

Immediate effects of a semi-occluded water-resistance ventilation mask on vocal outcomes in women with dysphonia

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Highlights

- SOVM-WR is a suitable alternative to WRT, but no immediate advantages were found.
- Both SOVM-WR and WRT may improve self-perceived vocal comfort and voice quality.
- Clinical improvement of voice quality was found on subject, but not on group level.

Abstract

Introduction: Semi-occluded vocal tract exercises (SOVTEs) are frequently used exercises in voice therapy. An important shortcoming to most SOVTEs is the inability to include continuous speech in these exercises. A variation of water-resistance therapy (WRT), during which a patient phonates through a resonance tube ending in water, was developed to include continuous speech: the semi-occluded water resistance ventilation mask (SOVM-WR). The current study investigated the immediate effects of this innovative technique on vocal outcomes of women with dysphonia.

Methods: A pretest-posttest randomized controlled trial was performed. Twenty female participants were randomly assigned to the experimental SOVM-WR group or the WRT (control) group. A blinded multidimensional voice assessment was conducted before and after a 30-minute therapy session with the assigned technique.

Results: No significant changes were found in acoustic or auditory-perceptual vocal outcomes in either of the groups, except for a significant increase in lowest frequency in both groups. Patient-reported outcomes (PROMs) showed significant improvements of vocal comfort, vocal effort, and voice quality in both groups, and participants indicated that they would use the techniques at home.

Conclusions: The similar results of the SOVM-WR to WRT and promising PROMs confirm its suitability as an alternative to the latter technique. Potential reasons for a lack of improvement of objective and auditory-perceptual vocal outcomes are vocal fatigue, tube dimensions and immersion, and the small sample size. Large-scale and longitudinal research is needed to examine whether the SOVM-WR has a higher transfer to spontaneous speech than WRT after a full therapy program.

Keywords: Voice therapy; SOVT; Dysphonia; Water-resistance therapy; Semi-occluded water-resistance ventilation mask

1. Introduction

Voice disorders are among the most frequently occurring communication disorders and have a significant psychosocial impact on the patient (Branski et al., 2006; Krischke et al., 2005; Wilson et al., 2002). Therefore, an adequate and evidence-based treatment is necessary. Both in voice therapy and voice training, achieving economic and efficient voice production with a resonant voice quality is an important goal (Schneider & Sataloff, 2007; Stemple & Hapner, 2014).

One group of techniques that aim to accomplish this goal are semi-occluded vocal tract exercises (SOVTEs). Higher vocal economy is achieved by partially occluding the vocal tract, which is mostly realized in the front of the oral cavity or the lips (Story et al., 2000; Titze, 2006; Titze & Story, 1997). This semi-occlusion causes a higher supraglottal pressure and consequently a higher interaction between the glottis and the supraglottal vocal tract (i.e. a higher source-filter interaction), at which acoustic energy is transported back from the semi-occlusion to the source (Andrade et al., 2014; Maxfield et al., 2014; Mills et al., 2017; Story et al., 2000; Titze, 2006). This interaction influences the vocal folds' oscillation by an impedance matching between the vocal tract and the vocal folds, lowering the phonation threshold pressure (PTP) and facilitating phonation (Andrade et al., 2014; Titze, 2006; Story et al., 2000; Titze & Story, 1997).

SOVTEs are often used in voice training by elite vocal performers as a warm-up exercise, or in voice therapy for people with dysphonia (Dargin & Searl, 2015; Guzman et al., 2013b; Smith & Titze, 2017). Examples of SOVTEs include lip trills (Gaskill & Erickson, 2008), tongue trills (Cordeiro et al., 2012), lingo-labial trills or raspberries (Nix, 1999), humming (Ogawa et al., 2013), voiced fricatives (Laukkanen et al., 1996), hand-over-mouth resonance (Andrade et al., 2014), cup phonation (Rosenberg, 2014), straw phonation (Guzman et al., 2013a; Titze, 2000), phonation through a glass or flexible resonance tube, possibly submerged in water (i.e. water resistance therapy; WRT) (Laukkanen et al., 1995; Sihvo & Denizoglu, 2007; Simberg & Laine, 2007) and the semi-occluded ventilation mask (SOVM) (Borragán et al., 1999). For this latter technique, a plastic anesthesia mask with a small hole in the middle is placed over the mouth (and in some cases over the nose as well) so that it is completely covered with no air escaping at the sides.

The SOVM can be used as a variant of cup phonation or hand-over-mouth resonance (Awan et al., 2018; Fantini et al., 2017; Frisancho et al., 2018; Lucchini et al., 2018). Previous studies have shown that the SOVM may have a potential positive influence on aerodynamic

and acoustic parameters in people with dysphonia (Awan et al., 2018; Frisancho et al., 2018; Guzman et al., 2020a) and in vocally healthy subjects (Awan et al., 2018; Fantini et al., 2017). Additionally, Fantini et al. (2017) and Guzman et al. (2020a) found a positive effect on the participants' self-evaluation of their voice after exercising with the SOVM. Regarding the source of vibration, Andrade et al. (2014) identify SOVM as an example of steady exercises, where only one source of vibration (i.e. the vocal folds) is present. In fluctuating exercises, however, a secondary source of vibration is added to the vocal tract, for example in lip or tongue trills or in WRT (Andrade et al., 2014). Fluctuating SOVTEs cause a greater 'massage effect' on the vocal folds due to the secondary vibration source that influences the vocal folds' vibratory pattern by generating fluctuating supraglottal pressure (Granqvist et al., 2015; Miller & Schutte, 1991; Simberg & Laine, 2007).

Nearly every traditional SOVTE has the disadvantage that exercises are limited to single phoneme tasks. Regarding the stable exercises, the SOVM enables the inclusion of continuous speech on word, sentence or text level during exercises, which might eventually lead to an easier transfer to spontaneous speech outside the therapy setting (Mills et al., 2017). This advantage disappears, however, when fluctuating exercises in the form of trills are presented simultaneously, as continuous speech is no longer possible in this case. In response to this shortcoming, a possible solution is the addition of a flexible resonance tube to the SOVM, which ends in water, in accordance with WRT with a flexible resonance tube (see Fig. 1). This latter technique will hereafter be referred to as the semi-occluded water-resistance ventilation mask (SOVM-WR). In doing so, fluctuating exercises, which have a massage effect on the vocal folds (Andrade et al., 2014; Miller & Schutte, 1991), can be presented during therapy at word, sentence and text level. This could increase generalization and transfer to spontaneous speech (Mills et al., 2017).



Fig. 1. The traditional water-resistance therapy approach (left) and the semi-occluded water-resistance ventilation mask (right).

Efficacy studies regarding this technique are scarce, although this type of SOVTE is included in the proprioceptive-elastic (PROEL) method, a therapy program aimed at rebalancing the phonatory system by reducing muscle tension and improving elasticity of the system (Borragan et al., 2008; Lucchini et al., 2018). Additionally, Meerschman et al. (2020) investigated the immediate effects of the SOVM-WR compared to WRT (with flexible tube)

on objective and perceptual vocal outcomes in musical theater students after a 30-minute training session. Both SOVTEs with SOVM-WR and WRT led to a significantly improved (increased) Dysphonia Severity Index (DSI), while the Acoustic Voice Quality Index (AVQI) only improved (decreased) in the WRT group. Furthermore, intensity range worsened (decreased) and semitone range improved (increased) in the SOVM-WR group, but not in the WRT group. Blinded auditory-perceptual assessment revealed a more strenuous speaking voice after the use of traditional WRT. Additionally, participants showed a slight preference for the SOVM-WR, although both techniques were perceived as comfortable vocal warm-up exercises. However, since the participants in this study were all vocally healthy individuals, these results cannot be transferred to people with an impaired voice quality. Only Guzman et al. (2021) examined the immediate effects of SOVM-WR combined with traditional WRT in dysphonic patients after six 30-minute therapy sessions over the course of three weeks. A reduction in perceived phonatory effort and perceptual aspects of vocal fatigue were observed, but the study did not discover significant differences in other outcome parameters. Because the SOVM-WR was combined with WRT in the experimental group, it is impossible to differentiate potential effects on vocal and self-reported outcomes between the two techniques.

