The Efficacy of the NHS Waterpipe in Superficial Hydration for People With Healthy Voices: Effects on Acoustic Voice Quality, Phonation Threshold Pressure and Subjective Sensations

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Summary: Objectives. This study examined the efficacy of the NHS waterpipe as a superficial hydration treatment in voice production in healthy young women.

Study Design. This is a prospective, single-blind, within- and between-subject experimental design.

Methods. Thirty six female university students (mean age 24.6 years, range 19−45 years) were recruited to the study. Participants were randomized to two experimental groups (E1 and E2) and a control group. E1 underwent hydration treatment with the NHS waterpipe filled with 0.9% saline that was immersed in a cup of heated water. E2 underwent a similar treatment but without heated immersion. The control group received no treatment. Acoustic Voice Quality Index (AVQI v03.01) and its subparameters, phonation threshold pressure, self-perceived phonatory effort and sensation of throat dryness was measured at three time points (before the intervention and immediately and 15 minutes after it).

Results. The Tilt of the AVQI's subparameters increased significantly in the E1 ($P = 0.027$) and E2 groups ($P = 0.027$) after the intervention. Furthermore, the E1 group had significantly lower harmonics-to-noise-ratio values at the third measurement point compared to the E2 group ($P = 0.023$). These findings may result from fluid transported to the vocal fold level. The sensations of throat dryness decreased in the E1 ($P = 0.001$) and E2 groups ($P < 0.0005$) after the intervention. Perceived phonatory effort decreased statistically significantly at the final measurement point in the E1 ($P = 0.002$) and E2 ($P = 0.031$) groups. No variables changed in the control group.

Conclusions. The waterpipe seems to be efficient in hydrating vocal folds on single use. It seems to be more efficient when employed with a hot water bath, albeit slightly impairing some acoustic values in the short term. Without the heated fluid, it still seems to decrease sensations of throat dryness and affect acoustic voice quality. The waterpipe does not seem to have an effect on phonation threshold pressure, and it seems to lower self-perceived effort just as efficiently whether the waterpipe is employed using a hot water bath or not. Further research is needed to prove the efficacy of long-term usage and usage with voice patients.

Key Words: Vocal hygiene−Vocal fold hydration−AVQI−PTP−PPE−Intervention.

INTRODUCTION

Surface hydration of the vocal folds

Sufficient vocal fold hydration is essential for vocal fold vibration.[1] Firstly, the hydration status of the vocal fold tissue affects the vibratory properties of the tissue.[2] This relationship can be explained by the concept of viscosity. For decades, it has been accepted that the vocal-fold tissue viscosity is determined by the water content of the tissue.[3] By adding low-viscosity liquid, such as water, to the tissue, the inner friction of the tissue and tissue viscosity decreases. This consecutively lowers the threshold pressure needed to initiate vocal fold vibration.[4]

Contrary, as the viscosity of the vocal fold mucosal blanket increases, the surface tension of the vocal fold also increases.[5] This limits the range of oscillatory motion.[6] However, by adding low-viscosity liquid to the vocal fold surface, the overall tissue viscosity decreases, and the tension decreases leading to improved oscillation.[4] Indeed, this is presumably the mechanism by which surface hydration treatments operate to improve vocal fold vibration. Since the earlier research, the relationship between vocal fold hydration and tissue viscosity has been demonstrated in various laboratory studies.[2,7,8]

Naturally, the hydration status is maintained by systemic hydration,[9] mechanisms of surface hydration,[10] and epithelial ion channels of the larynx,[11] in addition to humidity traveling to the laryngeal area via inhalation. Mechanisms of surface hydration include the secretory function of the mucosal glands in the larynx[12] and the lower airways.[10,13] Since the contact surface of the vocal folds does not contain secretory glands,[14] fluid secreted elsewhere is transported to the vocal fold surface, for instance by mucociliary transport.[6] The superficial hydration of the vocal folds serves to hydrate, lubricate, and protect the surface tissue.[10]

Accepted for publication August 18, 2021.

This paper was the result of two Master's theses in the *Master Program of Logopedics, Faculty of Social Sciences, Tampere University, Tampere, Finland

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Journal of Voice, Vol. ■■, No. ■■, pp. ■■−■■

0892-1997

https://doi.org/10.1016/j.jvoice.2021.08.012

It is widely accepted that regardless of the reason, vocal fold dehydration impairs the oscillation of the vocal fold tissue.[2,7,8] When vocal fold tissue is dehydrated, the typical oscillatory patterns are disrupted,[7] and the vibratory ability of the vocal folds is eventually ceased.[4,8] Furthermore, dehydration seems to increase the permeability of the epithelium, which weakens the protective function of the surface tissue against environmental factors.[11,15] Dehydration might result from the poor ingestion of fluids[16,17] or various environmental factors, such as the low relative humidity of inhaled air.[4,8]

Dehydration of the vocal folds has been reported to elicit undesirable subjective sensations such as dryness of the throat and increased perceived phonatory effort (PPE).[18,19] Dehydration studies have also reported increased perturbation values and decreased harmonics-to-noise-ratio (HNR) values,[20,21] and an increase in the minimum subglottal pressure needed to initiate and maintain vocal fold vibration (aka *phonation threshold pressure,* PTP).[19,22,23] Additionally, Hemler and colleagues[7] have stated that sufficient impairment of the vocal-fold oscillatory properties may induce compensatory hypertension during voice production. This may further elicit other voice problems, such as muscle tension dysphonia.[24]

Fortunately, problems induced by vocal fold dehydration seem to be treatable with sufficient vocal care, such as surface hydration treatment.[25] Common surface hydration treatments include indoor air humidifiers and various nebulizers and vaporizers. These treatments aim to manipulate the viscosity of the vocal fold surface fluids, and consequently to improve the oscillatory properties of the tissue and overall voice production.[4,26] Speech and voice therapists often recommend voice patients ensure the sufficient humidification of inhaled air.[20,26]

The surface hydration treatments have been somewhat investigated during the last twenty years.[25] It is rather well established that these treatments can restore the decreased function of dehydrated vocal folds.[18,20,25] Treatments have also exhibited promising results in treating patients with dysphonia.[27] However, the results have been somewhat different among healthy participants. For example, Vermeulen and colleagues[28] investigated how surface hydration treatment affects voice quality with or without systemic hydration, such as fluid ingestion. The results indicated that superficial hydration treatment with systemic hydration might impair the voice quality of healthy participants by increasing the acoustic values of jitter or shimmer.[28] Similarly, Zou and colleagues[21] noted an increase in jitter and shimmer in healthy participants' voices. However, this was only observed after sufficient hydration status was achieved, but hydration treatment was further continued. As stated by Hemler and colleagues,[7] this ceiling effect suggests that the adequate hydration status of the surface tissue had already been reached.

