected accordingly, based on whether the data met assumptions of normal distribution. In order to evaluate changes over the three time points (pre exercise, immediate post exercise, and 30 minutes post exercise) within each exercise condition, a repeated-measures analysis of variance (ANOVA) was used for normally distributed variables. For variables that did not meet the assumption of normality, the nonparametric equivalent, the Friedman test, was employed. Subsequent to the identification of significant findings, *post hoc* pairwise comparisons were conducted with a Bonferroni correction. A direct comparison between the low- and high-resistance exercise conditions was made using the paired-samples t test for normally distributed data and the Wilcoxon signed-rank test for non-normally distributed data.

RESULT

Acoustic analyses were conducted on voice recordings obtained from 47 healthy individuals included in the study. The Shapiro-Wilk test, applied to examine normal

TABLE 1.
Mean (SD) Values and Statistical Comparisons of Acoustic Parameters Over Time for Low- and High-Resistance Conditions (n = 47)

		Pre Exercise	Immediate Post Exercise	30 min Post Exercise	P^{*}
		Median (IQR)	**Median (IQR)**	**Median (IQR)**	
F0	Low	221.26 (148.18–241.29)^{a}	225.38 (201.40–247.50)^{b}	225.51 (178.84–240.28)^{a}	**0.003**
	High	223.44 (199.32–242.37)	230.27 (184.49–245.79)	224.54 (193.95–243.89)	0.758
P^{**}		0.574	0.357	0.505	
Jitt%	Low	0.38 (0.31–0.48)	0.32 (0.26–0.44)	0.38 (0.29–0.47)	**0.043**
	High	0.37 (0.30–0.53)	0.32 (0.27–0.46)	0.34 (0.28–0.48)	0.094
p^{**}		0.814	0.325	0.570	
Shimm%	Low	1.88 (1.53–2.28)	1.71 (1.26–2.27)	1.79 (1.35–2.31)	0.465
	High	1.76 (1.31–2.21)	1.55 (1.35–1.92)	1.67 (1.44–2.03)	0.212
p^{**}		0.175	0.597	0.325	
HNR	Low	31.32 (28.65–35.57)^{a}	34.25 (31.19–37.00)^{b}	33.39 (31.45–35.31)^{a,b}	**0.001**
	High	32.81 (30.71–35.68)	34.09 (31.94–35.99)	34.66 (31.97–36.26)	**0.027**
p^{**}		0.074	0.907	**0.036**	
		Mean ± SD	**Mean ± SD**	**Mean ± SD**	P^{***}
AVQI	Low	0.99 ± 0.63	0.83 ± 0.77	0.86 ± 0.79	0.090
	High	0.88 ± 0.77	0.78 ± 0.72	0.86 ± 0.73	0.385
p^{****}		0.072	0.499	0.938	

Statistical analyses were performed using *Friedman's test, **Wilcoxon signed-rank test, ***repeated-measures ANOVA, ****paired-samples *t* test.
^{a,b}Means in the same row with different superscript letters are significantly different from each other based on *post hoc* pairwise comparisons ($P < 0.05$).
Abbreviations: AVQI, acoustic voice quality index; F0, fundamental frequency; HNR, harmonics-to-noise ratio.

distribution, revealed that only the AVQI parameter met the normal distribution assumption for all measurements. Acoustic parameters (F0, jitter, shimmer, HNR, and AVQI) were analyzed across time points and resistance conditions, with detailed descriptive statistics and p values presented in Table 1. The ICC values for all acoustic parameters indicated good-to-excellent reliability (ICC range: 0.82–0.99).

Low-resistance condition

In the low-resistance condition, the Friedman test showed a significant effect of time on F0 ($\chi^2(2) = 11.617$, $P = 0.003$), Jitter ($\chi^2(2) = 6.298$, $P = 0.043$), and HNR ($\chi^2(2) = 13.319$, $P = 0.001$). Postexercise increases in F0 and HNR were observed immediately after the low-resistance exercise but were not sustained at 30 minutes. However, these changes were no longer significant at 30 minutes post exercise ($P > 0.05$ for both). Although the overall effect on Jitter was significant, *post hoc* tests did not reveal any significant pairwise differences (all $P > 0.05$). No significant changes were observed for Shimmer ($\chi^2(2) = 1.532$, $P = 0.465$). For AVQI, the overall repeated-measures ANOVA did not show a statistically significant effect of time ($F(2, 92) = 2.470$, $P = 0.090$), however, a numerical decrease in AVQI was observed immediately post exercise (Figure 1).