Therefore, the current study examined the immediate effects (i.e. the effects after a therapy session of 30 min) of the SOVM-WR compared to traditional WRT on perceptual and objective vocal outcomes and patient-reported outcome measures (PROMs) in women with dysphonia. It was hypothesized that the SOVM-WR would have positive effects on both perceptual and objective vocal outcomes, similar to the therapy effects in the WRT group. As previously mentioned, the SOVM-WR also allows for continuous speech to be included during exercises. Therefore, a greater improvement of the AVQI and auditory-perceptual evaluation was expected in this group than in the WRT group, as these outcome parameters are partially based on the evaluation of continuous speech. Lastly, participants in the SOVM-WR group were expected to have more positive subjective experiences with this innovative technique than the WRT group, because of the possibility to include continuous speech, which allows for more articulatory freedom.

2. Method

The protocol of this study was approved by the ethics committee of the Ghent University Hospital (project EC/2019/0721).

2.1. Participants

A total of 20 female participants (mean age 35.2 years, SD 12.43, range 19–57) were recruited during consultation in the voice clinic of the Ghent University Hospital. Inclusion criteria were: aged 18–65, and diagnosis of organic or functional dysphonia. The diagnosis was based on the results of a multidimensional voice assessment performed by a speech-language pathologist (SLP) and an ear, nose and throat (ENT) specialist. Voice disorders that were excluded from this study consisted of vocal fold paralysis or paresis, spasmodic dysphonia, total aphonia, presbyphonia and mutation disorders. Additionally, smokers and participants with hearing, articulation, fluency or neurological disorders were excluded. After inclusion, participants were randomly assigned to either the SOVM-WR group or the WRT group through block randomization. Baseline characteristics of the participants in both groups can be found in

Table 1

Baseline characteristics in the SOVM-WR and WRT group.

	Characteristic SOVM-WR (n = 10)		Group	Mann-Whitney U test or independent t-test WRT (n = 10)	
	M	SD	M	SD	p-value
Age	37.2	11.55	33.2	13.6	0.247
Dutch Voice Handicap Index	45.1	24.78	40.0	13.66	0.610
Dutch VTDS: total frequency score	22.3	8.65	18.1	7.86	0.295
Dutch VTDS: total intensity score	24.7	8.48	19.6	7.92	0.205
Dutch Corporal Pain Scale	9.0	4.97	4.2	4.79	0.014*

Abbreviations: SOVM-WR: semi-occluded water-resistance ventilation mask; WRT: water-resistance therapy; VTDS: Vocal Tract Discomfort Scale.
* $p < 0.05$.

Table 2

Voice-related risk factors, vocal abuse and vocal load in the SOVM-WR and WRT group.

Characteristic	Group		Fisher's Exact p-value
	SOVM-WR (n = 10)	WRT (n = 10)	
Functional voice disorder	7	7	>0.999
Allergies	4	5	>0.999
Reflux	5	3	0.650
Asthma	2	2	>0.999
Stress	2	3	>0.999
Smoking	0	0	>0.999
Vocal abuse (i.e. loud voice use, coughing, throat clearing)	8	8	>0.999
Hobbies with high vocal load	1	4	0.303
Professional voice user	4	6	0.656

Abbreviations: SOVM-WR: semi-occluded water-resistance ventilation mask; WRT: water-resistance therapy.

Table 1. In each group, 3 participants were diagnosed with organic dysphonia (vocal fold nodules, edema, or reflux laryngitis) by an ENT-specialist, while 7 participants received a diagnosis of functional dysphonia. Voice-related risk factors, vocal abuse and vocal load of all participants were documented prior to the experiment and can be found in Table 2.

2.2. Procedure

A pretest-posttest randomized controlled trial was performed. Pre-experimental voice assessments were conducted by an SLP specialized in voice diagnostics during regular consultations in the voice clinic. Each eligible patient was asked to participate voluntarily in the current study. After a written informed consent form was obtained, participants were randomly assigned to the SOVM-WR or WRT group and received 30 min of voice therapy from the first author (I.K.). The outline of the therapy session can be found in Table 3. After this session, a post-experimental voice assessment was performed by the SLP who conducted the pre-experimental assessment, blinded to group allocation.

2.3. Voice assessment

Pre- and post-experimental instrumental voice assessments consisted of a maximum performance task, acoustic analysis, and determination of the voice range profile, DSI and AVQI. All assessments were conducted in an acoustically isolated room in the voice clinic.

2.3.1. Instrumental voice assessment

2.3.1.1. Maximum performance task. In order to obtain the maximum phonation time (MPT, in s), participants were asked to sustain the vowel /a:/ as long as possible at their habitual pitch and loudness after maximal inspiration (De Bodt et al., 2015). Participants were seated while performing this task and were encouraged verbally by the SLP during phonation. The best of three attempts, which were timed using an online stopwatch, was retained for further analysis and calculation of the DSI.

2.3.1.2. Acoustic analysis. Participants were instructed to sustain the vowel /a:/ for several seconds after an automatic sequence (i.e. counting from one to two) at their habitual pitch and loudness in a Shure SM-48 microphone at a distance of 15 cm from the mouth. The fundamental frequency (f_0 , in Hz), jitter (%), shimmer (%), Noise-to-Harmonics Ratio (NHR) and variation in fundamental frequency (vf_0) were obtained using the Multi-Dimensional Voice Program of the Computerized Speech Lab (CSL, model 4500, Kay-PENTAX, Montvale, NY). In addition, jitter was used for calculation of the DSI.

2.3.1.3. Voice range profile. The participants' voice range profile (VRP) was determined by the CSL, using a Shure SM-48 microphone at a distance of 15 cm from the mouth. The procedure outlined by Heylen et al. (1998) was used for this task. Participants were instructed to sustain the vowel /a:/ for several seconds using their habitual pitch and loudness, followed by their lowest fundamental frequency (F-low), lowest intensity (I-low), highest fundamental frequency (F-high) and highest intensity (I-high) respectively. All participants received verbal encouragement and the desired productions were modelled by the SLP during this task. The

Table 3

Outline of the 30-minute therapy session (identical for both groups).

Content of therapy session

Education about SOVTEs (rationale, implementation) and material (SOVM-WR and/or WRT)

Preparatory exercises

- Eutonic posture
- Costo-abdominal breathing
- Blowing through SOVM-WR or WRT without phonation

Phonation through SOVM-WR or WRT on rounded, spread, and open vowels /u:/, /o:/, /a:/, /i:/, /y:/, /e:/ at a single comfortable pitch

Phonation through SOVM-WR or WRT on rounded, spread, and open vowels: ascending, descending and alternating pitch glides

Phonation through SOVM-WR or WRT on rounded, spread, and open vowels: increasing, decreasing, and varying loudness

Reading of oral words and sentences alternatively through SOVM-WR or WRT and without

- WRT: mental representation and prosody of the words and sentences
 - SOVM-WR: actual articulation
-

Abbreviations: SOVTEs: semi-occluded vocal tract exercises; SOVM-WR: semi-occluded water-resistance ventilation mask; WRT: water resistance therapy (with flexible resonance tube).

aforementioned parameters were used to calculate the participants' frequency and intensity range. Additionally, F-high and I-low were retained for DSI calculation.