In the studies investigating the hydration treatment's association with PTP, the results have been quite diverse. Verdolini-Marston and colleagues[29] and Verdolini and colleagues[26] noted that systemic hydration combined with superficial hydration decreased PTP. However, in the study of Roy and colleagues,[30] PTP did not decrease after superficial hydration, although the lubricant used was a diuretic (Mannitol). Furthermore, Tanner and colleagues[19,31] observed that PTP did not change notably after the superficial hydration intervention when the participants had first breathed dry air. After all, the research results concerning the efficiency of the superficial hydration seem to be quite ambiguous. Further investigation is needed to clarify the relationship between PTP and superficial hydration.

The NHS waterpipe

In Finland, voice specialists frequently instruct voice patients to use either indoor air humidifiers or direct humidifiers. In northern countries like Finland, the outdoor temperature drops considerably during winter, decreasing the relative humidity of the air. Consequently, the dryness of inhaled air may have adverse effects on voice production[2] even in the healthy population.[20] Therefore, it is essential to investigate the efficacy of humidifying treatments in people with normophonic voices, as these treatments could serve as prevention against dryness. In Finland, one humidifier commonly recommended to voice patients by speech and voice therapists is the NHS waterpipe (Oy Nordic Health Systems Ab, Hyvinkää).

The NHS waterpipe (Figure 1) is a small mechanical plastic inhaler for laryngeal and vocal fold surface hydration.[32] According to the instruction manual of the device, one loads the pipe with 5 ml of clear water or saline (0.9% saline recommended). Humidification occurs when air is inhaled through the pipe and exhaled through the nasal cavity. Additionally, one can immerse the pipe in a cup of heated water to amplify the effect of humidification.

According to the manual, the structure of the pipe mechanically disperses the fluid into fine droplets, which are then transported to the laryngeal cavity with the inhaled air. Due to this property, the pipe should also work without heating the fluid. To our knowledge, by immersing the pipe in a cup of heated water, the humidifying mechanism also utilizes vaporization. Indeed, voice clinicians in Finland usually instruct patients to use the pipe by immersing it in heated water.[33]

Despite its frequent use in voice care, no studies have been conducted on the NHS waterpipe's efficacy in surface hydration treatments. Because the operating principles of the device differ to some extent from similar devices, it is essential to investigate the efficacy of this device in treating the voice.

Aim of the study

The aim of the present study was to investigate the humidifying efficacy of the NHS waterpipe in the healthy population when used with and without immersion in the heated water. Efficacy was measured by changes in phonation threshold pressure (PTP), acoustic voice quality (*Acoustic Voice Quality Index,* AVQI v03.01) and subjective

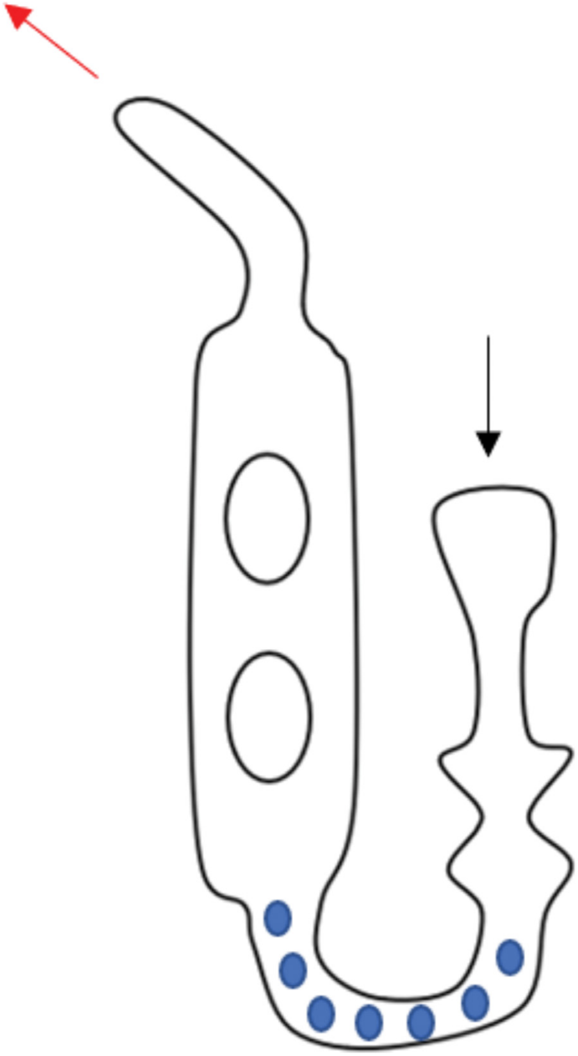

FIGURE 1. Illustration of the NHS waterpipe for humidifying the larynx and vocal fold surface. The arrows in the picture illustrate the direction of inhaled air. The circles at the bottom indicate the saline in the pipe. The upper horn of the device is a mouthpiece.

sensations of perceived phonatory effort (PPE) and throat dryness. The results of the study may give new information to clinicians about the possible effects related to humidification treatments.

MATERIAL AND METHODS

This study used a single-blind, prospective, within- and between-subjects experimental design. The participants were blinded to possible treatment options and to what intervention was expected to be more effective. The design is illustrated in Figure 2.

Participants

Thirty-six women aged 19−45 years (*M* = 24.6 years, *sd* = 6.39) volunteered to participate in the study. Most of the participants (n = 23) were first-year students in the Degree Programme of Logopedics at Tampere University. The target number of participants was based on previous studies investigating the effects of superficial hydration.[25] The aim was to include at least ten participants in each group at the final stages of analyses (target N ≥30).

Vocal health was assessed with self-reports by the participants, and a listening evaluation was performed by a speech/voice therapist. The samples were evaluated using a grade from the GRBAS scale (0 = healthy, 1−3 = dysphonic). Two participants' voices were mildly dysphonic only on the basis of the auditory-perceptual assessment. One of them was excluded during further delineation of the data, and another was similarly excluded from the PTP and PPE analyses, but was included in the AVQI analyses, since the acoustic values of this participant were not deviant. All participants were non-smokers, and none reported the use of diuretic medication. Further background information is presented in Table 1. The participants were randomized to two experimental groups (E1 and E2) and one control group (controls) (Figure 2).

Permission for recruiting participants was granted by the dean of the Faculty of Social Sciences at Tampere University, and a privacy notice on processing personal data and keeping a register was made for Tampere University. The participants gave their written consent for the research, which included information about anonymity, data privacy and data management. According to the Ethics Committee of the Tampere Region, the study did not need ethical approval because the study setting did not involve any physical or ethical risks to the participants.

Intervention

The experimental groups (E1 and E2) used the NHS waterpipe for a single five-minute session. In both groups, the pipe was filled with five millilitres of isotonic saline (0.9% NaCl). In the E1 group, the pipe was then immersed in a cup of heated water during the intervention. The E2 group used the pipe without the immersion in heated water. The average water temperature in the heated cup was 83.3°C (*sd* = 1.88), and the saline in the immersed pipe was expected to heat up to similar levels. The average temperature of the saline in the E2 group was 21.8°C (*sd* = 0.25) (measured from the saline bottle).

The participants were instructed to keep the waterpipe between their lips, sit in an upright position, and breathe for a single five-minute period through the waterpipe, inhaling through the mouth and exhaling through the nose. The instructions originated from the instruction manual of the device and from an instructional video.[33] The participants of the control group were instructed to remain silent for the time of the intervention procedure.

