The Effect of Superficial Hydration, With or Without Systemic Hydration, on Voice Quality in Future Female Professional Singers

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Summary: Objective. The aim of this study was to describe the effect of superficial hydration, with or without systemic hydration, on voice quality in future female professional singers by assessing acoustic and perceptual parameters of voice production as well as symptoms of vocal fatigue.

Study Design. This is an experimental design study.

Methods. A study was performed on a sample of 24 female voice majors to ascertain the effect of superficial hydration, with or without systemic hydration, on acoustic parameters and perception of vocal fatigue. The study replicated a prior study by van Wyk et al (2016) with some modifications; we looked at the effect of both systemic and superficial hydration independently and together on voice quality and vocal fatigue. Acoustic measurements including GRBASI, jitter, shimmer, F_0 MPT, frequency min and max, intensity min and max, and dysphonia severity index were measured along with perceived vocal fatigue using the Vocal Fatigue Index.

Results. A statistically significant increase in MPT values were obtained when comparing pre- and post-test results of the hypo hydrated ($P = 0.015$) and superficial hydration condition ($P = 0.004$). A significant increase in frequency min (Hz) within the hypo hydrated condition was also observed ($P = 0.019$). A significant increase was observed in the intensity min (dB) ($P = 0.010$) and F_0 min (Hz) ($P = 0.002$) within the combined hydration condition. Also, when superficial hydration was applied, mean shimmer % ($P = 0.016$), MPT (sec) ($P = 0.003$) and dysphonia severity index ($P = 0.020$) scores increased significantly in a between-group, post-test comparison. A significant reduction in mean intensity max (dB) ($P = 0.049$) and intensity min (dB) ($P = 0.018$) was also observed.

Conclusions. This study demonstrates that the use of superficial hydration results in positive outcomes of perceptual parameters of voice quality and symptoms of vocal fatigue in future female professional singers. However, mixed results were observed regarding the acoustic parameters of voice. The superficial hydration data is compelling enough to warrant implementing in a vocal hygiene protocol for singers.

Key Words: Future female professional singers−Phonotrauma−Superficial hydration−Vocal fatigue−Systemic hydration−Vocal hygiene.

INTRODUCTION

The human voice plays a vital role in effective communication. The significance of voice is even more evident when used as an occupational instrument.[1] Professional voice users (PVUs) rely on their voices as their ‘primary tool of trade’.[2,3] Yet, they exhibit the highest prevalence of voice disorders due to excessive vocal demands.[2,4,5] PVUs' depend on their voices to remain clear and stable throughout the working day,[6] although they are often exposed to a number of internal (loud talking, yelling, continuous voice use, stress, lack of vocal health awareness) and external (suboptimal room acoustics; background noise, vocal fold irritants) risk factors that may affect their vocal health.[7] Due to this increased exposure, the prevalence of voice disorders in the PVUs are increasing.[8] As a result, renewed focus has been placed on voice management and vocal health of the PVU.[9]

The professional singer is set apart from other voice professions as they require extensive vocal training to reach the highest levels of performance.[10] The conditioning of certain muscle groups in athletes is equally important as vocal exercise to the vocalist. If an athlete does not sufficiently train before a race, they are at risk of sustaining an injury. Similarly, inadequate practice, rehearsal and vocal training can result in vocal abuse and misuse.[11] Despite high vocal demands, singers often fail to consciously protect their voices.[12]

Singers regularly use their voices without adequate rest, in unfavourable environments, in an effortful manner, and do not allow sufficient time to recover after illnesses.[13] Singers are vulnerable to develop cumulative symptoms of vocal fatigue, resulting in an increase in effortful phonation due to a decrease in phonation abilities.[14] The sensation of chronic voice tiredness is a symptom of vocal fatigue and is associated with straining the larynx. Symptoms include restricted intensity and frequency ranges that are perceived as a change in voice quality.[15] It is therefore imperative that singers are trained in vocal hygiene to maintain healthy and

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efficient vocal mechanisms.[16−18] Without appropriate vocal hygiene training, singers are at risk of cumulative phonotrauma which, if unrelenting, will lead to voice disorders or vocal fold pathologies.[19] Singers with voice disorders may experience hoarseness, asthenia, variation in fundamental frequency, decreased volume and projection, low resistance when speaking, decreased vocal efficiency and vocal fatigue.[20] Such voice change may be physically and psychologically debilitating for the singer, as it may affect their ability to work.[21] It is thus recommended that preventative strategies, such as vocal hygiene programmes, are used to lower the risk of voice disorders in the PVU.[22] Often the most prescribed method of improving vocal hygiene is by increasing hydration levels.[23] Despite the fact that hydration has always been considered in vocal hygiene programs, the effect of hydration on voice quality has been understated.[10]

The concept of vocal fold hydration is generally understood as either systemic (intracellular water) or superficial (water being present in the vocal fold mucosa) and clinical voice management aims to improve both in order to attain optimal vocal efficiency.[24] Systemic hydration is when water is consumed orally and absorbed at cellular level. The internal vasculature of the vocal folds, regulate the fluid composition, whereas superficial hydration is reliant on the humidity of inhaled air.[25] Superficial hydration of the vocal mucosa and laryngeal epithelia is achieved through ion transport channels that control trans-epithelial water fluxes. This sustains the fluid layer necessary for local lubrication and optimal vocal fold vibratory patterns.[25] Maintaining adequate vocal fold hydration also protects epithelial cells against inhaled bacteria and irritants.[26] Although both biological hydration mechanisms are believed to maintain vocal fold vibration and optimal voice quality, the exact processes responsible for their joint influence are not fully understood.[27]