High-resistance condition

In the high-resistance condition, the Friedman test revealed a statistically significant effect of time only for the HNR parameter ($\chi^2(2) = 7.191$, $P = 0.027$). Although an increase in HNR was observed post exercise, subsequent *post hoc* comparisons did not identify any statistically significant differences between the time points (all $P > 0.05$). A nonsignificant trend toward a reduction in Jitter was also noted ($\chi^2(2) = 4.723$, $P = 0.094$). No other acoustic parameters showed significant changes over time ($P > 0.05$ for all).

Comparison of resistance conditions

To compare the outcomes of the low- and high-resistance conditions, paired-samples t tests or Wilcoxon signed-rank tests were used, depending on the data distribution. As there were no significant differences in any baseline (pre-exercise) values between the conditions, direct comparisons were made using the postexercise measurements. The analyses revealed that the two conditions differed significantly only in their HNR values at 30 minutes post exercise ($Z = -2.095$, $P = 0.036$). Specifically, the HNR values at this time point were significantly higher following the high-resistance exercise compared with the low-resistance exercise.

Comparison by gender subgroups

Subgroup analyses by gender were conducted for exploratory purposes. As the data were not normally distributed when analyzed by gender, nonparametric tests were used. The Friedman test was employed to assess changes over time, followed by the Wilcoxon signed-rank test for *post hoc* comparisons with Bonferroni correction.

Female participants

For female participants in the low-resistance condition, a significant change over time was found only for the HNR parameter ($\chi^2(2) = 8.486$, $P = 0.014$). *Post hoc* analyses indicated that this effect was driven by an immediate