Data collection and voice samples

The participants' conversational speaking pitch for further analyses was defined by asking the participants to count from one to five; the number three was selected for pitch

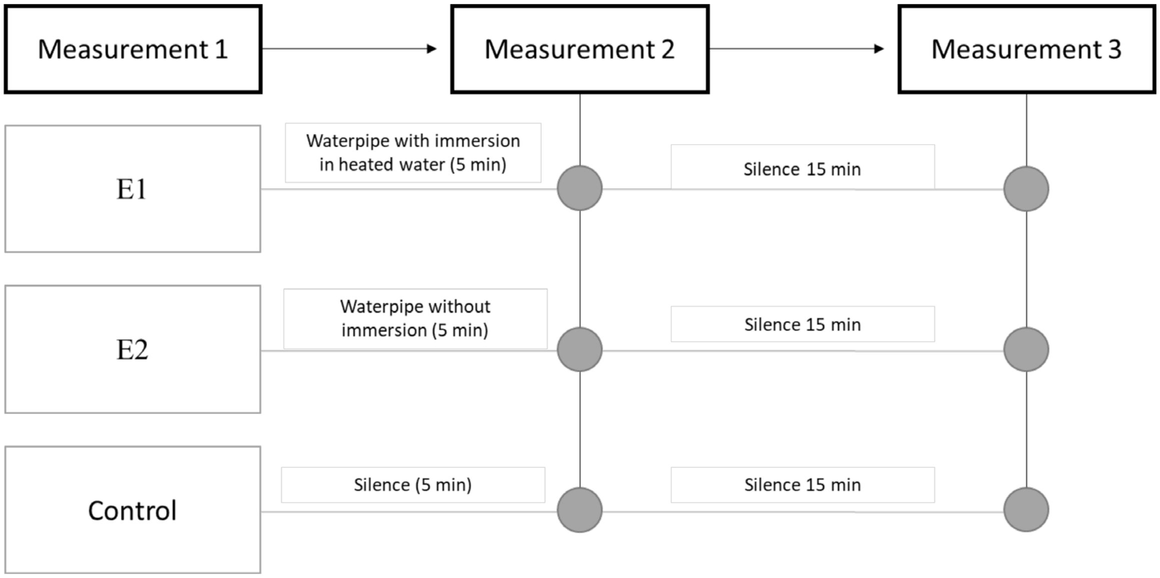

FIGURE 2. Study design for two experimental groups using waterpipes (with and without heated air) and a control group. E1 = experimental group 1; E2 = experimental group 2; Control = control group; Waterpipe = NHS waterpipe© (a plastic inhaler); Group E1 used the immersion-heated waterpipe with 0.9% saline, group E2 used the pipe with room-temperature 0.9% saline.

TABLE 1.
Background Information of the Participants and the Between-Groups Comparison

Group	E1 (n = 12)	E2 (n = 12)	Control (n = 12)	*P*-value
Age	28.3 (*sd* 10.1)	23.8 (*sd* 3.0)	21.4 (*sd* 2.0)	0.033
VHI	10.6 (*sd* 7.4)	17.1 (*sd* 8.2)	16.4 (*sd* 12.0)	0.212
Respiratory tract allergies	3	3	2	0.862
Allergy or asthma medication	1	4	1	0.176
Diagnosed asthma	none	1	1	0.611
Ingestion of fluids during previous 2 h	10	10	10	1.00
Voice-related hobbies	2	3	2	0.849
Voice-related education	4	4	none	0.079
Previous voice-related problems	2	2	3	0.849

For age (years) and VHI (Voice Handicap Index), mean values are presented with standard deviations (sd). For other background variables, the number of yes-answers is given.. Differences between groups were calculated with one-way ANOVA.
Abbreviations: E1 and E2= experimental groups; Control= control group.

measuring. Subsequently, the researcher selected five whole tones of a higher pitch to be used in the further PTP measurements. Phonation in the higher than conversational pitch was included, since earlier studies have found that it may be more sensitive to changes in PTP after hydration treatment.[29]

The voice samples (Table 2) were gathered at the Speech and Voice Research Laboratory during a two-week period in October 2020. Phonation threshold pressure and acoustic parameters of the voice were measured prior to the intervention, immediately after it, and 15 minutes after the end of the intervention. A fifteen-minute duration was selected based on a finding that the effects of a single superficial hydration treatment disappear after 20 minutes.[30]

Samples (frequency of 44.1 kHz) were recorded with the Computerized Speech Lab system (CSL Model 4500, Kay Elemetrics Corp., Lincoln Park, NJ). The bit depth was 16 bits. Three channels were recorded simultaneously. For channel 1, the acoustic signal was recorded with B&K 2238 Mediator equipment (Brüel & Kjær Sound & Vibration Measurement A/S, Denmark) with the microphone 30 centimetres from the participants' lips. Channel 1 was calibrated for SPL measurements using a B&K calibrator. For channel 2, the acoustic signal was recorded with a headband microphone (AKG C 544 L, Acoustics, Austria, Vienna) placed 4 cm from the corner of the mouth. For channel 3, the oral pressure was recorded using a Glottal Enterprises manophone MS-110 and PT-25 pressure sensor (Glottal Enterprises Inc., Syracuse, NY). A silicone tube (length 4 cm, diameter 4 mm) was connected to the sensor. The participants were instructed to keep the tube between their lips so that the head of the tube did not touch any oral structures and the outer end of it was not directed towards the expiratory airflow. The oral pressure signal was calibrated using a Glottal Enterprises PC-1 calibrator.

TABLE 2.
Voice Tasks Included in the Study Protocol

	Sample
1.	[pa:]-syllable sequences on defined habitual pitch, produced as quietly as possible.
2.	[pa:]-syllable sequences with a higher pitch of 5 whole tones, produced as quietly as possible.
3.	[pa:]-syllable sequences with a defined habitual pitch, produced with habitual loudness.
4.	[pa:]-syllable sequences with a higher pitch of 5 whole tones, produced with habitual loudness.
5.	3 x prolonged (approx. 5-second-long) phonation on the Finnish vowel [a:].
6.	Reading of a standard text sample: *Pohjantuuli ja aurinko* (Finnish translation of *The North Wind and the Sun*).

Samples 1–4 were gathered for PTP analyses and samples 5–6 for AVQI analyses.

Analysis

Acoustic voice quality index (AVQI)

The recorded speech samples were transferred to the PRAAT program,[34] in which the Acoustic Voice Quality Index (AVQI version 03.01 for the Finnish population) was executed to analyse voice quality. For the AVQI, the first 31 syllables of the Finnish standard text *Pohjantuuli ja aurinko* (*The Northwind and the Sun* in Finnish) and a 3-second-sample of the sustained Finnish vowel [a:] were utilized (Table 2). The sustained vowel was manually extracted from the middle of the second prolonged vowel sample.