When professional singers do not hydrate adequately, dehydration leads to the mucus layer on the vocal folds becoming thick and viscous, simultaneously increasing the weight and dryness of the vocal folds, impeding smooth vibratory patterns, and elevating vulnerability to vocal injury.[28] Lubricated vocal fold mucosa necessitates less subglottic air pressure compared to when the vocal mechanism is dry, thus sufficient surface hydration is essential to optimal vocal fold oscillation. The minimum subglottic air pressure required to activate vocal fold oscillation is termed phonation threshold pressure (PTP).[29] It is widely understood that decreased PTP reflects a reduced amount of effort and stress placed on the vocal mechanism.[30] In a recent systematic review, it was determined that when the vocal folds become desiccated due to insufficient systemic hydration, adverse effects on noise-to-harmonics ratio, shimmer, jitter, frequency, and the s/z ratio can be seen. In turn, water intake led to substantial improvements in shimmer, jitter, frequency, and maximum phonation time.[31]

The application of superficial hydration through the use of nebulisers, humidifiers, and steam inhalation, has been common practice as a means to maintain optimal voice quality over the years.[27] Clinicians recommend the application of nebulisation, humidification and/or steam inhalation to inhibit vocal fold drying.[24] Despite the fact that these recommendations have grown popular amongst professional voice users, the underlying mechanisms contributing to maintaining adequate vocal fold hydration are in question.[27,32,33] Thus, the validity of these clinical recommendations must be questioned and substantiated by current evidence-based research.

Although many studies have scrutinized the outcome of superficial hydration in various vocal measures, few have examined its effects in singers. Three previous studies aimed to determine the influence of superficial hydration on the functioning of the vocal folds in singers.[27,34,35] Conversely, opposing findings have been reported. There is a definitive effect of dehydration on various aspects of voice acoustics shown; yet contradictory or simply nonsignificant changes are present on the effects of rehydration.[1,27,33,36−38] Prior studies have mainly concentrated on the effect of hydration on PTP and PPE and not on the acoustic parameters of the voice or voice quality.[32] Thus, it is of vital importance to determine if increased superficial hydration is justified as an approach to improving vocal quality in future female professional singers, as well as in vocal hygiene recommendations for the prevention and intervention of voice disorders.

Evidence suggests that if both systemic and superficial hydration levels are increased it is possible that voice production may benefit. Despite this emerging knowledge, strong evidence for positive outcomes of superficial hydration treatments is lacking.[28] Studies on PVU with vocal training, such as singers, are often overlooked.[38]

It must also be noted that previous research has mostly focused on male singers and have neglected superficial hydration outcomes in females, the population who are more vulnerable to the effects of dehydration on the vocal folds.[34,39−41] Therefore, more scientific knowledge is required to improve the performance as well as the occupational health of this group.[42] It is also imperative to gain better insight into the use of systemic and superficial hydration in vocal hygiene programs.[38] This study hypothesizes that an increase in superficial hydration will significantly improve the perceptual and acoustic characteristics of the future female professional voice, and more so with accompanied systemic hydration. In light of the information provided thus far, the following research questions are posed:

1. What is the effect of superficial hydration, with or without systemic hydration, on voice quality in future female professional singers?
2. What is the effect of superficial hydration on perceived vocal fatigue (VF) in future female professional singers?

METHOD

Aim

The aim of this study was to describe the effect of superficial hydration, with or without systemic hydration, on voice quality in future female professional singers.

Research design

A within-subject, experimental, two group comparative, pretest post-test research design was applied where female voice majors between the ages of 18 and 32 acted as their own control.

Participants

A purposive sample of 24 females with an average age of 21.38 years (*SD* = 2.60), enrolled for singing at, or alumni from the Department of Music, University of Pretoria, were selected to take part in the study. Limiting the gender of the participants will allow for the elimination of confounding variables related to gender-based differences in fundamental frequencies of voice range profiles (VRPs). The dysphonia severity index (DSI) is significantly influenced by an increase in age; therefore, a maximum age of 32 years was set.[43] The use of a homogeneous population promotes external validity and therefore trustworthiness of research outcomes.

Only singers who were not diagnosed with previous voice disorders by an otolaryngologist (ENT) or current infection or disease affecting vocal fold functioning were included, as these would have influenced perceptual and acoustic results. Factors that may have influenced voice quality such as allergies, gastroesophageal reflux disease , sinusitis, and so forth, were not regarded as exclusion criteria, but were taken into consideration. Seven participants (29.2%) reported having an allergy; namely anaesthesia, pet hair, dust, peanuts, caffeine and/or codeine. Six participants (25.0%) reported gastroesophageal reflux disease, five (20.8%) reported sinusitis and eleven (45.8%) were on prescribed medication. It was also considered that three participants (12.5%) were smokers. A significant reduction of the DSI and fundamental frequency and a reduced MPT has previously been observed in female smokers and should therefore be taken into consideration.[44]

Participants were randomly assigned to two experimental groups of 12 (superficial hydration only n = 12 and superficial and systemic hydration combined n = 12) and acted as their own control (hypo hydration n = 24).

Control and experimental conditions

Control conditions (hypo hydration)

The participants were required to refrain from alcoholic and carbonated drinks twelve hours prior to testing. They were allowed to eat their regular breakfast, but not within 2 hours prior to testing.[38] Those who were in the control group on a given day were not allowed to ingest any fluids 2 hours prior to singing, nor during the 2-hour rehearsal. Participants were asked to sign an adherence letter before testing to measure consistency of adherence to the stipulated conditions to ensure fidelity.