2.3.1.4. Dysphonia severity index. The DSI is an objective and quantitative correlate of voice quality and capacities, based on a weighted combination of the parameters MPT (in s), F-high (in Hz), I-low (in dB) and jitter (in%) according to the formula 'DSI = 0.13 MPT + 0.0053 F0-high - 0.26 I-low - 1.18 jitter(%) + 12.4' (Wuyts et al., 2000). DSI scores usually range from -5 to +5, with higher scores indicating better vocal capacities and a score of +1.6 being used as the cut-off value between normal and impaired voice quality.

2.3.1.5. Acoustic voice quality index. The AVQI is a multivariate model to objectively measure voice quality based on both a sustained vowel and continuous speech, and was developed by Maryn et al. (2010). To calculate the AVQI, a weighted combination of the output of 6 acoustic time- (i.e. shimmer local, shimmer local dB, harmonics-to-noise ratio (HNR)), frequency- (i.e. general slope of the spectrum, tilt of the regression line through the spectrum) and quefrequency-domain (smoothed cepstral peak prominence (CPPs)) measures is modelled in the linear regression formula '2.571 [3.295 - 0.111 (CPPs) - 0.073 (HNR) - 0.213 (shimmer local) + 2.789 (shimmer local dB) 0.032 (slope) + 0.077 (tilt)]' (Maryn et al., 2010). Participants were seated during this task, and were instructed to sustain the vowel /a:/ for several seconds, followed by reading the Dutch oronasal reading passage 'Papa en Marloes' (Appendix A; Van de Weijer & Slis, 1991) aloud. The speech samples were recorded using a desk mounted Samson C01U Studio Condenser Microphone (Samson), which was positioned at a distance of 30 cm from the mouth, and the software program Praat, version 6.0.40 (Boersma & Weenink, 2013). All samples were recorded using a sampling frequency of 44.1 kHz and were saved as a mono channel WAV file with a bit depth of 16 bits. The middle three seconds of the /a:/ and the first two sentences of the reading passage were used to calculate each participant's AVQI score with a cut-off value of 2.95, with higher scores indicating a pathological voice quality (Maryn et al., 2010). Additionally, the pre- and post-experimental speech samples were used for the blinded perceptual voice assessment.

2.3.2. Auditory-perceptual voice assessment

The auditory-perceptual voice evaluation was performed blindly by an SLP (I.M.) experienced in voice diagnostics using the GRBASI scale (Dejonckere et al., 1996; Hirano, 1981). All speech samples contained a sustained /a:/ and continuous speech (i.e. reading of the complete passage 'Papa en Marloes'), and were anonymized and presented in a randomized order. To ensure intrarater reliability, 20% of the speech samples were randomly repeated throughout the assessment. Additionally, 20% of the speech samples were assessed in a randomized order by another SLP specialized in voice diagnostics (E.D.), blinded to group allocation or time (pre or post therapy) to assure interrater reliability.

2.4. Patient-reported outcome measures

Four questionnaires were completed before the experiment: the Dutch version of the Voice Handicap Index (VHI; De Bodt et al., 2000; Jacobson et al., 1997), the Dutch version of the Vocal Tract Discomfort Scale (VTDS; Luyten et al., 2016), the Corporal Pain scale (CPS; Van Lierde et al., 2010) and a questionnaire consisting of several VAS on the participants'

subjective self-evaluation regarding their voice quality at that time (Appendix B). The VHI is an instrument to measure the psychosocial impact of a voice problem on the patient and consists of 30 statements that gauge physical and functional limitations, as well as the patient's emotional perception of his/her voice problem (De Bodt et al., 2015). In the current study, the participants' total scores on the VHI were compared between the SOVM-WR and WRT groups, which is illustrated in Table 1. The VTDS is a tool to evaluate a patient's symptoms and sensations of discomfort in the vocal tract as a consequence of their voice problem by rating the frequency and intensity of 8 symptoms on a scale from 0 to 6 (Santi et al., 2020). For the purposes of the current study, the sum of all frequency and intensity scores was used to compare both groups (Table 1). The same approach was used to compare total scores on the CPS between the groups (Table 1).

As stated before, self-evaluation of voice quality before the experiment was measured using a VAS questionnaire, with 0 mm indicating the most negative answer and 100 mm the most positive. Specifically, the participants were asked to rate their voice quality (from *bad* to *good*), physical effort of phonation (from *effortful* to *effortless*), and comfort of phonation (from *uncomfortable* to *comfortable*). After the therapy session, one final questionnaire was completed (Appendix B), similar to the pre-experimental VAS questionnaire. Participants rated their voice quality after the experiment, vocal effort and comfort during and after the experiment, their experience with the applied therapy technique (from unpleasant to pleasant) and whether they would practice that technique at home (*yes* or *no*).

2.5. Voice therapy session

Both groups received one therapy session of 30 min, which is outlined in Table 3. Participants of both groups were provided with a flexible silicone resonance tube with a length of 35 cm and an inner diameter of 10 mm, as is commonly used in WRT (Andrade et al., 2016; Tyrmi et al., 2017), and a large cup filled halfway with water. An immersion of 2 cm in the water, which yields less impedance and oral pressure (Andrade et al., 2016), was chosen since most participants had no previous experience with water-resistance SOVTEs. For the SOVM-WR group, a disposable anesthesia ventilation mask was attached to the resonance tube. The mask (8 cm in length, 6.5 cm in width and 3 cm in depth) had an opening of 10 mm in diameter and was held in one hand by the participants. A small mask that covered the mouth but not the nose, identical to the one used by Meerschman et al. (2020), was chosen because it was easier to confirm correct placement and avoid air leakage, since the participants could freely inhale through the nose without removing the mask. Fig. 1 shows the WRT and the SOVM-WR technique. The content of the therapy session was identical in both groups, as can be seen in Table 3. The only difference was the inclusion of articulation during the SOVT condition in the SOVM-WR group, while the participants in the WRT group were instructed to phonate on an /u:/ with a mental representation and prosody of the words and sentences they read.

2.6. Statistical analyses

All statistical analyses were performed using IBM SPSS Statistics 26 (SPSS Corporation, Chicago, IL, U.S.) at a significance level of $\alpha = 0.05$. Baseline characteristics of continuous data (Table 1), as well as the outcome parameter regarding the participants' subjective experience

with these techniques were compared using the Mann-Whitney U test. In order to compare categorical data between both groups for the baseline characteristics and self-evaluation data, a Fisher's Exact test was carried out. Linear mixed model analyses were performed to compare groups over time for continuous outcome measures of the instrumental voice assessment and self-evaluation questionnaires. For the categorical outcomes from the auditory-perceptual voice assessment, General Linear Model analyses were performed. Time, Group, and Group x Time interactions were specified as fixed factors. Within-group effects of time were determined by post hoc pairwise comparisons, with Bonferroni corrections for the participant's self-evaluation due to the three time points. A two-way mixed, single-measures, consistency Intraclass Correlation Coefficient (ICC(3,1)) was used to analyze inter- and intrarater reliability, which has been shown to be identical to a weighted kappa with quadratic weights for ordinal scales, and the two may be substituted interchangeably (Norman & Streiner, 2008). Guidelines described by Koo and Li (2016) were used for interpretation of inter- and intra-rater reliability: poor below 0.50, moderate between 0.50 and 0.75, good between 0.75 and 0.90, excellent above 0.90.

3. Results

3.1. Maximum performance task and acoustic analysis

No significant Group, Time or Group x Time interactions were found for MPT or any of the acoustic parameters. The evolution of shimmer was somewhat different between both groups, although no statistical significance was reached: in the SOVM-WR group, shimmer decreased (improved) slightly, while it increased (worsened) insignificantly in the WRT group. The results of the statistical analyses for all outcome parameters are presented in Table 4.