The AVQI is a multiparametric tool developed to objectively measure distorted voice quality and to differentiate distorted voices from healthy ones.[35] The value of the AVQI settles typically between 0−10. It measures six subcomponents to compose the final index: Smoothed Cepstral Peak Prominence (CPPs), HNR, Shimmer local (%), Shimmer dB, spectral Slope (Slope) and spectral Tilt (Tilt), from which it emphasizes the CPPs value.

The CPPs illustrates the prominence of the first cepstral harmonic in relation to the background noise.[36] HNR measures the relation of the periodic and aperiodic signal, and both shimmer values measure the irregular variation of signal amplitude from cycle to cycle.[37] Slope illustrates the distinction of spectral energy between the ranges of 0−1000 Hz and 1000−10 000 Hz, and Tilt illustrates the tilt of the regression line drawn between the aforementioned frequency ranges. An increased Tilt might indicate increased hypertension,[38] increased loudness of voice, or increased high-frequency noise.[39]

The AVQI version 03.01 has proved a valid instrument in measuring a disordered voice,[37,40] and it has been validated for various languages.[38,40,41] The diagnostic accuracy is high,[37,42] and reliability varies between studies from moderate to high.[37,40,43] However, the reliability[44] and sensitivity[45] might decrease when measuring only slightly disordered voices. Moreover, the subcomponents of the AVQI may be sensitive to the sound pressure level (SPL) used,[46,47] and SPL differences between the text and vowel samples used to calculate the AVQI may further distort the final AVQI.[39]

In the validation process of this newer version of AVQI for Finnish speakers, 197 participants including voice patients and healthy controls were studied.[38] The voice samples were perceptually assessed by 10 voice professionals. Further analysis (A_{ROC}) indicated a cutoff value of 1.83 to have the best discriminative power (sensitivity 81.3%, specificity 82.2%) for differentiating disordered voices from healthy ones. Language-specific validation is needed, since the scores, ranges, and cutoff values in AVQI depend greatly on the cohort and language studied.[48]

The AVQI is sensitive for intervention-induced changes in voice,[49,50] and it can thus be considered reliable in measuring treatment efficacy. However, there is some variability within subjects when measured repeatedly (eg. Pierce et al.[48]). This is naturally the case in all other parameters.

Phonation threshold pressure (PTP)

PTP is the lowest subglottal air pressure needed to initiate and maintain phonation.[51] Subglottal pressure can be estimated from the intraoral pressure during the voiceless plosive [p],[29] since the peak pressure measured during the occlusion phase of the plosive has been noted to be approximately equal to simultaneous subglottal pressure.[52] Therefore, when the [pa:] phonation is produced as quietly as possible, the PTP can be estimated from the intraoral pressure.

The participants repeated the syllable strings until correct pitch and loudness were reached (Table 2, voice tasks 1−4). The participants were instructed to produce the strings smoothly, connectedly and at a 180-bpm tempo. Intraoral pressure signals were collected and analysed with Key Pentax Computer Speech Lab (model 4500) equipment to estimate the PTP. The quietest [pa:]-syllable strings were detected from the acoustic signal with the PRAAT program. Subsequently, the strings with the lowest SPL values were selected for further examination. Two syllable strings from each three measurement points were selected, one produced at a conversational pitch, and one with a higher pitch.

The average PTP values were measured from the calibrated pressure graphs. The first and the last syllables were excluded from the estimate, since they were assumed to differ from other syllables in loudness, smoothness and stress. The PTP was estimated from the pressure graph, from the point where the signal reached a steady maximum during the [p] phoneme occlusion. To ensure the accuracy of the PTP estimate, the analyses were only made from the flat or slightly ascending pressure graphs.[53]

Six subjects were excluded from the data due to the deviant pressure graph shapes. The measurement accuracy in the PTP measurements was investigated so that one third of the samples (180 out of 540) was measured three times. The intra-rater reliability was strong (Pearson's r = 0.994–0.995, P = 0.000). The repeated measurements did not differ significantly from each other (related samples Friedman's two-way analysis of variance, Test statistics 5.312, df 2, asymptotic significance 0.07). The mean difference between the repeated measurements was 0.026 cH_2O and *sd* 0.099 cm H_2O. Thus, it may be concluded that a difference in PTP should be >0.1 cm H_2O in order to be considered a real difference and not a potential measurement error.

Subjective evaluations

The participants rated the perceived phonatory effort (PPE) and sensations of throat dryness after giving voice samples. Both characteristics were rated on a 10 cm visual analogue scale (VAS). The extreme ends were for the first 0 = no effort at all . . . 10 = great effort, and for the second 0 = very dry . . . 10 = not dry at all. The participants were not allowed to see their previous answers. The scores were measured with a precision of 0.1 centimetres, and the result was transferred to millimetres (0−100 mm) for statistical analyses. The values of the throat dryness were inverted to 0 = not dry at all . . . 100 = very dry for the presentation of the results.

Statistical analyses

Statistical analyses were executed with IBM SPSS Statistics for Windows, version 26 (IBM, Armonk, NY). The normality of the data distribution was tested with the Shapiro-Wilk test ($W = P > 0.05$), and deviant values were explored with boxplot figures and with studentized residuals of the analysis of variance (ANOVA).

The AVQI, its sub-parameters, PTP and PPE were normally distributed. For them, the *within-changes* in group values were calculated using two-way mixed ANOVA with repeated measures. Further analysis was made separately for each group, with repeated measures ANOVA, to recognize possible changes after the intervention. Differences *between groups* were measured with two-way mixed ANOVA. The results were verified with Bonferroni paired comparison and by examination of the main effects with Tukey HSD and repeated measures ANOVA. If the assumption of sphericity was violated, Greenhouse-Geisser correction was employed. The variable of *throat dryness* (skewed distribution) was analysed with Friedman's test (within-group changes) and the Kruskal−Wallis H-test (between-group differences). The results were presented with adjusted *P*-values, and *post hoc* tests were conducted with Bonferroni correction. The threshold for statistical significance was set at $P < 0.05$ in all the analyses.

Controlling the random variables

A digital meter was used to measure room and fluid temperatures and relative humidity (RH) in the laboratory. The mean room temperature was 22.8°C (accuracy ± 1°C, *sd* = 0.78), and there was a moderate correlation only with CPPs values in the E1 group (r = -0.68, P = 0.02). The mean RH was 42.4% (accuracy ± 4%, *sd* = 3.7), and there was no correlation between the RH and measured voice parameters ($P > 0.05$). The mean temperature of the heated water bath in the E1 group was 83.3°C (*sd* = 1.88), and the temperature of the saline in the E2 group was 21.8°C (*sd* = 0.25; measured from the bottle). There was no correlation between fluid temperature and the results of the voice parameters.

The mean SPL used in the voice samples for AVQI was 70.1 dB for the first (*sd* = 3.3), 70.7 dB for the second (*sd* = 3.20) and 71.2 dB for the third measurement point (*sd* = 2.81). According to the one-way ANOVA, there were no statistically significant differences between the groups, measured with the change in SPL between measurement points 1 and 2 or 1 and 3 ($P > 0.05$).