Experimental conditions

Systemic hydration schedule. The systemic hydration schedule used in the study was followed by the participants in the combined superficial and systemic hydration experimental group. Similar to control conditions, participants were required to refrain from alcoholic and carbonated drinks 12 hours prior to singing. Participants were asked to only consume 1 cup of a caffeinated beverage as contrary to popular belief, caffeine is allowed in moderation as a conservative amount will not negatively affect voice production.[31] They were allowed to eat their regular breakfast, but not within 2 hours prior to singing.[38] Founded on a pharmacokinetic analysis where it has been reported that complete absorption of water in the plasma and blood cells occurs within 75−120 minutes after ingestion.[45] In the schedule, it was stipulated that the participants were only allowed to commence drinking water 30 minutes prior to singing. They were required to drink 500 mL of bottled water (Nestle Pure Life Mineral Water) during the 1-hour rehearsal, focusing on drinking approximately 250 mL/30 minutes of singing. This notion is supported by previous research that reported significant improvement in voice parameters when ingesting water during rehearsal.[46]

Superficial hydration schedule. The superficial hydration schedule used in the study was followed by the participants in both experimental groups. This was implemented through each of the participants receiving 3 mL of nebulised isotonic saline (a salt solution that has the same osmotic pressure as bodily fluids) (0.9% NaCI) before, in a 5-minute break in the middle of as well as after the 1-hour signing rehearsal. The nebuliser used for this study was a CA-MI Flo Eolo Nebuliser This is a piston compressor nebuliser designed for nebulisation therapy. The Eolo operating pressure is 1.1 Bar 16 psi 110 kPa, the maximum airflow is 51/min. Standard infection control procedures were implemented through each participant receiving their own mask and tubing that remained sealed until use.

Voice assessment protocol

A case history questionnaire was provided and completed to best gather the participant's voice histories regarding the information including age, level of voice training, general heath (reflux and allergies), medical history, and vocal habits (smoking, alcohol consumption, and vocal abuse).

Participants were also asked to complete the vocal fatigue index (VFI)[47] twice for comparison of self-perceived vocal fatigue. Participants completed the VFI after control and experimental conditions. This index aimed to reliably identify those suffering from vocal fatigue. The VFI is a 19-question scale used to quantify the amount of vocal fatigue suffered by a given individual and discriminate between those with dysphonia and those without. Participants rated 19 voice statements (eg "My voice feels tired when I talk more") according to how applicable they were to them and their voice. Ratings were from 0−4, 0 being never and 4 being always. Three factors were examined relating to vocal fatigue due to questions being separately aimed at 1. Tiredness of voice, 2. Physical discomfort and, 3. Improvement of symptoms with rest. With factors 1 and 2 increased vocal fatigue was indicated by a higher score. Inversely, with factor 3 an increased score indicated decreased vocal fatigue.[47]

Perceptual and acoustic voice parameters were measured in both pre- and post-test assessments. A pretest was conducted after which participants were required to carry out a 1-hour routine classical singing rehearsal and immediately thereafter, the post-test was conducted.

All perceptual analysis of voice was conducted within a sound proof voice laboratory by the researcher. The GRBASI 4-point Rating[48] was used to rate the perceptual quality of the participant's voices as they read the phonetically balanced rainbow passage,[49] and sang 5 repetitions of the C Major five finger scale. Audio recordings of the voices of each participant were made using the Ashampoo Music Studio 5 Voice Recording Software, recording in MP3 format. The recorder was held at a fixed distance of 30 cm from the mouth to obtain the most consistent results across different participants and to obtain optimal quality recordings.[9,13] A listeners panel of five qualified speech-language therapists was used to score the perceptual data as a previous study on the reliability in perceptual analysis of voice quality, found that even when a small number of listeners are used, inter-rater reliability remains high.[50] The voice recordings were presented in random order to remove bias. Each member of the panel of listeners gave a rating for each component of the GRBASI scale and consensus was reached by majority vote for each component. Thus, the use of an uneven number of listeners eliminated the possibility of a split-vote. Due to the listeners panel being blind to which recordings are from which group of experimental or control conditions this increased the objectivity and reliability of the perceptual measures. Majority consensus was reached through independent scoring in a quiet room, of all 96 samples, in one session.

The maximum phonation time (MPT) of all participants was taken using the steady state vowel /a/ after maximum inspiration and the best time over three repetitions were recorded. MPT was considered normal when greater than or equal to 15.1 seconds.[51]

Multidimensional voice program analysis and tVRP of the computerized speech lab (CSL) (MODEL 4105B; KayPENTAX) was conducted on all the participants in a sound-proof voice laboratory. Acoustic analysis of the voice was accomplished using a microphone set at 10 cm away from the mouth. The multidimensional voice program analysis was used to evaluate the jitter (*jitt %*), shimmer (*shim %*), fundamental frequency variation (vF_0) and noise-to-harmonics ratios of each participant. The VRP depicted the participant's minimum and maximum volume and pitch capacities across their vocal range.

The DSI, a multi-parametric tool, was employed to generate an objective vocal quality score based on acoustic results.[43] A score was then generated using the maximum phonation time (MPT in seconds), highest frequency (Hz), lowest intensity (dB) and jitter (%).The following set of voice measurements was taken into consideration when calculating the DSI (as per the equation below); maximum phonation time (MPT in seconds), highest frequency (F_0(F_0high in Hz), lowest intensity (I—low in dB), and jitter (%) (KayPENTAX, 2008).

$$\mathrm{DSI} = 0.13 \times \mathrm{MPT(s)} + 0.0053 \times F_0\Big(-\mathrm{High(Hz)} - 0.26 \times \mathrm{I} - \mathrm{Low(dB)} - 1.18 \times \mathrm{Jitter(\%)} + 12.4\Big)$$

Adult norms indicate that values of DSI > 0 are normal, while values in the range of −5 < DSI < 0 may be considered either severely, moderately, or mildly dysphonic. These norms were used as a guideline.[52]

Data analysis

The statistical software programme SPSS was used in all data analyses. Since the sample size was less than 50, the Shapiro-Wilk's statistic was used instead of the Kolmogorov-Smirnov statistic in order to test for normality. If the *P* value (significance level (Sig.)) is greater than 0.05, then normality is assumed. Since many of the *P*-values are less than 0.05, for many of the variables considered in this study, normality cannot be assumed for all variables. Thus, nonparametric methods were used in this study.