3.2. Voice range profile

As demonstrated in Table 5, a significant Time effect was found for lowest frequency ($p = 0.048$), which showed an increased (worse) lowest frequency. Post-hoc within-group comparisons showed that lowest frequency increased significantly in the WRT group (mean difference: 8.250, $p = 0.031$), whereas the SOVM-WR group showed a non-significant increase (mean difference: 2.099, $p = 0.539$). Highest frequency showed an opposite evolution and decreased (worsened) over time in both groups, although not significantly. Consequently, frequency range (in HZ) decreased non-significantly over time ($p = 0.068$). No significant changes within or between groups were found for lowest and highest intensity, nor for intensity range.

3.3. Multiparametric voice quality indices

Results for the evolution of the multiparametric voice quality indices DSI and AVQI in the SOVM-WR and WRT groups can be found in Table 6. No significant Time, Group or Time x Group interactions were found for DSI and AVQI in either of the groups. A non-significant Time effect was observed for DSI, which decreased (worsened) in both groups ($p = 0.293$). An opposite trend was found for the AVQI, which decreased (improved) non-significantly in both groups ($p = 0.113$), with a mean difference of - 0.240 in the SOVM-WR group, and - 0.327 in

Table 4

Evolution of maximum phonation time and acoustic parameters in the SOVM-WR and WRT group.

Outcome (clinical cut-off value)	Time	Group SOVM-WR		Linear Mixed Model WRT		Group x Time <i>p</i> -value	Group <i>p</i> -value	Time <i>p</i> -value
		Mean	95% CI	Mean	95% CI			
<i>Maximum performance task</i>								
<i>MPT (16.2 s)</i>	Pre	16.005	[12.979, 19.031]	14.338	[11.312, 17.364]	0.832	0.385	0.473
	Post	15.740	[12.714, 18.766]	13.853	[10.798, 16.907]			
<i>Acoustic analysis</i>								
<i>f₀</i>	Pre	181.730	[167.714, 195.746]	193.644	[179.628, 207.660]	0.323	0.294	0.504
	Post	184.803	[170.787, 198.820]	193.038	[178.943, 207.132]			
<i>Jitter (1.04%)</i>	Pre	2.040	[1.417, 2.662]	1.852	[1.230, 2.475]	0.581	0.889	0.612
	Post	2.028	[1.406, 2.651]	2.112	[1.462, 2.762]			
<i>Shimmer (3.81%)</i>	Pre	5.435	[4.292, 6.579]	4.572	[3.468, 5.677]	0.146	0.689	0.721
	Post	4.709	[3.566, 5.853]	5.019	[3.875, 6.162]			

Abbreviations: Abbreviations: SOVM-WR: semi-occluded water-resistance ventilation mask; WRT: water resistance therapy; CI: confidence interval; MPT: maximum phonation time; f_0 : fundamental frequency; * significant effect ($p < 0.05$).

Note: clinical cut-off values based on [De Bodt et al. \(2015\)](#).

Table 5

Evolution of frequency and intensity range in the SOVM-WR and WRT group.

Outcome (clinical cut-off value)	Time	Group SOVM-WR		WRT		Linear Mixed Model		
		Mean	95% CI	Mean	95% CI	Group x Time p-value	Group p-value	Time p-value
<i>Frequency (in Hz)</i>								
<i>Lowest f (142 Hz)</i>	Pre	142.103	[131.207, 152.999]	131.739	[120.843, 142.635]	0.222	0.316	0.048*
	Post	144.202	[133.306, 155.098]	139.989	[128.911, 151.067]			
<i>Highest f (867 Hz)</i>	Pre	698.560	[564.400, 832.720]	640.347	[506.187, 774.507]	0.757	0.577	0.150
	Post	650.031	[515.871, 784.191]	608.577	[472.636, 744.518]			
<i>f range (725 Hz)</i>	Pre	546.499	[415.341, 677.657]	508.608	[377.450, 639.766]	0.578	0.528	0.068
	Post	505.829	[374.671, 636.987]	434.551	[301.178, 567.923]			
<i>Intensity (in dB)</i>								
<i>Lowest I (51 dB)</i>	Pre	58.9	[56.791, 61.009]	57.4	[55.291, 59.509]	0.330	0.526	0.602
	Post	57.9	[55.791, 60.009]	57.7	[55.533, 59.882]			
<i>Highest I (96 dB)</i>	Pre	93.6	[89.377, 97.823]	97.7	[93.477, 101.923]	0.390	0.255	0.341
	Post	93.5	[89.277, 97.723]	95.8	[91.475, 100.088]			
<i>I range (45 dB)</i>	Pre	34.7	[29.956, 39.444]	40.3	[35.556, 45.044]	0.207	0.201	0.581
	Post	35.6	[30.856, 40.344]	38.0	[33.201, 42.891]			

Abbreviations: SOVM-WR: semi-occluded water-resistance ventilation mask; WRT: water resistance therapy; CI: confidence interval, f: frequency, I: intensity; * significant effect ($p < 0.05$).

Note: clinical cut-off values based on [De Bodt et al. \(2015\)](#).

Table 6
Evolution of the multiparametric indices DSI and AVQI in the SOVM-WR and WRT group.

Outcome (clinical cut-off value)	Time	Group SOVM-WR		Group WRT		Linear Mixed Model		
		Mean	95% CI	Mean	95% CI	Group x Time p-value	Group p-value	Time p-value
DSI (+1.6)	Pre	0.630	[-0.735, 1.995]	0.600	[-0.765, 1.965]	0.534	0.744	0.293
	Post	0.450	[-0.915, 1.815]	-0.088	[-1.491, 1.316]			
AVQI (2.95)	Pre	3.878	[3.071, 4.685]	3.629	[2.810, 4.448]	0.800	0.584	0.113
	Post	3.638	[2.831, 4.445]	3.302	[2.495, 4.109]			

Abbreviations: SOVM-WR: semi-occluded water-resistance ventilation mask; WRT: water-resistance therapy; CI: confidence interval; DSI: Dysphonia Severity Index; AVQI: Acoustic Voice Quality Index; WRT: water resistance therapy; * significant effect ($p < 0.05$).

Note: clinical cut-off values based on [Maryn et al. \(2010\)](#) and [Wuyts et al. \(2000\)](#).