RESULTS

Baseline equivalence

One-way ANOVA was used to determine baseline equivalence. The groups were equal for PTP, PPE, subjective

TABLE 4.
The Values of the HNR and Tilt Results at Three Measurement Points for the Two Experimental Groups and the Control Group

	E1			E2			Control		
	Mean	Range	sd	Mean	Range	sd	Mean	Range	sd
HNR (dB)		n = 10			n = 11			n = 11	
Point 1	21.10	19.63−24.08	1.38	22.24	19.28−24.88	1.74	21.035	19.48−23.43	1.17
Point 2	21.40	19.27−23.92	1.58	23.04	19.46−26.03	1.97	21.73	21.73−22.74	0.90
Point 3	21.07	18.20−24.00	1.76	23.18	19.19−26.75	2.11	22.06	19.39−23.87	1.41
Tilt (dB)		n = 11			n = 11			n = 12	
Point 1	-12.14	-13.65 to -10.52	0.86	-12.18	-12.90 to -11.11	0.50	-11.83	-13.08 to -10.70	0.71
Point 2	-12.04	-13.69 to -10.79	0.90	-12.05	-12.80 to -11.15	0.75	-11.82	-13.07 to -10.78	0.73
Point 3	-11.96	-13.52 to -10.71	0.88	-11.92	-12.97 to -10.92	0.59	-11.72	-12.68 to -10.57	0.64

Measure 1 = prior to the intervention; Measure 2 = immediately after the intervention; Measure 3 = 15 minutes after the end of the intervention. The n-values presented in the Table represent the n-values after the delineation of the data.
Abbreviations: E1 and E2= experimental groups; Control= control group; sd= standard deviation.

evaluations, AVQI and its sub parameters ($P > 0.05$), except for Slope ($F(2, 29) = 3.56$, $P = 0.041$). For the background information, participants differed significantly only in age ($P < 0.05$, Table 1).

Acoustic voice quality index (AVQI)

AVQI values (including sub-parameters) at three measurement points are shown in the Appendix. The HNR values (Table 4) differed significantly between the groups ($F(2, 29) = 3.75$, $P = 0.036$, partial $\eta^2 = 0.205$), but there were no two-way interactions between the intervention and the measurement points. A *post hoc* test (Bonferroni) revealed a difference between the E1 and E2 groups' results ($P = 0.042$), which was localized at the third measurement point. There, the HNR was 2.1 dB lower in the E1 group than in the E2 group ($F(1, 19) = 6.09$, $P = 0.023$, partial $\eta^2 = 0.202$).

The HNR values were further adjusted to the SPL level at the third measurement point, but the between-group difference remained significant ($P = 0.044$). The control group did not differ significantly from the experimental groups in the HNR values.

Within-group changes were observed in the Tilt values ($F(2, 63) = 8.44$, $P = 0.001$, partial $\eta^2 = .383$; Table 4). The values increased in every group. The overall change was significant for the groups E1 ($F(2, 20) = 4.36$, $P = 0.027$, partial $\eta^2 = 0.304$) and E2 ($F(2, 20) = 4.37$, $P = 0.027$, partial $\eta^2 = 0.304$), but the localized difference was significant only for the E1 group between measurement points 1 and 3 ($P = 0.041$). Changes in Tilt values did not correlate with the SPL. For the control group, no significant changes were observed between the measurement points.

The other variables did not show significant changes, but some trends were found. The mean AVQI scores increased 0.11 through the measurement points 1 and 3 in the E1 group but decreased 0.06 in the E2 group and 0.24 in the control group. The changes of the CPPs in the groups were very small and somewhat dissimilar: the mean values increased in the E2 and control group but decreased in the E1 group. In the Shimmer % values, the trend for the E1 group was increasing through all three measurement points (mean change 0.11), while the trend for the control group was decreasing (mean change 0.43). In the E2 group, the values varied and the mean values at points 1 and 3 were the same.

PTP

No statistically significant differences were observed in the PTP values within or between the groups, but mean trends were observed. In the groups E1 and E2, the PTP increased between points 1 and 2, and decreased between points 2 and 3 (Table 5). The control group had a decreasing trend throughout the three measurements. Between points 1 and 2, the increase was observed in both the conversational and high-pitch voice samples. In the conversational pitch, the increase was greatest in the E2 group (+0.13 cm H_2O), while in the higher pitch, the increase was greatest in the E1 group (+0.22 cm H_2O).

For all the groups, the PTP value was lowest in the last measurement point. Between points 1 and 3, the PTP decreased most in the control group's conversational voice samples (-0.14 cm H_2O); in turn, for the high-pitch sample, the change was greatest in the E2 group (-0.16 cm H_2O). All individual changes exceeded the measurement error, which was 0.1 cm H_2O.

In the conversational pitch, individual PTP changes from the measurement point 1 to 2 ranged from -1 to +0.71 cm H_2O in the E1 group, from -1.07 to +0.33 cm H_2O in the E2 group, and from -0.84 to +0.70 cm H_2O in the control group. Individual changes from measurements 2 to 3 ranged from -0.37 to +0.80 cm H_2O in the E1 group, from -0.38 to +0.85 cm H_2O in the E2 group, and from -0.80 to +1.20 cm H_2O in the control group. *In the higher pitch*, the ranges of PTP changes from measurement point 1 to 2 were from -1.01 to +0.52 cm H_2O in the E1 group, from -0.30 to +0.39 cm H_2O in the E2 group, and from -0.70 to 1.28 cm H_2O in the control group. The changes from the measurements 2 to 3 were from -0.59 to +1.91 cm H_2O in the group E1, from -0.15 to +0.88 cm H_2O in the group E2, and from -0.63 to +1.38 cm H_2O in the control group.

Subjective evaluations

Statistically significant differences were not found between or within groups in the PPE. However, a *post hoc* test

TABLE 5.
PTP Results (cm H2O) in Two Different Pitches at Three Measurement Points

Group	Pitch	Measurement point 1		Measurement point 2		Measurement point 3	
		Mean	sd	Mean	sd	Mean	sd
E1	Conversational	2.51	0.84	2.55	0.44	2.41	0.53
	High	2.54	0.83	2.76	0.63	2.44	0.71
E2	Conversational	2.39	0.46	2.52	0.47	2.33	0.66
	High	2.66	0.47	2.67	0.47	2.50	0.49
Control	Conversational	2.70	0.79	2.62	0.69	2.56	0.57
	High	3.01	0.64	3.00	0.73	2.86	0.82

Measurement points 1 = prior to the intervention; 2 = immediately after the intervention; 3 = 15 minutes after the end of the intervention.
Abbreviations: E1 and E2= experimental groups; Control= control group; sd= standard deviation.

(Bonferroni) revealed significant differences within the groups E1 ($F(2, 18) = 6.170$, $P = 0.002$) and E2 ($F(2, 18) = 4.220$, $P = 0.031$) between measurements 1 and 3 (Table 6). The participants found they put less effort into their phonation 15 minutes after the end of the hydration treatment compared to the baseline situation. The decrease of the VAS value was 7.2 (range +5.0 to -26.0) for the E1 group and 10.2 (range -1.0 to -25.0) for the E2 group.