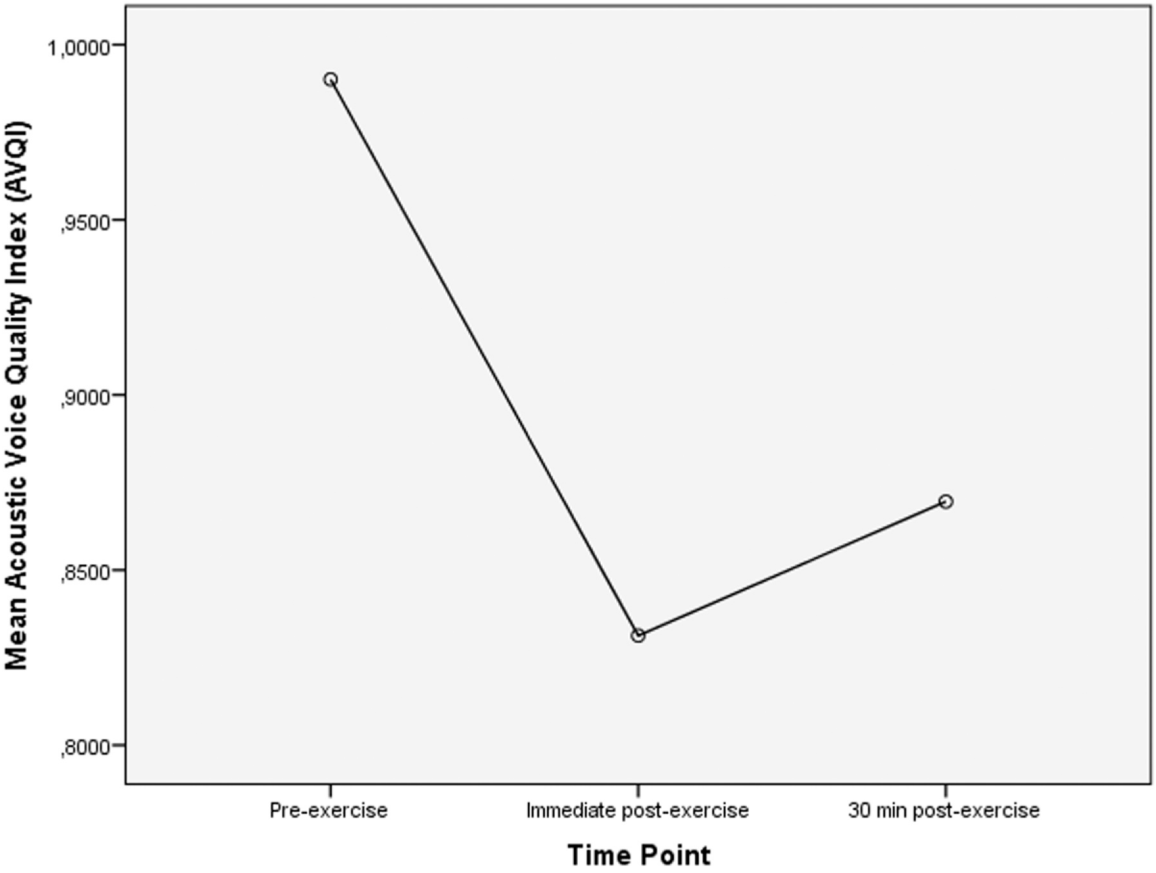

FIGURE 1. Mean acoustic voice quality index (AVQI) scores at pre exercise, immediate post exercise, and 30 minutes post exercise for the low-resistance condition.

postexercise change ($P = 0.011$). In the high-resistance condition, no significant changes were observed for any acoustic parameter over time ($P > 0.05$). Detailed statistics are presented in Table 2.

Male participants

For male participants in the low-resistance condition, the Friedman test indicated significant changes over time for both the F0 ($\chi^2(2) = 15$, $P = 0.001$) and AVQI ($\chi^2(2) = 7.4$, $P = 0.025$) parameters. *Post hoc* analyses for F0 revealed a significant increase from the preexercise baseline to the immediate postexercise measurement ($P = 0.002$). These changes were transient and not maintained at 30 minutes. For the AVQI parameter, although the overall test was significant, *post hoc* pairwise comparisons with Bonferroni correction did not reveal any statistically significant differences between the time points. In the high-resistance condition, no significant changes were observed for any parameters ($P > 0.05$). Detailed statistics are presented in Table 3.

Self-perception

Regarding self-perception, the Wilcoxon signed-rank test revealed no statistically significant differences between the low- and high-resistance conditions for ratings of voice quality, phonatory comfort, or vocal fatigue (all $P > 0.05$). Although the difference between the conditions was not significant, descriptive statistics indicated that participants in both groups tended to report an increase in voice quality and comfort, and a decrease in fatigue, immediately after the exercises. The detailed frequency distributions, percentages, mean ranks, and p values for these self-perception ratings are presented in Table 4.

Descriptively, participants in both conditions reported positive changes in self-perception, particularly immediately after the exercises. Regarding voice quality, a substantial majority in both the low- (80.9%) and high-resistance (74.5%) conditions reported an improvement immediately post exercise. This proportion remained high at 30 min for the high-resistance group (70.2%) but decreased more noticeably for the low-resistance group (63.8%). A similar pattern was observed for phonatory comfort; 80.8% (low resistance) and 68.2% (high resistance) of participants reported increased comfort immediately post exercise, with these rates decreasing to 65.9% and 61.7% at the 30-minute mark, respectively. For vocal fatigue, the most common response was a decrease in fatigue. In the low-resistance condition, 51.0% of participants reported decreased fatigue immediately after the exercise, compared with 29.8% in the high-resistance condition. At 30 minutes post exercise, the

TABLE 2.
Mean (SD) Values and Statistical Comparisons of Acoustic Parameters Over Time for Female Participants in Low- and High-Resistance Conditions (n = 37)