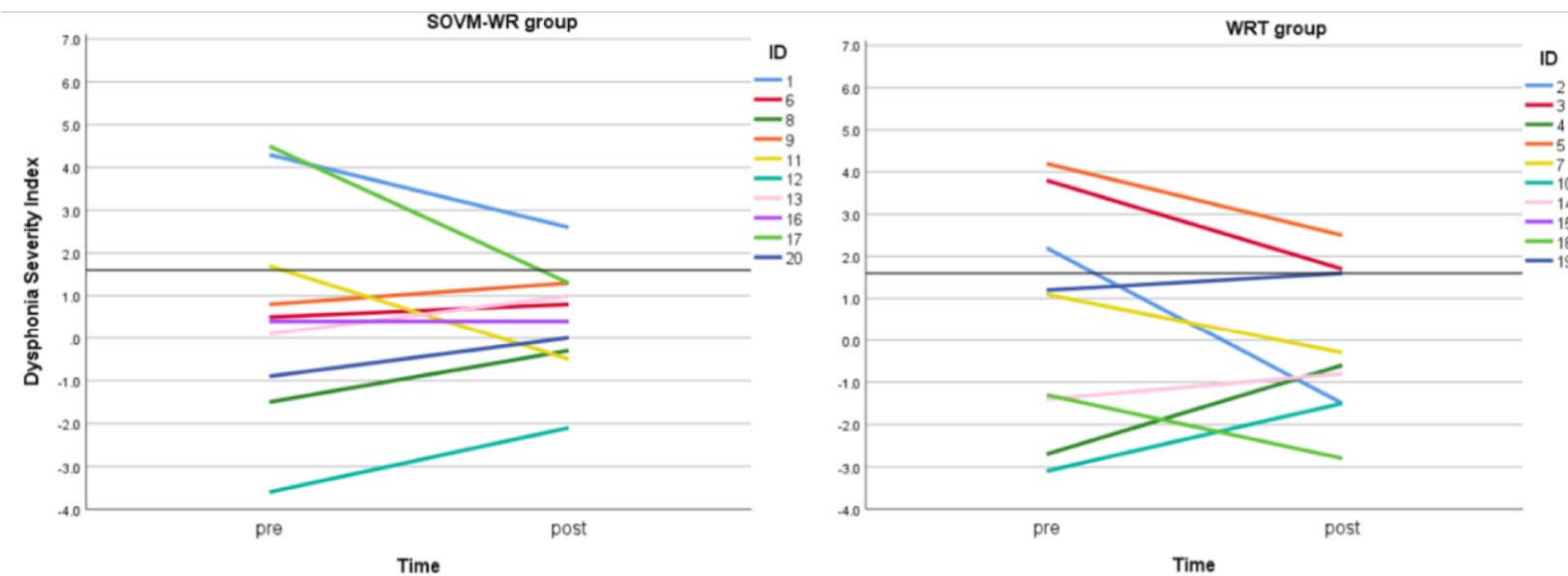


Fig. 2. Evolution of Dysphonia Severity Index in the SOVM-WR and WRT group (individual level).

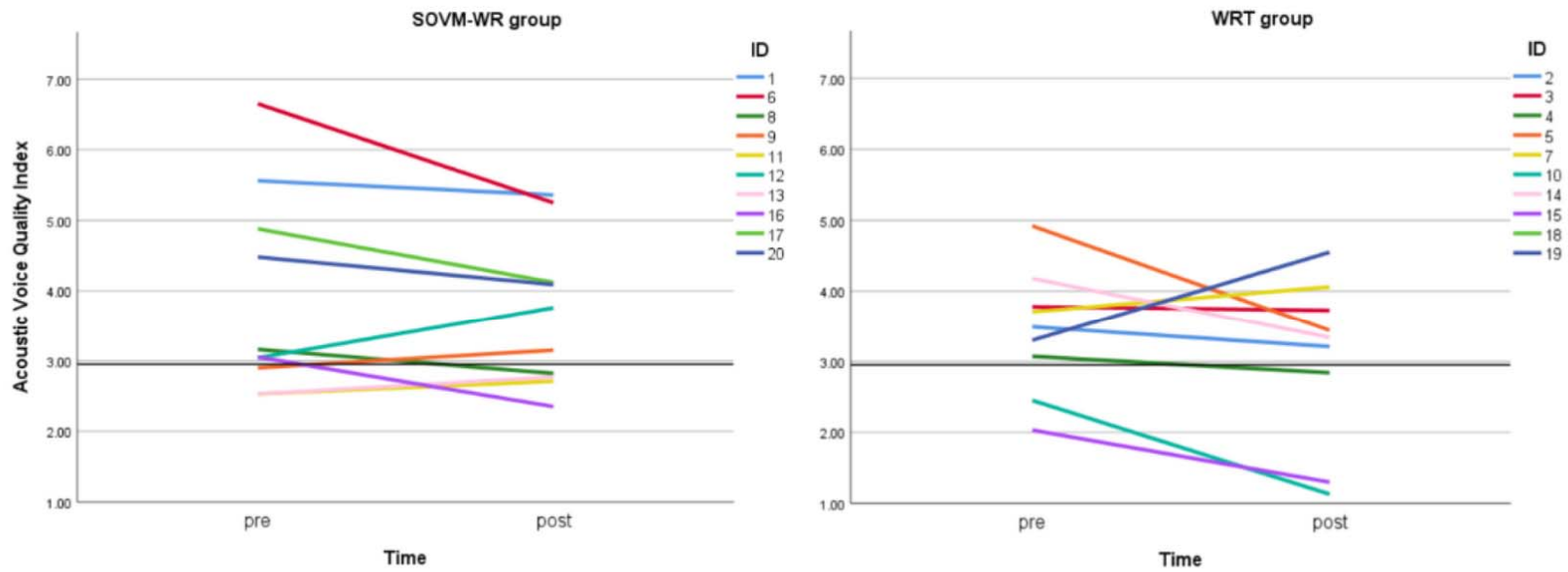


Fig. 3. Evolution of Acoustic Voice Quality Index in the SOVM-WR and WRT group (individual level).

the WRT group. The evolution of DSI and AVQI of the participants in both groups on an individual level is illustrated in Figs. 2 and 3 respectively.

3.4. Auditory-perceptual voice assessment

Calculation of the ICC revealed an excellent intrarater reliability for Grade, Strain and Instability (ICC = 1.000) and a good intrarater reliability for Roughness (ICC = 0.778) and Asthenia (ICC = 0.821). Intrarater reliability was moderate for the parameter Breathiness (0.727). A moderate interrater reliability was found for Roughness (ICC = 0.684) and Breathiness (ICC = 0.667), but interrater reliability was poor for Grade (ICC = 0.444), Asthenia (ICC = 0.343), and Strain (ICC = 0.373). For the parameter Instability, interrater reliability could not be calculated because at least one component variable showed no variance (i.e. Instability was consistently rated 0 by one of the SLPs).

No significant Group x Time interactions or Time effects were found for any of the parameters, which indicated no statistically significant evolution over time in the groups (see Table 7). A significant Group effect was found for the parameter Strain, demonstrating a significant difference between the SOVM-WR and the WRT group regardless of time (pre or post), in which the WRT group received a higher mean score. Post-hoc between-group comparisons revealed no significant differences between the groups pre-therapy (mean difference: 0.633, $p = 0.077$) or post-therapy (mean difference: 0.511, $p = 0.150$).

3.5. Patient-reported outcome measures

A statistically significant Time effect was found for the question “How does your voice sound?”, in which both groups indicated that their voice sounded better after the therapy session ($p = 0.003$). Effort of phonation also significantly decreased (improved) in both groups ($p = 0.001$). Within-group analyses revealed a significant improvement (decrease) in self-evaluation of vocal effort after the therapy compared to pre-therapy in the SOVM-WR group (mean difference: - 15.75, $p = 0.015$) and in the WRT group (mean difference: - 13.80, $p = 0.038$). A statistically significant Time effect was also found for self-evaluated comfort of phonation, which increased (improved) in both groups ($p < 0.001$). Within-group analyses revealed a statistically significant difference between pre- and post-therapy time points in the SOVM-WR group (mean difference: 19.60, $p = 0.005$). Likewise, the WRT group showed statistically significant improvements between pre- and during therapy time points (mean difference: 18.30, $p = 0.010$) and between pre- and post-therapy (mean difference: 18.00, $p = 0.008$). All results of the outcome parameters are presented in Table 8 and individual evolutions in both groups for vocal effort, vocal comfort, and self-perceived voice quality are illustrated in Figs. 4, 5, and 6 respectively. Regarding the participants’ opinion on the therapy method, an independent student’s t-test did not reveal a statistically significant difference between the SOVM-WR ($M = 72.3$, $SD = 14.17$) and WRT group ($M = 73.8$, $SD = 10.59$), $t(18) = -0.268$, $p = 0.792$. Lastly, all participants indicated that they would practice the assigned technique at home.

Table 7

Evolution of auditory-perceptual parameters (GRBASI) in the SOVM-WR and WRT group.