For continuous variables, the Wilcoxon signed-rank tests were used to determine statistically significant differences for related samples, for example, it was used for the comparisons between pretest and post-test for a specific group. For continuous variables, the Mann-Whitney *U* test was used to determine statistically significant differences for independent samples, for example, it was used for the superficial hydration only group and combined hydration group comparisons. For frequencies (counts) the Fisher's Exact tests were used in order to determine whether the frequencies differed statistically significantly from each other.

Since the GRBASI data is Likert-type ordinal data, the Mann-Whitney test was used to test for statistically significant differences between the independent groups (superficial vs combined) and the Wilcoxon signed-rank test was used to test for statistically significant differences between the related groups (control vs superficial and control vs combined). Since none of the *P* values was less than 0.05, it shows that, although there were some differences, they are not statistically significant.

RESULTS

Participants reported that on average they rehearse 10 hours (*SD* = 5.51) a week and the majority of (87.5%, n = 21) of participants reported a negative change in their voices after rehearsals; namely breathiness (n = 6), painful voice production (n = 2), grade of voice disorder (n = 12), roughness (n = 5), loss of voice (n = 3), generally softer voice (n = 7) or weaker voice on certain pitch levels (n = 5).

In Table 1, Fisher's Exact tests were used in order to determine whether the frequencies differed statistically significantly from each other. Only the frequencies and the *P* values are presented for brevity. If the *P*-value is less than

TABLE 1.
Frequency Distribution of GRBASI Scores

(Control n = 24, Superficial n = 12 & Combined n = 12)

GRBASI	Condition		Normal (Score = 1)	Slight (Score = 2)	Moderate (Score = 3)
Grade of voice disorder	Hypo hydration	Pretest	83% (n = 20)	17% (n = 4)	0% (n = 0)
		Post-test	50% (n = 12)	46% (n = 11)	4% (n = 1)
		P value	0.030*	0.060	1.000
	Superficial hydration	Pretest	75% (n = 9)	25% (n = 3)	0% (n = 0)
		Post-test	75% (n = 9)	25% (n = 3)	0% (n = 0)
		P value	1.000	1.000	-
	Combined hydration	Pretest	58% (n = 7)	33% (n = 4)	8% (n = 1)
		Post-test	50% (n = 6)	50% (n = 6)	0% (n = 0)
		P value	1.000	0.680	1.000
Roughness	Hypo hydration	Pretest	92% (n = 22)	8% (n = 2)	0% (n =0)
		Post-test	63% (n = 15)	37% (n = 9)	0% (n = 0)
		P value	0.036*	0.036*	-
	Superficial hydration	Pretest	58% (n = 7)	42% (n = 5)	0% (n = 0)
		Post-test	67% (n = 8)	33% (n = 4)	0% (n = 0)
		P value	1.000	1.000	-
	Combined hydration	Pretest	75% (n = 9)	17% (n = 2)	8% (n = 1)
		Post-test	67% (n = 8)	33% (n = 4)	0% (n = 0)
		P value	1.000	0.640	1.000
Breathiness	Hypo hydration	Pretest	83% (n = 20)	17% (n = 4)	0% (n = 0)
		Post-test	83% (n = 20)	17% (n = 4)	0% (n = 0)
		P value	1.000	1.000	-
	Superficial hydration	Pretest	75% (n = 9)	25% (n = 3)	0% (n = 0)
		Post-test	100% (n = 12)	0% (n = 0)	0% (n = 0)
		P value	0.217	0.217	-
	Combined hydration	Pretest	50% (n = 6)	50% (n = 6)	0% (n = 0)
		Post-test	100% (n = 12)	0% (n = 0)	0% (n = 0)
		P value	0.014*	0.014*	-
Asthenia	Hypo hydration	Pretest	96% (n = 23)	4% (n = 1)	0% (n = 0)
		Post-test	83% (n = 20)	13% (n = 3)	4% (n = 1)
		P value	0.348	0.609	1.000
	Superficial hydration	Pre test	83% (n = 10)	17% (n = 2)	0% (n = 0)
		Post-test	83% (n = 10)	17% (n = 2)	0% (n = 0)
		P value	1.000	1.000	-
	Combined hydration	Pretest	92% (n = 11)	8% (n = 1)	0% (n = 0)
		Post-test	92% (n = 11)	8% (n = 1)	0% (n = 0)
		P value	1.000	1.000	-
Strain	Hypo hydration	Pretest	96% (n = 23)	4% (n = 1)	0% (n = 0)
		Post-test	88% (n = 21)	8% (n = 2)	4% (n = 1)
		P value	0.609	1.000	1.000
	Superficial hydration	Pretest	100% (n = 12)	0% (n = 0)	0% (n = 0)
		Post-test	100% (n = 12)	0% (n = 0)	0% (n = 0)
		P value	1.000	-	-
	Combined hydration	Pretest	92% (n = 11)	8% (n = 1)	0% (n = 0)
		Post-test	83% (n=10)	17% (n=2)	0% (n=0)
		P-value	1.000	1.000	-
Instability	Hypo hydration	Pretest	92% (n = 22)	8% (n = 2)	0% (n = 0)
		Post-test	92% (n = 22)	4% (n = 1)	4% (n = 1)
		P value	1.000	1.000	1.000
	Superficial hydration	Pretest	75% (n = 9)	25% (n = 3)	0% (n = 0)
		Post-test	92% (n = 11)	8% (n = 1)	0% (n = 0)
		P value	0.590	0.590	-
	Combined hydration	Pretest	75% (n = 9)	25% (n = 3)	0% (n = 0)
		Post-test	83% (n = 10)	17% (n = 2)	0% (n = 0)
		P value	1.000	1.000	-

* Significance level: $P < 0.05$.