		Pre Exercise	Immediate Post Exercise	30 min Post Exercise	
		Median (IQR)	Median (IQR)	Median (IQR)	P^{*}
F0	Low	227.84 (218.65–248.81)	237.2 (215.00–250.95)	230.52 (218.84–240.53)	0.182
	High	233.27 (219.81–248.15)	235.63 (221.10–248.15)	232.21 (219.53–244.71)	0.704
P^{**}		0.925	0.689	0.428	
Jitt%	Low	0.38 (0.32–0.48)	0.30 (0.26–0.44)	0.38 (0.30–0.49)	0.062
	High	0.33 (0.28–0.55	0.31 (0.27–0.46)	0.34 (0.27–0.49)	0.433
P^{**}		0.875	0.334	0.361	
Shimm%	Low	1.81 (1.52–2.26)	1.77 (1.26–2.27)	1.80 (1.35–2.33)	0.482
	High	1.74 (1.31–2.01	1.51 (1.32–1.80)	1.66 (1.35–2.00)	0.313
P^{**}		0.116	0.369	0.172	
HNR	Low	32.18 (30.60–35.73)^{a}	35.22 (32.18–37.54)^{b}	34.02 (32.31–35.62)^{a,b}	**0.014**
	High	33.88 (31.12–35.84	34.76 (33.36–36.20)	35.03 (33.55–37.24)	0.132
P^{**}		0.084	0.862	**0.32**	
AVQI	Low	1.06 (0.77–1.72)	1.3 (0.54–1.43)	0.97 (0.67–1.54)	0.192
	High	1.02 (0.59–1.53)	0.79 (0.52–1.41)	0.88 (0.50–1.42)	0.828
P^{**}		0.070	0.424	0.274	

Statistical analyses were performed using *Friedman's test, **Wilcoxon signed-rank test.
^{a,b}Means in the same row with different superscript letters are significantly different from each other based on *post hoc* pairwise comparisons ($P < 0.05$).
Abbreviations: AVQI, acoustic voice quality index; F0, fundamental frequency; HNR, harmonics-to-noise ratio.

proportion reporting decreased fatigue was 34.1% for the low-resistance and 42.5% for the high-resistance condition.

DISCUSSION

Studies report the positive effects of water resistance exercise on the voice. However, evidence regarding the short-term effects of these exercises at different pressure levels in healthy individuals is variable and limited. The present study compared the short-term effects of low- and high-resistance water phonation exercises performed with the DoctorVox AIO-Vox® device in healthy adults. To address this aim, the selected acoustic parameters (F0, jitter, shimmer, HNR, and AVQI) were chosen because they are

TABLE 3.
Mean (SD) Values and Statistical Comparisons of Acoustic Parameters Over Time for Male Participants in Low- and High-Resistance Conditions (n = 10)

		Pre Exercise	Immediate Post Exercise	30 min Post Exercise	
		Median (IQR)	Median (IQR)	Median (IQR)	P^{*}
F0	Low	112.47 (104.891–25.05)^{a}	120.25 (110.83–136.35)^{b}	113.43 (104.78–136.06)^{a}	**0.001**
	High	113.54 (112.73–127.42)	116.7 (108.91–126.81)	115.91 (110.43–123.34)	0.741
P^{**}		0.169	0.202	0.559	
Jitt%	Low	0.37 (0.31–0.48)	0.34 (0.29–0.41)	0.34 (0.28–0.41)	0.067
	High	0.39 (0.32–0.51)	0.34 (0.31–0.42)	0.36 (0.34–0.46)	0.082
P^{**}		0.799	0.646	0.441	
Shimm%	Low	1.91 (1.53–2.28)	1.63 (1.24–2.09)	1.77 (1.51–1.90)	0.407
	High	2.03 (1.70–2.37)	1.76 (1.55–2.2)	1.75 (1.57–2.03)	0.670
P^{**}		0.575	0.507	0.507	
HNR	Low	29.26 (28.08–30.43)	31.34 (30.46–32.33)	31.29 (29.64–31.97)	0.061
	High	30.07 (26.02–31.53)	31.3 (29.87–32.77)	31.87 (29.56–33.06)	0.150
P^{**}		0.646	0.508	0.646	
AVQI	Low	0.2 (0.07-0.8)	-0.01 ((−0.33)–0.5)	0.17 ((−0.76)–0.64)	**0.025**
	High	0.45 ((−0.13)–0.62)	0.27 ((−0.38)–0.42)	0.61 (0.24–0.76)	0.670
P^{**}		0.575	0.646	**0.022**	