Outcome	Time	SOVM-WR		WRT		General Linear Model		
		Mean(SD)	95% CI	Mean(SD)	95% CI	Group x Time p-value	Group p-value	Time p-value
<i>Grade</i>	Pre	1.50(0.707)	[1.097, 1.903]	1.56(0.527)	[1.131, 1.980]	0.807	0.607	0.807
	Post	1.40(0.699)	[0.997, 1.803]	1.56(0.527)	[1.131, 1.980]			
<i>Roughness</i>	Pre	1.20(0.789)	[0.759, 1.641]	0.78(0.667)	[0.312, 1.243]	0.491	0.240	0.843
	Post	1.00(0.667)	[0.559, 1.441]	0.89(0.601)	[0.424, 1.354]			
<i>Breathiness</i>	Pre	1.00(0.816)	[0.460, 1.540]	1.33(0.707)	[0.764, 1.902]	0.546	0.546	0.546
	Post	1.00(1.054)	[0.460, 1.540]	1.00(0.707)	[0.431, 1.569]			
<i>Asthenia</i>	Pre	1.50(0.707)	[0.949, 2.051]	1.00(0.707)	[0.419, 1.581]	0.554	0.240	0.554
	Post	1.50(1.080)	[0.949, 2.051]	1.33(0.866)	[0.752, 1.914]			
<i>Strain</i>	Pre	0.70(0.823)	[0.215, 1.185]	1.33(0.866)	[0.882, 1.845]	0.805	0.026*	0.516
	Post	0.60(0.699)	[0.115, 1.085]	1.11(0.601)	[0.600, 1.623]			
<i>Instability</i>	Pre	0.40(0.516)	[0.135, 0.665]	0.11(0.333)	[-0.168, 0.390]	0.460	0.168	0.460
	Post	0.20(0.422)	[-0.065, 0.465]	0.11(0.333)	[-0.168, 0.390]			

Abbreviations: SOVM-WR: semi-occluded water-resistance ventilation mask; WRT: water resistance therapy; CI: confidence interval.

* significant effect ($p < 0.05$).

Table 8

Evolution of patient-reported outcome measures in the SOVM-WR and WRT group.

Time	Group SOVM-WR		WRT		Linear Mixed Model		
	Mean	95% CI	Mean	95% CI	Group x Time p-value	Group p-value	Time p-value
<i>How does your voice sound? (bad – good)</i>							
Pre	54.70	[43.772, 65.628]	41.10	[30.172, 52.028]	0.716	0.082	0.003*
Post	65.15	[54.222, 76.078]	54.10	[43.172, 65.028]			
<i>How effortless is phonation? (effortful – effortless)</i>							
Pre	51.75	[40.747, 62.753]	50.20	[39.197, 61.203]	0.965	0.681	0.001*
During	62.50	[51.497, 73.503]	59.60	[48.597, 70.603]			
Post	67.50	[56.497, 78.503]	64.00	[52.997, 75.003]			
<i>How comfortable is phonation? (uncomfortable – comfortable)</i>							
Pre	51.90	[41.851, 61.949]	46.70	[36.651, 56.749]	0.475	0.578	<0.001*
During	62.00	[51.951, 72.049]	64.70	[54.651, 74.749]			
Post	71.50	[61.451, 81.549]	65.00	[54.951, 75.049]			

Abbreviations: SOVM-WR: semi-occluded water-resistance ventilation mask; WRT: water resistance therapy; CI: confidence interval.

* significant effect ($p < 0.05$).

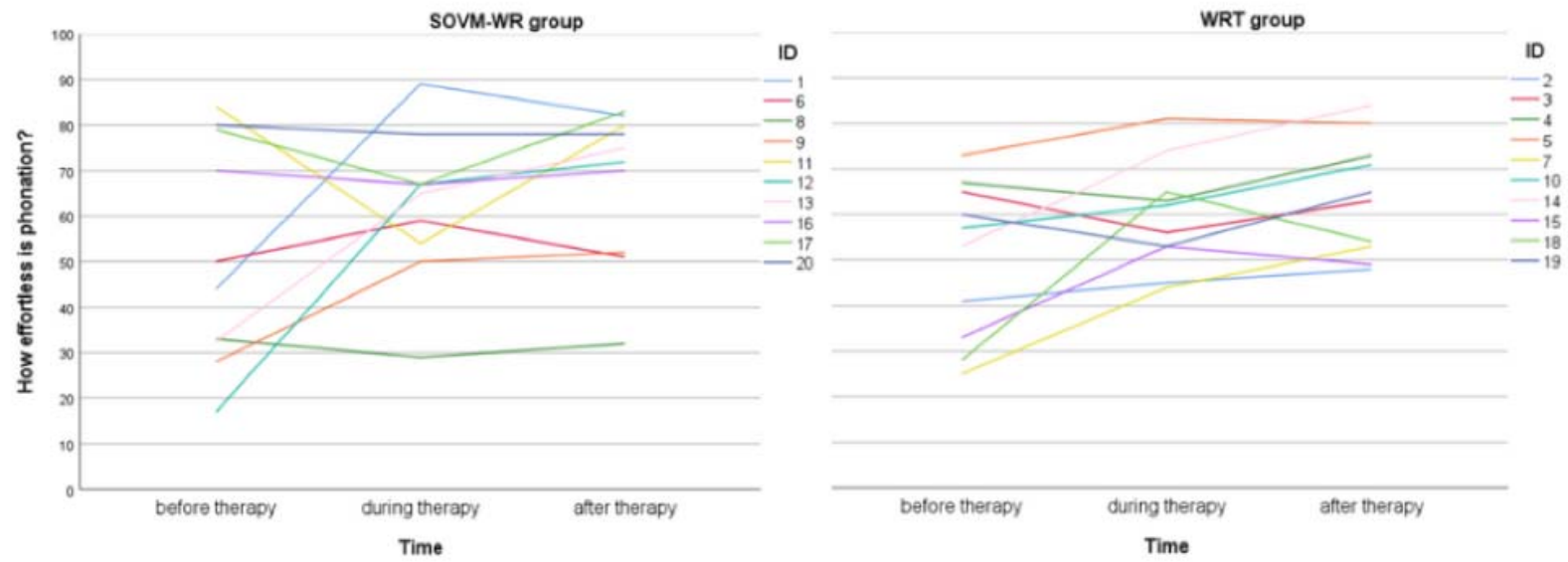


Fig. 4. Evolution of vocal effort in the SOVM-WR and WRT group (individual level).

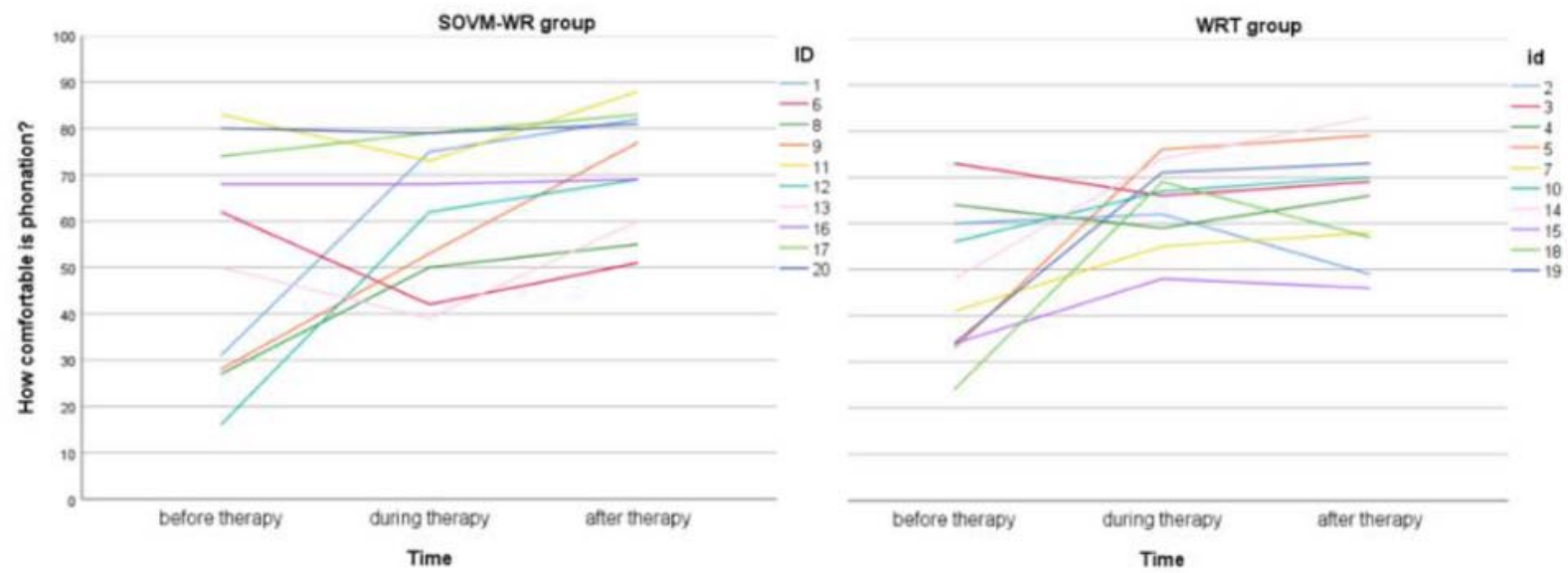


Fig. 5. Evolution of vocal comfort in the SOVM-WR and WRT group (individual level).