0.05, there is a statistically significant difference in the frequencies. The only significant perceptual differences (Table 1) observed between the pre- and post-test results were in the hypo hydrated, and combined hydration conditions. In the hypo hydration group G (grade of voice disorder) was significantly increased (P = 0.030) as eleven participants (46%; n = 11) present with slight, and one participant (4%; n = 1) with moderate G (grade of voice disorder) at post-test. Similarly, R (roughness) also significantly increased in the hypo hydration condition (P = 0.036) as 92% (n = 22) of the participants roughness levels were perceived as normal at pretest and 37% of participants (n = 9) present with slight roughness at post-test. In the combined hydration group B (breathiness) was significantly decreased (P = 0.014) as half of the participants (50%; n = 6) presented with slight breathiness at pretest and all of the participants (100%; n = 12) were scored as "normal" at post-test.

When comparing the change between pre- and post-test of MPT of both hypo hydration and superficial hydration conditions, using the Wilcoxon signed-rank tests, a significant increase in duration was noted in both conditions (P = 0.015 and P = 0.004, respectively) (Table 2). Significant increases between the pre- and post-test within the hypo hydrated condition was also observed in frequency min (Hz) (P = 0.019) (Table 2). When comparing pre- and post-test results within the combined hydration condition, significant differences were observed in the intensity (dB) min (P = 0.010) and F_0(Hz) min (P = 0.002) as both increased from pre- to post-test (Table 2).

For the between-group comparisons, Mann-Whitney tests were run. There is no table for the pretest results, as there were no significant differences between the groups pretest. Between-group, post-test comparisons, using the Mann-Whitney tests, (Table 3) revealed significant differences between the control group and superficial hydration groups only. Outcomes show that where superficial hydration was applied mean shimmer % (P = 0.016), MPT (sec) (P = 0.003), and DSI (P = 0.020) scores increased significantly (Table 3). A significant reduction in mean intensity (dB) max (P = 0.049) and intensity (dB) min (P = 0.018) was observed, (Table 3). No significant differences were found between the control group and combined hydration group or when comparing the two experimental conditions, superficial and combined hydration.

The Vocal Fatigue Index outcomes (Table 4) show that the mean values of perceived vocal fatigue Factors 1 and 2 decreased insignificantly with superficial hydration compared to control condition, indicating slightly reduced vocal fatigue in the forms of tiredness of voice and physical discomfort when superficial hydration is introduced. Both factor 1 (P = 0.044) and 2 (P = 0.029) were however, significantly decreased in the combined hydration group when compared to the control condition. It must also be noted that when comparing the experimental conditions for Factor 1, the combined hydration group had significantly (P = 0.016) decreased perceived vocal fatigue when compared to superficial hydration group.

TABLE 2.
Acoustic Parameter Outcomes and Pretest -Post-test Comparisons

(Control n = 24, Superficial n = 12 & Combined n = 12)

	Hypo Hydration			Superficial Hydration			Combined Hydration		
Acoustic Parameters	Pretest Mean (SD)	Post-test Mean (SD)	P Value	Pretest Mean (SD)	Post-test Mean (SD)	P Value	Pretest Mean (SD)	Post-test Mean (SD)	P Value
Jitter%	0.93 (0.77)	0.79 (0.59)	0.219	1.07 (0.75)	0.90 (0.66)	0.583	0.87 (0.42)	0.59 (0.39)	0.060
Shimmer%	3.86 (2.02)	3.29 (1.84)	0.253	3.74 (1.30)	4.73 (2.52)	0.182	3.30 (1.52)	3.13 (1.59)	0.583
F_0 (Hz)	2.47 (3.89)	1.21 (0.72)	0.157	2.05 (2.20)	3.42 (8.30)	0.388	1.28 (0.65)	3.59 (8.51)	0.480
MPT (sec)	14.92 (4.38)	15.88 (3.96)	0.015*	15.00 (3.72)	18.83 (5.67)	0.004*	15.75 (2.77)	17.42 (4.48)	0.065
Frequency (Hz) Max	938.85 (173.54)	945.32 (221.03)	0.986	924.42 (212.43)	993.64 (279.19)	0.721	948.29 (117.86)	1077.37 (241.09)	0.286
Frequency (Hz) Min	138.02 (33.70)	157.20 (37.59)	0.019*	151.35 (17.69)	163.17 (34.95)	0.374	141.86 (42.35)	153.46 (44.18)	0.456
Intensity (dB) Max	103.42 (5.81)	104.63 (5.17)	0.302	100.42 (6.23)	100.67 (7.61)	0.953	103.50 (5.71)	103.17 (7.44)	0.475
Intensity (dB) Min	57.63 (6.53)	60.04 (4.90)	0.152	57.67 (3.92)	58.50 (4.74)	0.623	56.17 (4.71)	59.33 (5.25)	0.010*
F_0 (Hz) Max	827.34 (150.55)	768.57 (178.19)	0.194	858.72 (209.92)	839.25 (200.64)	0.182	791.09 (130.45)	804.02 (180.43)	0.433
F_0 (Hz) Min	185.69 (101.04)	188.53 (74.57)	0.415	216.36 (77.35)	217.91 (105.96)	0.814	188.55 (107.02)	213.93 (95.62)	0.002*
DSI	3.11 (1.69)	2.89 (2.24)	0.558	3.09 (2.10)	3.96 (2.17)	0.308	3.82 (1.32)	4.30 (2.64)	0.609

* Significance level: $P < 0.05$.