Statistical analyses were performed using *Friedman's test, **Wilcoxon signed-rank test.
^{a,b}Means in the same row with different superscript letters are significantly different from each other based on *post hoc* pairwise comparisons ($P < 0.05$).
Abbreviations: AVQI, acoustic voice quality index; F0, fundamental frequency; HNR, harmonics-to-noise ratio.

TABLE 4.
Frequency Distribution and Statistical Comparison of Self-Perception Ratings for Low- and High-Resistance Conditions (n = 47)

	Time	Resistance	Very Much Decreased	Slightly Decreased	Unchanged	Slightly Increased	Very Much Increased	Mean Rank	*P*
Voice quality	Immediate post exercise	Low	0 (0.0)	6 (12.8)	3 (6.4)	28 (59.6)	10 (21.3)	12.50	0.407
		High	0 (0.0)	5 (10.6)	7 (14.9)	21 (44.7)	14 (29.8)	10.81	
	30 min post exercise	Low	0 (0.0)	6 (12.8)	11 (23.4)	21 (44.7)	9 (19.1)	12.29	0.702
		High	0 (0.0)	7 (14.9)	7 (14.9)	23 (48.9)	10 (21.3)	11.56	
Phonatory comfort	Immediate post exercise	Low	2 (4.3)	2 (4.3)	5 (10.6)	30 (63.8)	8 (17.0)	12.57	0.585
		High	1 (2.1)	6 (12.8)	7 (14.9)	26 (55.3)	7 (14.9)	20.69	
	30 min post exercise	Low	0 (0.0)	3 (6.4)	13 (27.7)	22 (46.8)	9 (19.1)	9.43	0.160
		High	2 (4.3)	9 (19.1)	7 (14.9)	20 (42.6)	9 (19.1)	8.70	
Vocal fatigue	Immediate post exercise	Low	5 (10.6)	19 (40.4)	6 (12.8)	14 (29.8)	3 (6.4)	12.54	0.390
		High	4 (8.5)	10 (21.3)	13 (27.7)	17 (36.2)	3 (6.4)	8.50	
	30 min post exercise	Low	6 (12.8)	10 (21.3)	14 (29.8)	16 (34.0)	1 (2.1)	10.71	0.846
		High	4 (8.5)	16 (34.0)	12 (25.5)	14 (29.8)	1 (2.1)	11.39	

sensitive indicators of short-term changes in vocal stability and voice quality, while self-perception measures were included to capture clinically relevant experiential responses. The findings indicate that both conditions of exercise resulted in short-term changes in some acoustic parameters and self-perception of voice, but most of these changes did not reach statistical significance.