The sensation of the throat dryness decreased after the intervention in the E1 and E2 groups (Table 7). The VAS values were significantly different at the three measurement points for the groups E1 ($\chi 2(2) = 13.556$, $P = 0.001$) and E2 ($\chi 2(2) = 16.048$, $P < 0.0005$; Friedman's test). The Kruskal−Wallis H-test revealed differences between the groups at the second ($\chi 2(2) = 9.076$, $P = 0.011$) and third ($\chi 2(2) = 6.841$, $P = 0.033$) measurement points. According to the *post hoc* test, the values in the E2 group differed significantly from the control group's values at measurement points 2 ($P = 0.014$) and 3 ($P = 0.045$). The change in throat dryness between the points 1 and 3 was -7.45 (in VAS) for the E1 group and -16.5 for the E2 group.

DISCUSSION

The aim of this study was to assess the efficacy of the NHS waterpipe as a superficial laryngeal hydration treatment utilized in two different ways. The efficacy was measured instrumentally with the AVQI (v03.01) and PTP, and subjectively with PPE and sensations of throat dryness, at three time points (baseline, immediately after the treatment, and 15 minutes after the end of the treatment). Participants were randomized to three study groups: two experimental groups (E1 and E2) and a control group. The E1 group underwent a single five-minute hydration treatment with a waterpipe filled with 0.9% saline immersed in a cup of heated water. The E2 group received a similar hydration treatment but without the heating of the waterpipe. The control group received no treatment.

No significant within-group changes or between-group differences were observed after the intervention in AVQI value or its sub-parameters CPPs, Shimmer, or Slope. However, the spectral Tilt increased significantly after the intervention in both groups using the water pipe. The HNR values were also significantly higher in the participants that did not use heated saline (E2) than in those using it (E1), when measured 15 minutes after the end of the hydration treatment. In PTP, mean trends were observed. The PTP values increased immediately after the hydration in those using the waterpipe (E1 and E2), but the values decreased in the participants without vocal tract hydration (controls). After the 15-minute delay time, the PTP was lower in each group compared to the baseline values. Subjective throat dryness decreased significantly in both groups using the waterpipe (with or without heating) after the intervention, and the decrease was greater in the participants whose waterpipe was not heated (E2). Similarly, PPE decreased significantly 15 minutes after the intervention in the groups using the waterpipe, but the change was greater in the participants with the heated waterpipe (E1).

Treatment effects on the AVQI and PTP

AVQI

The effects of the hydration treatment on AVQI (v03.01) and its subparameters were somewhat against what one could expect on the basis of previous studies. According to Finkelhor and colleagues,[3] by adding low-viscosity fluid, such as saline, to the tissue, the viscoelastic properties should improve. Indeed, this relationship has been verified by earlier studies.[7,8] It has also been shown that acoustic analysis of the voice is able to reveal the alterations in the hydration status and thus changes in the viscosity of the tissue.[20]

The observed increase in the Tilt value in both experimental groups could result from increased adductory tension or SPL along with the measurements,[38] or from increased high-frequency noise in the samples.[39] However, the increased tension would also be expected to increase the Slope, CPPs[54] and perhaps HNR, which was not the case. Also, the SPL did not correlate with the Tilt values, implying that SPL was not the sole underlying factor either. It is therefore reasonable to suggest that high-frequency noise increased in the voices of the experimental groups, also increasing the Tilt values sensitive to it.

This speculation gains support from the study of Tyrmi and Ikävalko,[55] who found that Tilt decreased after vocal loading and increased after a recovery period. According to

TABLE 6.
The Values of the PPE (Change in VAS in mm) for Two Experimental Groups and Control Group at Three Measurement Points

	Scale 0 = no effort at all . . . 100 = great effort					
Group	Measurement Point 1		Measurement Point 2		Measurement Point 3	
	Mean	sd	Mean	sd	Mean	sd
E1	56.3	3.90	47.0	11.0	46.1	7.24
E2	51.5	6.44	53.5	7.48	44.3	12.06
Control	58.4	9.34	56.7	8.29	56.1	11.64

Measurement points 1 = prior to the intervention. 2 = immediately after the intervention. 3 = 15 minutes after the end of the intervention.
Abbreviations: E1 and E2= experimental groups; Control= control group; sd= standard deviation.

TABLE 7.

The Values of Throat Dryness (Measured in VAS in mm) for Two Experimental Groups and Control Group at Three Measurement Points

Scale 0 = not dry at all . . . 100 = very dry

Group	Measurement Point 1		Measurement Point 2		Measurement Point 3	
	Mean	sd	Mean	sd	Mean	sd
E1	50.3	15.3	41.0	19.3	42.9	15.2
E2	55.7	11.1	37.3	17.6	39.2	19.9
Control	58.7	11.3	56.5	15.36	57.7	17.3

Measurement points 1 = prior to the intervention, 2 = immediately after the intervention, 3 = 15 minutes after the end of the intervention.
Abbreviations: E1 and E2= experimental groups; Control= control group; sd= standard deviation.

the researchers, it was the high-frequency noise in the voice that decreased after vocal loading and increased after recovery, similarly altering the Tilt values. Thus, it is possible to speculate that the increased Tilt in the present study would reflect an increased amount of high frequency noise in the voice due to the increased amount of fluid on the vocal fold surfaces. After all, no such changes were observed in the control group.

The HNR values in the last measurement were higher in the group that used the waterpipe without heating rather than in those with heated fluid. In previous studies, the HNR values have either increased[20,27] or remained unchanged.[26,56] An explanation for this discrepancy could be that the baseline status of the participants affect how they benefit from the hydrating treatment. For example, Hemler and colleagues[56] stated that improving already optimal acoustic values with hydrating treatments is quite unlikely. In fact, this has been demonstrated in studies where dehydration is employed prior to the hydration treatment: after the hydration treatment, values tend to return to the baseline instead of increasing above it.[20,57] Further addition of fluid to a membrane already at optimal hydration status may then result in a temporary excessive fluid causing noisiness to the voice. This effect would eventually disappear when mucociliary transport[57] and the activity of the membrane ion channels[58] processed the additional fluid. The results of the present study may indicate that fluid was more efficiently transported to the laryngeal surfaces when the waterpipe was employed from the cup of heated water. This may distort the vibratory properties of healthy vocal folds momentarily, seen as a decrease in HNR.

The observed trends in the means of the AVQI, CPPs, and shimmer were also somewhat unexpected. The AVQI has typically decreased after hydration treatment,[27] indicating improved overall voice quality. Similarly, perturbation has been shown to decrease after treatment.[20,27] However, in a study by Zou and colleagues,[21] the acoustically measured quality of voice was reported to decrease when the hydration treatment was continued after reaching the optimal hydration status. Similarly, Vermeulen and colleagues[28] observed increasing perturbation values when superficial hydration was added to the systemic hydration treatment in healthy subjects. This again seems to suggest, as Hemler and colleagues argued,[56] that hydration treatment does not improve acoustic parameters of voice when the speaker's hydration status is already optimal.