TABLE 3.
Acoustic Parameter Between-Group Post-test Comparisons

(Control n = 24, Superficial n = 12 & Combined n = 12)

	Control vs. Superficial			Control vs. Combined			Superficial vs. Combined		
Acoustic Parameters	Mean (SD)	Mean (SD)	*P* Value	Mean (SD)	Mean (SD)	*P* Value	Mean (SD)	Mean (SD)	*P* Value
Jitter%	0.79 (0.59)	0.90 (0.66)	0.733	0.79 (0.59)	0.59 (0.39)	1.000	0.90 (0.66)	0.59 (0.39)	0.141
Shimmer%	3.29 (1.84)	4.73 (2.52)	0.016*	3.29 (1.84)	3.13 (1.59)	0.718	4.73 (2.52)	3.13 (1.59)	0.053
F_0 (Hz)	1.21 (0.72)	3.42 (8.30)	0.622	1.21 (0.72)	3.59 (8.51)	0.520	3.42 (8.30)	3.59 (8.51)	0.623
MPT (sec)	15.88 (3.96)	18.83 (5.67)	0.003*	15.88 (3.96)	17.42 (4.48)	0.094	18.83 (5.67)	17.42 (4.48)	0.977
Frequency (Hz) Max	945.32 (221.03)	993.64 (279.19)	0.123	945.32 (221.03)	1077.37 (241.09)	0.652	993.64 (279.19)	1077.37 (241.09)	0.369
Frequency (Hz) Min	157.20 (37.59)	163.17 (34.95)	0.240	157.20 (37.59)	153.46 (44.18)	0.557	163.17 (34.95)	153.46 (44.18)	0.467
Intensity (dB) Max	104.63 (5.17)	100.67 (7.61)	0.049*	104.63 (5.17)	103.17 (7.44)	0.291	100.67 (7.61)	103.17 (7.44)	0.247
Intensity (dB) Min	60.04 (4.90)	58.50 (4.74)	0.018*	60.04 (4.90)	59.33 (5.25)	0.898	58.50 (4.74)	59.33 (5.25)	0.772
F_0 (Hz) Max	768.57 (178.19)	839.25 (200.64)	0.496	768.57 (178.19)	804.02 (180.43)	0.765	839.25 (200.64)	804.02 (180.43)	0.908
F_0 (Hz) Min	188.53 (74.57)	217.91 (105.96)	0.569	188.53 (74.57)	213.93 (95.62)	0.359	217.91 (105.96)	213.93 (95.62)	0.620
DSI	3.11 (1.69)	3.96 (2.17)	0.020*	3.11 (1.69)	4.30 (2.64)	0.782	3.96 (2.17)	4.30 (2.64)	0.817

* Significance level: $P < 0.05$.

DISCUSSION

This study examined the effect of superficial hydration, with or without systemic hydration, on voice quality in a population (n = 24) of future female professional singers. For perceptual analysis, the grade of voice disorder and roughness indicated that lack of hydration had a significant effect on voice quality (P = 0.030 and P = 0.036, respectively). Half (n = 12) of the participants were identified with a perceptually increased grade of voice disorder after the singing rehearsal in the hypo hydrated condition. Increased perceptual roughness was also present in 46% (n = 11) of participants after vocal performance in hypo hydration. This deterioration in perceptual voice quality may be an indication of vocal fatigue.[46] Similar findings were reported in a previous study on Indian men where no hydration was provided. An increase in grade of voice disorder was noted on the GRBAS scale following an oral reading vocal loading task.[53] In contrast, another study examining the effects of vocal load without hydration on perceptual quality of voice in vocally healthy females documented a significant decrease in breathiness observed, suggesting an improvement of voice subsequent to loading regardless of applied hydration.[54]

It was also found, that perceptual breathiness was significantly reduced (P = 0.014) in all (n = 24) participants in the combined hydration group where both superficial hydration and systemic hydration was applied. This serves to question whether the positive change in decreased breathiness seen in the current study is due to the applied hydration or simply caused by the vocal loading task itself, a 1 hour classical signing rehearsal. In a recent study examining the effect of systemic hydration on the vocal quality of future professional vocal performers GRBASI scores revealed a statistically significant increase (P = 0.046) for the grade of voice disorder measure in the hypo hydrated group in comparison to the hydrated group.[38] Conversely, no detectable auditory perceptual differences in voice quality were previously reported, between systemically hydrated and hypo hydrated conditions, when 20 untrained singers were subjected to extended karaoke singing.[46] The perceptual results obtained in the current study support the hypothesis that increased hydration, in the form of both superficial and systemic hydration combined, decreased perceptual breathiness in the performing singer. Inadequate hydration may conversely lead to increased perceptual grade of voice disorder and roughness in vocal quality.