Following exercise, significant changes were observed in the F0, jitter, and HNR parameters in the low-resistance condition; F0 and HNR increased, while jitter decreased. The significant overall effect observed for jitter, in the absence of corresponding significant pairwise differences, may reflect variability in jitter measurements over time rather than a consistent exercise-related effect. In the high-resistance condition, only an increase was observed in HNR. Although there was a decrease in AVQI values, it did not reach statistical significance. A decrease in AVQI is generally interpreted as reflecting improved overall acoustic voice quality. There are inconclusive findings in the extant literature regarding the effects of short-term water-resistant phonation on acoustic parameters in healthy individuals. Laukkanen et al,[32] using resonance tube phonation in air with artificially lengthened vocal tracts, reported a decrease in F0 with increasing tube length. Since immersion depth, tube length, and internal diameter all affect resistance levels, different acoustic results are likely to be observed depending on the level of resistance applied. In a study by Bonette et al[33] involving female participants without vocal complaints, participants performed three 3-minute exercises: an experimental exercise consisting of phonation into a flexible resonance tube immersed in water, a control exercise using tongue trills, and a placebo exercise involving an unvoiced fricative. Vocal self-assessment improved significantly more after the water resistance exercise than after the control and placebo exercises, whereas no significant differences were observed in acoustic or auditory-perceptual measures. A similarly designed study by Cielo et al[34] compared the short-term effects of phonation into a glass tube immersed in water and the finger kazoo exercise, reporting acoustic improvements primarily related to resonance and stability for the water-based exercise, despite no significant differences in auditory-perceptual outcomes. In a study with professional voice users, Oliveira et al[35] compared flexible resonance tube phonation in water with the lip trill technique and found that the water-based exercise increased vocal tract length by altering oropharyngeal geometry, whereas acoustic improvements were not prominent for this exercise condition. Similarly, Fadel et al's study with singers[36] reported that a 3-minute SOVTE using the LaxVox® tube resulted in an increase in F0, accompanied by improvements in self-perceived voice quality, similar to that observed in our study.

In the current study, the significant increase observed in the HNR indicates that the harmonic components of the voice signal have become more dominant than the noise components, suggesting a relative improvement in harmonic structure. These findings support the research of Guzmán et al[18] in their study that evaluated the effects of submerged tube phonation at different depths, measurements were taken both during and after exercise. During the phonation exercise in water at a depth of 5 cm, F0 increased, while HNR and jitter decreased. After the exercise, F0 and HNR increased, while jitter decreased. This was interpreted as indicating a more regular and harmonic glottal oscillations. The results also suggest that tube immersion depth has different effects on phonation. Taken together, these variations across studies may be attributed to methodological differences in how resistance is manipulated, as the present study increased resistance by restricting the air outlet area rather than by altering tube length, diameter, or water immersion depth, which may partly account for the observed differences in acoustic outcomes.

The direction of change in acoustic parameters varies in individuals with voice disorders. A systematic review by

Pozzali et al[37] indicated that tube phonation and other SOVTEs—including both air-based and water resistance exercises—generally have a significant effect on F0, but the direction of this effect varies across studies. The frequent observation of F0 reductions in dysphonia highlights the importance of examining the direction of change in healthy individuals in the current study. The type, duration, and method of application of the exercise may also contribute to these differences.[38]

According to *post hoc* analyses, the disappearance of the effect observed in several acoustic parameters at the 30th minute indicates that the effect of exercise is temporary and that regular practice may be necessary for sustained results. Although there was a trend toward an increase in HNR over time in the high-resistance condition, this trend was not significant in the *post hoc* analyses. This suggests that low-resistance exercises are more effective at improving voice quality immediately in healthy individuals. This finding implies that such exercises may be particularly suitable as a warm-up routine for professional voice users. Although the present study was conducted in vocally healthy individuals, these findings suggest that similar exercise approaches may also be beneficial for professional voice users, including voice performers, by supporting vocal readiness and addressing functional needs in performance-related contexts.

When comparing the two exercises, it is noteworthy that HNR was significantly higher in the high-resistance condition only at 30 minutes post exercise. From a practical perspective, modulating resistance by adjusting the air outlet area—as implemented in the present study—may represent a more feasible and less physically demanding approach than altering water immersion depth, particularly in clinical and everyday voice practice. While this finding suggests that the effect of high-resistance exercise may last longer, the fact that the difference is limited to a single parameter is insufficient to demonstrate a clinically significant superiority.

High-resistance exercises are known to be recommended for cases of hypofunction or to increase vocal muscle tone.[1,24] A study by Guzman et al[16] showed that water depth has a significant effect on Contact Quotient, with deeper immersion producing higher CQ values. This finding suggests that high-resistance exercises may be more suitable for long-term muscle activation and strengthening goals. The study also demonstrated that during phonation performed at high resistance (10 cm), subglottic and oral pressures increased, but transglottic pressure decreased. This indicates that the amplitude of vocal fold vibration may be reduced, which could lead to lower impact stress and create a “massage-like” mechanical stimulation.[6,25,39] On the other hand, increased intraglottal pressure and closure force may increase the risk of vocal fatigue. [40] Although no significant increase in self-perception of vocal fatigue scores was observed in the current study, participants’ reports of less relaxation and less reduction in vocal fatigue compared with lower resistance could be explained by this mechanism.