Another issue to address is the one raised in the study by Huttunen and Rantala[27]: improvements in acoustic parameters were observed in individuals with voice disorders. It is possible that the baseline status of their mucosal hydration level differed from that of our healthy participants. They also used breathing exercises in addition to hydration treatment. Due to these facts, the results are not directly comparable. AVQI seems also to be somewhat less sensitive when measuring a healthy voice, as in the present study, compared to the voices of voice patients.[44] Thus, it would be important to include voice patients in studies to come to assess possible differences in treatment efficacy compared to healthy controls.

In general, the changes found in the parameters were small. On the other hand, all changes in the control group are statistically non-significant, while significant changes are found in the test groups, suggesting that the intervention has had an effect. Whether or not a change in a parameter is clinically meaningful is related to perception and functionality. While it has been shown that aperiodicities and noise are related to the perception of hoarseness,[59] it is difficult to give any exact limits for the smallest perceivable deviation or the smallest deviation that is possible to relate to the hoarseness rating (eg, Kreiman & Garret[60]).

Concerning the normal variability of acoustic measures, Pierce and colleagues[48] show test-re-test variability in AVQI and its sub-parameters for normophonic females. They found for instance the following variation ranges: AVQI 2.21-4.45, shimmer local 1.3−4.2, and shimmer dB 0.11−0.38. However, as they gave the other sub-parameter values separately for sustained vowel and connected speech, their results are not directly comparable with the results of the present study. The threshold value differentiating dysphonic voices from normophonic voices has been given for AVQI value (03.01 Finnish): >1.83.[38] Threshold values for sustained vowels include, eg, shimmer % >3.81, shimmer dB >0.35, and HNR <7 dB.[61] Moreover, Maryn et al[35] reported mean values for AVQI and its sub-parameters in normophonic and dysphonic voices. For instance, a mean value for Tilt was -10.51 dB (*sd* 0.73) in normophonic voices and -9.45 dB (*sd* 1.38) in dysphonic voices. Similarly, the HNR values were 22.92 dB (*sd* 2.09) and 18.66 dB (*sd* 4.71), respectively. However, Maryn et al[35] used the older version of AVQI.

In the present study, none of the mean values of the acoustic parameters changed to the extent that they would be considered abnormal. Even if some individual voices did obtain values over the AVQI threshold, studies show that normophonic speakers occasionally produce voices that can be considered acoustically abnormal.[48] There is also in general a great intra-individual variability in the quality of healthy voices.[62]

Regardless of the fact that acoustic values indicated a possible voice quality deterioration after the hydration treatment, the results could also be interpreted to show how well the fluid was transported to the surface of the vocal folds. This deterioration in the acoustic measures may be clinically insignificant, and the results thus suggest that a waterpipe is indeed effective in hydrating the vocal folds. This hydration effect seems to be more efficiently reached by immersing the pipe in heated water. This is most likely due to the fact that heated water adds vaporization to the pipe's fluid dispersion mechanism. In fact, during the five-minute treatment period, the heated saline escaped from the waterpipes (in the E1 group), which did not occur with the room-temperature saline (in the E2 group). However, it seems that employing the waterpipe solely without heating also provides a hydrating effect but without increasing the measured noisiness of the voice signal.

PTP

The PTP results were against our expectations, considering previous studies in the field.[26,29,30,63] Immediately after the hydration treatment, the PTP increased in both groups using the waterpipe, while in earlier studies the PTP has either decreased[26,29] or remained unchanged[19] after the hydration treatment. Thus, the results of the present study seem to suggest that vocal fold hydration with a waterpipe has a negative effect on phonation threshold pressure immediately after the intervention.

However, there are some methodological differences between the present study and earlier ones. In earlier studies, the PTP was not measured *immediately* after the hydration intervention. For example, Roy and colleagues[30] measured the PTP five minutes and Verdolini and colleagues[26] 15 minutes after the end of their interventions. In our study, the PTP was measured approximately one minute after the end of the intervention. In fact, when the results of this study are compared from the third measurement to the previous studies, the results seem more similar. There, the PTP was lower than at the baseline for all the groups. Moreover, the decrease in the PTP values were as great or even greater in the control group compared to the experimental groups. This may indicate that the decrease in the PTP observed in the third measurement could result from a rehearsal effect, not from the use of the waterpipe.

Furthermore, the increase in the PTP observed in the second measurement for the experimental groups indicates that the hydration treatment with the waterpipe had an overall effect on the PTP. albeit the effect was negative. This could indicate that fluid was transferred to the surfaces of the vocal folds. There, the excessive fluid could have increased the mass of the fluid layer and further affected the oscillatory properties of the tissue. Since no previous information about the immediate effect of the surface hydration intervention on PTP values is available, future research should address the possible consequences of this momentary build-up of excessive fluid, as well as its clinical relevance.

Treatment effects on the PPE and throat dryness

According to our results, using a waterpipe decreases the speakers' phonation effort more than if they were merely quiet. The positive effect was seen only 15 minutes after the end of the intervention. Significant differences were not detected between the experimental groups, which suggests that immersion in heated water does not produce a superior effect.

An association between the PPE and hydration does not seem to be clear. Verdolini and colleagues[26] noted a decrease in PPE after hydration, but the change was not significant. Tanner, Roy, Merrill and Elstad[31] in turn, observed an increase in PPE after the intervention, but the result was not significant either. The results by Roy et al[31] resemble ours. However, it is not clear if this momentary increase in the PPE in our study (from point 1 to point 2) is clinically meaningful, since the effect occurred only in group E2 and was not present 15 minutes after the intervention. Furthermore, while the mean changes exceeded the variability observed in the control group, some individuals did not report lower PPE after the hydration treatment.

The participants of the two experimental groups felt significantly less dryness in their throats after using the waterpipes, as has also been reported in earlier studies.[18,28] Furthermore, in the present study, the mean change in the experimental groups exceeded the variability observed in the control subjects. This suggests that the changes can be considered true and potentially clinically relevant, and that the waterpipe is indeed effective in remediating sensations of throat dryness even in the healthy population. However, it should be noted that not all the subjects reported remediation of the throat dryness, thus individual variability exists.

Interestingly, the effect of the treatment for throat dryness was superior in the group using the pipe with room-temperature saline (the E2 group). It has been shown that even small background differences in participants may affect how they benefit from a treatment.[56] This may explain our result regarding throat dryness, too. Although our experimental groups did not differ significantly, the throat dryness in the E2 group was slightly lower than in the E1 group before the intervention.