It is possible that the effect of vocal fatigue contributed to the following changes in acoustic parameters; A significant increase in Frequency Min (P = 0.019) in hypo hydration from pretest to post-test indicates a reduction in the singer's ability to reach lower notes and therefore a deterioration of vocal range when the vocalist is inadequately hydrated. Average Intensity (dB) Min and F_0 (Hz) Min also increased significantly in the combined hydrated condition from pretest to post-test (10.1% and 00.0% respectively).The percentage change for Intensity (dB) Min and F_0 (Hz) Min increased with 5.6% and 23.0%, respectively. As previously

TABLE 4.
Outcomes and Comparisons for Individual Factors on the VFI for Hypo hydrated, Superficial Hydration and Combined Hydration

(Control n = 24, Superficial n = 12& Combined n = 12)

	Mean (SD)		
Condition	Factor 1. Tiredness of Voice	Factor 2 Physical Discomfort	Factor 3 Improvement of Symptoms with Rest
Hypo hydration	21.83 (9.13)	7.5 (4.49)	9.62 (1.68)
Superficial hydration	21.58 (8.96)	7.4 (4.54)	10.25 (1.35)
Combined hydration	11.75 (9.31)	4.25 (4.11)	10.75 (1.48)
Between group comparison	*P* value		
Control vs superficial hydration	0.773	0.890	0.697
Control vs combined hydration	0.044*	0.029*	0.129
Superficial vs combined hydration	0.016*	0.065	0.428

* Significance level: $P < 0.05$.

seen in the hypo hydration condition pre- to post-test comparisons, this indicates a significant reduction in the range of both loudness and pitch. In the PVU, frequency and intensity changes are essential variables in order to identify early vocal fatigue[55] as this may indicate a deterioration in elasticity and viscosity of the vocal fold mechanism.[42] When singers attempt to reach their highest and lowest frequencies or intensities, prime elasticity is necessary in order to reach notes without strain. The increase in intensity (dB) min and F_0 (Hz) min for the combined hydration condition clinically manifested as a smaller voice range, with decreased loudness projection which is undesirable for the singer's performance. In previous research on hydration and vocal quality, frequency (Hz), intensity (dB) and F_0 (Hz) did not reveal significant changes; however, in a single study on systemic hydration and habitual pitch in females, a significant deterioration in F_0 (Hz) was found after fasting.[56] Values remained within normal limits despite the decrease seen. Similar to the current study, in the application of superficial hydration on teachers, a statistically significant increase was previously found in F_0 (Hz) for the /a:/ vowel ($P = 0.036$).[4] This increase was recognised as the vocal folds possibly became lighter and thus were able to oscillate more efficiently when well lubricated.[4] It is possible that there is comparable causation for the increase in F_0 (Hz) min seen presently.

Conceivably, vocal fatigue also contributed to significantly increased mean Shimmer ($P = 0.016$) scores as well as a significant reduction in mean Intensity (dB) Max ($P = 0.049$) scores obtained when comparing the experimental and control condition post-test results where superficial hydration was applied. It was expected that shimmer, would improve in the superficial hydration condition, as with increased hydration levels in previous studies.[1] In contrast, shimmer values, significantly worsened ($P = 0.016$) within this condition, thus the cycle-to-cycle variation in amplitude increased with superficial hydration. Similarly, a previous study found a statistically significant decrease ($P \leq 0.050$) in shimmer in the hypo hydrated condition, revealing an inverse positive effect of a hypo hydrated condition. Unlike the current study, following the ingestion of fluids, a statistically significant ($P \leq 0.05$) decrease in shimmer results was however reported.[56] Previous studies have nevertheless, reported that jitter is recognized as a more accurate indication of perturbation in synthesized speech signals when compared to shimmer, and should thus be interpreted with caution.[57]

From the acoustic results a significant increase in MPT (sec) ($P = 0.015$) was observed in the hypo hydrated condition from pretest to post-test (10.1% and 00.0% respectively). Even though the outcome of improved MPT in hypo hydration does not support the hypothesis, it points to the possibility of a warm-up effect present. Research has previously yielded evidence on this effect in literature on speech-language pathologists and young choir girls.[58] This phenomena caused an improvement in vocal quality after 30 minutes of vocal stretches and exercises. Beneficial outcomes due to vocal warm-up for the acoustic analysis have previously been seen in both singers and nonsingers.[59] Another study observed the vocal warm-up effect when employed in young choir girls, indicating increased glottal closure and positive fine-tuning of the vocal folds position.[60]

One must however consider the positive change seen MPT (sec) in both the superficial hydration condition from pretest to post-test as well as when comparing the experimental and control condition post-test results. Both show that where superficial hydration was applied mean significant positive increase in MPT (sec) was observed, ($P = 0.004$) and ($P = 0.003$) respectively. In previous studies mixed or nonsignificant results were reported for the effect of dehydration on MPT, specifically when fasting.[56,61] Yet, one study focusing on the effects of systemic hydration found a statistically significant increase in MPT for sounds /a/ (P = 0.012) and /s/ (P = 0.024) after hydration.[38] This increased in MPT may be due to nimble, pliable and therefore easily vibrated vocal folds requiring reduced subglottic pressure needed in order to vibrate for lengthier periods. Thus, the results found for the MPT outcomes of the current study further support the hypothesis of the benefits of hydration.[38] DSI (P = 0.020) scores also increased significantly whereas Intensity (dB) Min (P = 0.018) significantly reduced when comparing the experimental and control condition post-test results of the superficial hydration group. A previous study only reporting on the effects of systemic hydration and hypo hydration on the Dysphonia Severity Index yielded no significant results.[38] Superficial hydration can alternatively be seen to significantly improve overall acoustic vocal quality via increased DSI scores (P = 0.020). For a PVU who depends on optimal voice quality, any improvement thereof contributes to enhancing in the overall professional vocal performance. Improvement may be perceptual, regarding decreased grade of voice disorder, roughness and breathiness present in the voice when performing. Longer MPT, the ability to produce softer voice (Intensity Min) and most importantly overall improved voice quality (DSI) is also vital improvement observed, depending on the individual. Improvement can also be considered as consistent decreased perceived vocal fatigue in the singer when increased superficial and combined hydration is employed.