Gender subgroup analyses showed significant increases in HNR in women under the low-resistance condition, and in F0 and AVQI in men under the low-resistance condition. Although there was a decrease in jitter in both groups, this was not significant. Similarly, there was an increase in HNR in men, though not to a significant level ($P > 0.061$). Although gender-specific hypotheses were not formulated a priori, these findings prompted exploratory interpretations. One possible explanation may relate to known gender differences in laryngeal anatomy, baseline F0, and vocal fold mass. Males, who typically exhibit lower baseline F0 and greater vocal fold mass, may show more pronounced changes in overall acoustic voice quality under low-resistance conditions, whereas females may respond more favorably to higher resistance in terms of harmonic structure and glottal regularity. These findings are supported by the literature, as previous studies have reported that gender may affect SOVTE responses.[9,15,41,42] Given the relatively small number of male participants (n = 10), these subgroup findings should be interpreted with caution and considered exploratory rather than confirmatory.

The positive effects of water resistance-based therapeutic approaches on voice self-assessment are more pronounced than on objective assessments.[19] Exercises performed against water resistance have been shown to improve self-perceived voice quality and phonatory comfort.[5,20,43] However, it appears that subjective improvements in short-term interventions may not always align with objective measurements. In addition, it should be noted that self-perception outcomes in the present study were assessed using nonvalidated single-item ratings, which may limit the precision of subjective measurement. Nevertheless, it is important to recognize that self-perception plays a key role in clinical motivation and exercise compliance. An important finding of the present study is the dissociation between subjective voice improvements and limited objective acoustic changes. While participants consistently reported improved voice quality and comfort following both resistance conditions, these perceptions were not consistently mirrored by statistically significant changes in acoustic measures. This discrepancy highlights the complex relationship between perceived vocal effort, comfort, and measurable acoustic outcomes.

This study has several limitations. First, the study’s focus on healthy young adults and its short-term design limits the generalizability of the findings to different age groups or long-term outcomes. Additionally, the resistance created by manipulating the air outlet area was not measured numerically, as resistance was not aerodynamically quantified and intraoral pressure was not directly measured; instead, resistance levels were operationally defined based on standardized exercise conditions. To guide individual use of these commercial devices, future research incorporating direct intraoral pressure measurements may further elucidate the physiological mechanisms underlying this exercise approach. Furthermore, the absence of laryngeal visualization represents an additional limitation, as subtle structural or functional vocal fold differences could not be objectively verified. The imbalance in gender distribution may also limit generalizability. Future studies with larger, more balanced sample sizes and longer follow-up periods will more clearly demonstrate the role of different resistance levels in the vocal mechanism. In addition, future research may examine the applicability of these exercises to broader populations, including individuals with chronic pain conditions who may exhibit differential responses to resistance levels, as well as to nonclinical contexts such as voice pedagogy and singer training, to better understand their effects on vocal comfort and efficiency.

CONCLUSION

Among SOVTEs, water resistance exercises are notable for providing both sensory feedback and mechanical stimulation. These exercises include a secondary vibration source, which is thought to produce a "massage-like" effect.[1,38] This study suggests that in healthy individuals, low-resistance water exercises performed with the DoctorVox AIO-Vox® are associated with short-term changes in certain acoustic parameters, whereas high-resistance exercises exhibit more limited and potentially delayed acoustic responses. These findings suggest that in clinical practice, low-resistance exercises may be preferable for achieving acute vocal relief and enhancing voice quality, while high-resistance exercises could be considered for long-term goals of muscle activation and strengthening. Given the number of statistical comparisons performed, an increased family-wise error risk cannot be entirely excluded, and the findings should be interpreted with caution. Overall, the results highlight the importance of individualizing resistance levels in voice therapy and provide foundational data to guide clinical applications.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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