Another factor biasing the results of both PPE and throat dryness is the subjective nature of self-reported sensations. How well people are able to perceive their sensations is affected by their previous experiences.[18,19] It is also possible that inhaling heated air (such as in the E1 group) may produce different sensations from inhaling room-temperature air (E2 group). As Wolkoff[64] summarizes, humans have no separate sense that perceives solely dryness; the sensation of dryness is composed of multiple sensations. This is possibly also true for PPE. Thus, each of these may be perceived in different ways by different individuals, and this may be found in our results. It might also be that our participants anticipated favourable effects from the usage of the waterpipe, and thus overrated their sensations in both subjective evaluations. This could explain why the PTP did not change significantly, but the PPE did. The PPE and PTP have indeed been thought to be interconnected through the changes in tissue viscosity.[26]

Methodological considerations and recommendations for further studies

No measurable changes were noted in the PTP in the present study, and those found were on average small but still exceeded the margin of error in the measurements. The magnitude of the individual changes roughly corresponded to those reported in previous studies on the effects of surface hydration (mean 0.36 cm H_2O, *sd* 0.22 at comfortable pitch: 0.44 cm H_2O, *sd* 0.77 at high pitch).[11] It should also be noted that the reliability of the p-occlusion method for measuring PTP has been questioned, since it may require considerable amount of training before the subjects learn to reach the true threshold.[65] Indeed, a considerable variability in individual trials of PTP has also been shown in a meta-analysis study.[11] In order to improve the reliability of PTP measurements, a mechanical shutter technique or phonation into a thin straw, as suggested by Titze,[65] may be worth trying.

In the present study, there were different groups for different interventions. Although the baseline equivalence was demonstrated, it is likely that this was not assessed for all the possible intervening factors. One such factor might be the menstrual cycle of females, which, due to hormonal fluctuations, have been suggested to have an effect on vocal folds and voice.[66] This was not controlled for and might have placed the study groups in different starting positions at the baseline. The menstrual cycle should be considered and controlled for in future studies. Following studies could also employ a within-subjects design. This could reduce individual baseline differences, especially when the number of participants is small.

It is also critical to acknowledge the effect of vocal warm-up on the measures. In the present study, the voice tasks were not considered to be fatiguing or loading for healthy subjects. For a warm-up effect, the direction of acoustic changes (eg, in HNR) observed in the present study differed from those reported in the studies investigating vocal warm-up,[67] and PPE has not been reported to react to vocal warm-up treatments.[68] Thus, vocal warm-up alone does not explain the observed changes in this study.

Lastly, it is noteworthy that the present study employed a short-term intervention in measuring the efficacy. Further studies should measure the efficacy in the long term, for example after four weeks of daily usage. That is indeed how the waterpipe is expected to be used in clinical practice.

CONCLUSIONS

The hydration treatment did not have a statistically significant effect on the PTP, AVQI, or its sub-parameters CPPs, Shimmer, or Slope, when measured between or within study groups in vocally healthy female participants. However, the Tilt and HNR values of AVQI and the results of subjective measurements in this study yielded significant findings, which suggest that a waterpipe with 0.9% saline may be efficient in hydrating the vocal folds. Humidity seems to be somewhat more efficiently transported to the laryngeal region if the air inhaled through the waterpipe is heated; however, this adds some noisiness to the voice signal as measured with Tilt and HNR. It is not clear, however, if the noisiness is auditory-perceptually meaningful, since the changes were small. The waterpipe also appears to have an effect when the fluid is at room temperature; this way of using the device lessens the overall noisiness somewhat. Breathing humid air with or without heating decreases the degree of the perceived phonatory effort and eases the sensation of throat dryness.

CONFLICT OF INTEREST

The authors have no conflicts of interest in relation to this article.

FUNDING

No funding was provided.

ACKNOWLEDGMENTS

The authors wish to thank the laboratory technician Tero Ikävalko, MA, for his help in the voice laboratory, and the students from Tampere University for their time given to this research as participants.

APPENDIX. VALUES FOR THE AVQI AND ITS PARAMETERS FOR TWO EXPERIMENTAL GROUPS AND A CONTROL GROUP AT THREE MEASUREMENT POINTS

	E1				E2				Control			
	Mean	Min	Max	sd	Mean	Min	Max	sd	Mean	Min	Max	sd
AVQI												
1.	1.17	0.37	1.94	0.46	1.34	0.30	2.16	0.55	1.24	0.42	1.93	0.47
2.	1.26	0.03	2.37	0.76	1.20	0.28	2.19	0.62	0.96	0.22	1.47	0.50
3.	1.29	0.24	2.34	0.77	1.28	0.31	2.29	0.62	1.00	0.22	1.80	0.55
CPPs												
1.	13.85	12.16	15.05	0.80	13.53	11.80	15.49	1.04	13.60	11.30	15.20	1.29
2.	13.88	12.11	15.86	1.22	13.85	11.85	15.72	1.11	14.06	11.16	16.53	1.58
3.	13.71	11.76	15.88	1.41	13.81	11.94	15.10	1.08	14.11	11.79	16.59	1.50
HNR (dB)												
1.	21.10	19.63	24.08	1.38	22.24	19.28	24.88	1.74	21.05	19.48	23.43	1.17
2.	21.40	19.27	23.92	1.58	23.04	19.46	26.03	1.97	21.73	19.83	22.74	0.90
3.	21.07	18.20	24.00	1.76	23.18	19.19	26.75	2.11	22.06	19.39	23.87	1.41
Sh%												
1.	3.65	2.74	5.07	0.64	3.57	2.37	4.64	0.68	3.82	2.87	4.77	0.58
2.	3.73	2.69	4.93	0.76	3.31	2.43	4.32	0.64	3.71	2.69	5.07	0.69
3.	3.77	2.83	5.15	0.73	3.57	2.61	4.71	0.63	3.39	2.25	4.20	0.62
ShdB												
1.	0.39	0.33	0.45	0.04	0.37	0.30	0.46	0.05	0.39	0.31	0.45	0.04
2.	0.41	0.33	0.50	0.05	0.36	0.31	0.43	0.05	0.40	0.34	0.50	0.05
3.	0.40	0.32	0.53	0.06	0.39	0.29	0.46	0.05	0.38	0.29	0.45	0.05
Slope (dB)												
1.	-22.50	-24.49	-19.52	1.79	-24.88	-27.12	-22.26	1.37	-23.60	-28.17	-19.48	2.52
2.	-21.54	-24.72	-18.32	2.15	-25.03	-28.34	-21.78	2.41	-23.15	-28.14	-19.53	2.33
3.	-22.48	-25.35	-18.57	2.22	-25.84	-29.10	-22.35	2.23	-23.49	-28.74	-17.93	2.92
Tilt (dB)												
1.	-12.14	-13.65	-10.52	0.86	-12.18	-12.90	-11.11	0.50	-11.83	-13.08	-10.70	0.71
2.	-12.04	-13.69	-10.79	0.90	-12.05	-12.80	-11.15	0.75	-11.82	-13.07	-10.78	0.73
3.	-11.96	-13.52	-10.71	0.88	-11.92	-12.97	-10.92	0.59	-11.72	-12.68	-10.57	0.64

In the left column. each parameter and measurement points 1–3 is presented. Measures: 1. = prior to the intervention. 2. = immediately after the intervention. 3. = 15 minutes after the end of the intervention. sd = standard deviation.
Abbreviations: Control= control group; E1 and E2= experimental groups 2; Sh%= Shimmer %; ShdB= Shimmer dB.

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