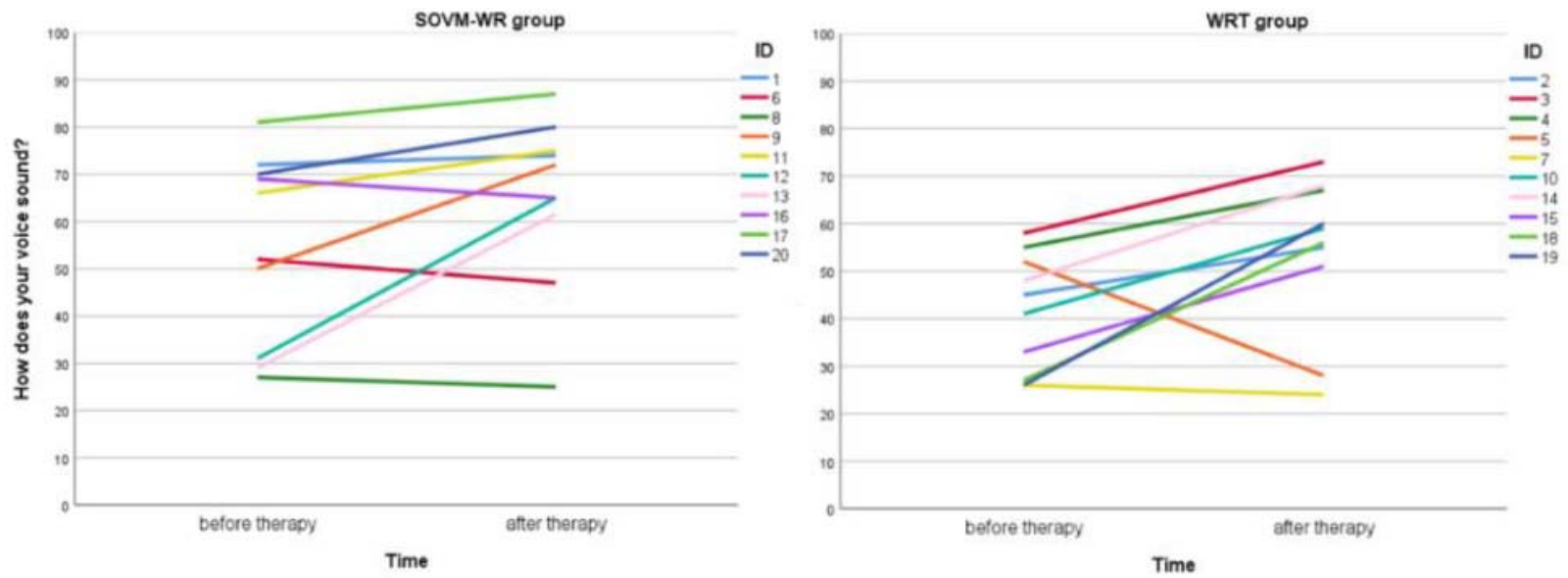


Fig. 6. Evolution of self-perceived voice quality in the SOVM-WR and WRT group (individual level).

4. Discussion

The purpose of the current study was to compare the immediate effects of the SOVM-WR and WRT on the objective, perceptual and patient-reported vocal outcomes in women with dysphonia. It was hypothesized that SOVM-WR would result in a greater improvement of outcome parameters that are partly based on continuous speech (i.e. AVQI and auditory perceptual evaluation) due to the nature of the technique (Awan et al., 2018; Mills et al., 2017).

In general, few changes in acoustic and aerodynamic parameters were observed in either of the groups. These findings are similar to those of Guzman et al. (2021), although the average instrumental parameters were already within normal range before voice therapy in the latter study. WRT, like other SOVTEs, is commonly used to improve vocal economy and efficiency (Calvache et al., 2019; Laukkanen et al., 2008; Titze, 2006), and its benefits have been reported in previous studies (Guzman et al., 2017b; Mailänder et al., 2017; Mendes et al., 2019). The fact that the current study revealed no changes in acoustic or aerodynamic parameters on group level may partially be the result of several methodological differences, such as selected outcome parameters and the investigated population. No decrease in jitter was found in the WRT or the SOVM-WR group, which contradicts a recent study by Guzman et al. (2017b), who reported that jitter decreased in vocally healthy participants during and after a 5 min session of phonation through a resonance tube submerged 5 cm into water. It is possible that a more superficial submersion of 2 cm in water, as was used in the current study, does not yield the same benefits as a deeper submersion, which induces higher flow resistance (Andrade et al., 2016) and potentially more regular changes in vertical larynx position (Horáček et al., 2017). Additionally, the diameter of the tube may also be of importance in influencing the effects of voice therapy, because of its impact on flow resistance and oral pressure (Andrade et al., 2016; Smith & Titze, 2017). Maxfield et al. (2014) suggest that a smaller diameter could provide airflow resistance at a level that is similar to that produced by the glottis in female patients. In this respect, it is possible that the diameter used in the current study (i.e. 10 mm) might not have produced sufficient resistance to cause a significant improvement in most acoustic and aerodynamic parameters. On the other hand, a larger diameter might provide a higher degree of massage-like sensation, which could increase vocal comfort in patients with vocal complaints (Guzman et al., 2020b). It would be interesting for future research to examine the effects of tube diameter on vocal outcomes in order to determine the optimal diameter for effective voice therapy in patients with dysphonia. Another aspect that may influence the immediate effect of the SOVTEs, besides depth of submersion and tube diameter, is the duration of the therapy session. Echternach et al. (2020) reported an increase in jitter after a ten-minute WRT session with an immersion of 5 cm in participants with vocal fold mass lesions. According to the authors, it is possible that a ten-minute session of WRT provokes too much vocal loading for patients with vocal fold mass lesions. Similarly, Paes and Behlau (2017) found that PROMs, MPT and vf_0 worsened after five minutes of straw phonation in dysphonic women, but not in vocally healthy women. Differences in exercise duration might offer another explanation as to why the current study revealed different results than Guzman et al. (2017), where vocally healthy participants only practiced for five minutes. In this regard, it seems useful to take the duration of WRT exercises into consideration when developing a treatment plan. More research is necessary on this topic, but several studies seem to report an optimal exercise duration of five to ten minutes

(Gillespie et al., 2022; Kang et al., 2019; Menezes et al., 2011). In the current study, a duration of 30 min was selected in accordance with the study by Meerschman et al. (2020) on SOVM-WR in musical theater students, and to allow for completion of all levels of exercises (i.e. vowel, word, sentence, and text level).