The vocal fatigue index yielded outcomes that were most consistently aligned with the proposed hypothesis. Factors 1 and 2 (Self-perceived tiredness of voice and physical discomfort), decreased slightly whereas, factor 3 (improvement of symptoms with rest) increased slightly with applied superficial hydration. The decrease of factors 1 and 2 and the increase of factor 3 occurred more significantly with added systemic hydration schedule, indicating reduced perceived vocal fatigue through adequate hydration. Both tiredness of voice (P = 0.044) and physical discomfort (P = 0.029) were, significantly decreased by combined hydration when compared to the control condition. It must also be noted that when comparing the experimental conditions, combined hydration significantly (P = 0.016) decreased vocal fatigue compared to superficial hydration. A previous study aimed to determine the amount of singing required to experience perceived vocal fatigue in untrained amateur karaoke singers, found that when provide with regular but brief systemic hydration and vocal rests amateur karaoke singers sang significantly longer before vocal fatigue was reported (mean 101.93 minutes) than the group without taking water or rests (mean 85.48 minutes).[46] Another study examined the effect of a laryngeal desiccation challenge and subsequent nebulised isotonic saline in trained male singers and nonsingers. Demonstrating an increase after laryngeal desiccation and decrease after nebulised saline treatment in all self-perceived measures of vocal effort.[35]

Although mixed results on acoustic parameters must be considered, from the results, it is inferred that superficial hydration has a positive effect on various acoustic and perceptual parameters of voice quality as well as vocal fatigue in the future female professional singer. Vocal hygiene programs can benefit from this clinically relevant data by providing a cost-effective and efficient method to improve voice perceptual quality and decreased perceived vocal fatigue. Optimal vibration of the vocal folds is permitted when one makes use of adequate superficial and systemic hydration; this in turn increases ease of phonation, allowing a performance to be as effortless as possible. Singers are then free to focus on performance value, without additional anxiety caused by the perceptual voice quality or vocal fatigue.

Limitations and recommendations

There are several potential limitations to the current study which warrant mention. The sample included in this study was a small group of young, vocally healthy, future female singers (n = 24). It may be that age, vocal health, and/or vocal training influence susceptibility to laryngeal dehydration, and it is therefore recommended that future research should be conducted on a larger sample (Franca, 2006). VFI ratings may have been influenced by participants' expectation that treatment would improve vocal hydration and decrease vocal effort. The examiner did their best to prevent bias during experimental procedures, but it is possible that a bias did exist. Due to the VFI rating being done by the participants, they may have been biased to give improved ratings when receiving hydration compared to hypo hydration merely due to previous education and pre-existing notions on hydration within vocal hygiene in their studies as future professional singers. One must also always consider the possible presence of the placebo effect.[62]

It is recommended that future research studies consider a variety of occupational groups that may benefit from the results. Additionally, for future research on the effect of superficial hydration on voice quality, it is recommended that participants all follow a similar warm-up program (30 minutes of vocal stretches and exercises) before testing in all conditions to eliminate the possible voice quality changes as a result of the warm-up effect.[59] Although all participants were asked to perform a short vocal exercise in the current protocol before pretest, this is not sufficient to eliminate the influence of possible warm up effect. In future similar studies on women, the effect of the menstrual cycle and ovulation on the superficial lamina propria must be monitored and taken into consideration.[63] It would also be recommended that participants use the same rehearsal music to control consistency of phonation tasks during the 1-hour routine rehearsal. Lastly, superficial as well as systemic hydration are complex variables to control due to differences in bodily fluid balance from participant to participant. Although measures were in place to control the intake of fluids and food before testing, it may be possible that more rigorous control over this variable could allow for more reliable research outcomes (Timmermans et al, 2002). The amount and duration of nebulized isotonic saline needed to alter superficial hydration is poorly defined in literature.[64,65] Future research should focus on hydration schedules of differing durations and doses and compare these results. Control measures for time, voice rest, warm-up, cool-down and vocal training should also be considered. Despite its limitations, this study is the one of the few examining nebulized isotonic saline treatment as superficial hydration in future female professional singers. It will serve as a basis for future research in this area.

CONCLUSION

Many clinicians advocate for increased hydration as an important component of vocal hygiene. However, on the topic of applied superficial hydration through nebulisation, a greater evidence base is required to determine the exact relationship with, and effect on with voice quality, and substantiate the clinical application thereof. In a professional environment where optimum voice quality is crucial, any improvement in voice quality contributes to the overall enhancement of performance in the future professional singer. In this study, it was confirmed that the use of superficial hydration had positive outcomes on the perceptual parameters of voice quality and vocal fatigue in future female professional singers. Although mixed results were found regarding the acoustic parameters of voice, the positive results obtained pertaining to perceptual voice quality and vocal fatigue supports the use of hydration as a preventative measure that should be included in vocal hygiene programs. It is warranted that further investigation must be done to verify if perceptual breathiness is improved by means of combined superficial and superficial hydration or merely through vocal warm up. This application of superficial alongside systemic hydration may assist future female professional singers who rely heavily on not only voice production but optimal vocal quality, as the primary tool for occupational success.

CONFLICT OF INTEREST

The authors have no conflicts of interest to declare.

SUPPLEMENTARY DATA

Supplementary data related to this article can be found online at doi.org/10.1016/j.jvoice.2020.01.008.

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