No significant evolution in frequency or intensity range was found for either of the groups, although an increase of lowest frequency was observed in both groups. Few studies have investigated the effects of WRT or SOVM-WR on VRP, although similar findings have been reported for WRT (Mailänder et al., 2017; Meerschman et al., 2020). Mailänder et al. (2017) did not reveal significant improvements of frequency or intensity range in healthy female participants after a three-week training program with WRT, but an expansion in the upper contour of the VRP was reported. Likewise, Meerschman et al. (2020) did not observe any significant immediate effects of WRT on frequency or intensity range in musical theater students after a 30-minute therapy session. However, a decrease in intensity range and an increase in semitone range was reported in the SOVM-WR group (Meerschman et al., 2020), which was not reflected in the current study. Another study observed an immediate improvement of frequency range in healthy amateur choristers after a three minute vocal warm-up exercise of WRT (Cardoso et al., 2019). It is possible that a shorter duration of practice encourages more favorable immediate effects, while longer sessions (e.g. 30 min) might cause a certain degree of vocal fatigue immediately afterwards, as discussed above. However, since Cardoso et al. (2019) determined the VRP of the singing voice in healthy subjects by means of an ascending and descending glissando, their results cannot be compared to those of the current study, where another methodology was implemented to investigate the VRP of the speaking voice in a different population.

No significant changes in the multiparametric voice quality indices DSI or AVQI were found in the WRT and SOVM-WR groups, although a mild improvement of AVQI was observed. Barsties and Maryn (2013) have shown that a difference of 0.54 between two consecutive AVQI scores can be clinically relevant, so while the mean improvement in both groups did not reach this value, seven participants had a decrease in AVQI greater than 0.54 (3 in the SOVM-WR group, 4 in the WRT group) after one therapy session. Two (one in each group) had a worse AVQI, and the remaining participants showed a smaller evolution. Due to the small sample size in the current study, it remains important to analyze the evolution of voice quality on an individual level. The fact that several participants already achieved a clinically relevant improvement of AVQI after one therapy session could illustrate the usefulness of the SOVTEs in clinical practice. However, our results still differ somewhat from a recent similar study by Meerschman et al. (2020), which reported a significant positive evolution of DSI and AVQI at group level in musical theater students after a 30-minute therapy session of WRT. Differences in the vocal capacities between vocally healthy future elite vocal performances and dysphonic speakers could explain these contradictory results. Future research could help identify patient characteristics that may predict the success of voice therapy outcomes. Another study reported no significant evolution of DSI in patients with dysphonia after eight therapy sessions of WRT (Meerschman et al., 2019), which seems to be more in line with the current findings. Again, this lack of improvement in vocal capacities in our study might be the result of beginning vocal fatigue in the WRT group, which may have been compensated for after multiple therapy sessions (Meerschman et al., 2019).

None of the auditory-perceptual vocal outcomes revealed a significant evolution after the therapy session in either of the groups. Considering certain principles of motor learning important in voice therapy, such as repetition and massed practice (Iwarsson, 2015; Patel et al., 2011), it is possible that one 30-minute session is insufficient to elicit important auditory-perceptual changes in voice quality. Our results are similar to those of Meerschman et al. (2020), who reported no significant changes in auditory-perceptual vocal outcomes based on a VAS, except for an increase in Strain in the speaking voice of musical theater students after a 30-minute session of WRT, but no changes in the SOVM-WR group. Additionally, since a four-point ordinal scale was used for the auditory-perceptual assessment in the current study, more subtle changes in auditory-perceptual voice quality were maybe not detected.

The PROMs showed that both groups reported a better voice quality, less vocal effort and more vocal comfort after the therapy session compared to before the start of the session, similar to findings from previous studies investigating self-evaluation of voice quality after WRT or SOVM-WR in healthy or dysphonic participants (Guzman et al., 2018, 2021; Guzman et al., 2017a; Meerschman et al., 2019, 2020). This decrease in vocal effort might be the result of a lower PTP during the SOVTE, which facilitates phonation (Conroy et al., 2014; Story et al., 2000; Titze & Abbott, 2012), but no PTP measurements were performed in the current study. It is also hypothesized that WRT and SOVM-WR may produce a 'massage effect' on the vocal folds due to the bubbling water (i.e. a secondary vibration source), which may increase vocal comfort in the participants (Andrade et al., 2014). A minority of the participants in the SOVM-WR group reported some difficulties with avoiding air leakage due to unfamiliarity with the material, which may explain slightly lower scores of vocal effort and comfort during the session in these individuals. However, this issue was quickly resolved with repeated exercise and additional cueing by the therapist. Furthermore, all participants held a positive opinion on WRT and SOVM-WR and indicated that they would practice it at home. This insight should not be neglected in a therapeutic setting, considering that patient preference remains an important aspect within the evidence-based practice model (Haynes et al., 1996). For example, several studies have found a decrease in VHI score after a therapy program of WRT or SOVM-WR (Guzman et al., 2021; Guzman et al., 2017a; Mailänder et al., 2017; Meerschman et al., 2019), demonstrating its value in voice therapy. The SOVM-WR has the potential to induce the same benefits as WRT and may provide benefits to the patient's psychosocial wellbeing regarding their voice.

4.1. Limitations

The current study also has its limitations. Due to the small sample sizes of each group and the lack of male participants in the current study, results cannot be generalized to the entire dysphonic population. Further research with larger sample sizes is needed to verify or refute the current findings. Additionally, both participants with either a diagnosis of organic or functional dysphonia were included. However, it is possible that patients with an organic voice pathology react differently to certain interventions, resulting in inconclusive results (Speyer, 2008). More research with larger groups or the inclusion of only a specific voice pathology is desirable to compare the effects of voice therapy between patients with organic dysphonia and patients with functional dysphonia. It should also be noted that only the immediate effects of one session with WRT or SOVM-WR were measured in the current study. Given that motor learning occurs in different stages which span over different time periods,

it is possible that short-term effects do not fully predict possible long-term changes. Longitudinal research on this topic would therefore be useful in order to investigate long-term motor learning processes in voice therapy. Lastly, it is not possible to fully exclude the possibility of a placebo effect on PROMs in the current study due to the lack of a sham group.

5. Conclusion

Neither WRT nor SOVM-WR revealed significant positive effects on objective and auditory-perceptual vocal outcomes in dysphonic women after a 30-minute therapy session. Possible explanations for this lack of improvement include water depth, tube diameter, lack of transfer of the techniques, and vocal fatigue; more research is needed to discover the optimal water immersion and dimensions of the resonance tube for specific therapy goals and patient populations. Additionally, an increased self-perceived voice quality and vocal comfort and decreased vocal effort were reported in both groups, which reaffirms the merit of both techniques regarding patient-reported outcome measures in voice rehabilitation.

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CRedit authorship contribution statement

Imke Kissel: Methodology, Formal analysis, Investigation, Supervision, Visualization, Data curation, Writing – original draft, Writing – review & editing. Tine Papeleu: Investigation, Writing – review & editing. Jolien Verbeke: Investigation, Writing – review & editing. Kristiane Van Lierde: Conceptualization, Methodology, Investigation, Resources, Writing – review & editing. Iris Meerschman: Conceptualization, Methodology, Investigation, Resources, Writing – review & editing. Evelien D’haeseleer: Conceptualization, Methodology, Resources, Supervision, Writing – review & editing.

Declaration of Competing Interest

There is no conflict of interest

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Appendix A: Dutch oronasal reading passage 'Papa en Marloes

Papa en Marloes staan op het station.

Ze wachten op de trein.

Eerst hebben ze een kaartje gekocht.

Er stond een hele lange rij, dus dat duurde wel even.

Nu wachten ze tot de trein eraan komt.

Het is al vijf over drie, dus het duurt nog vier minuten.

Er staan nog veel meer mensen te wachten.

Marloes kijkt naar links, in de verte ziet ze de trein al aankomen.

Appendix B: VAS questionnaire – participants' self-evaluation (translated from Dutch)

Pre-experimental questionnaire

How does your voice sound at this moment?

Bad

Good

How effortful is phonation at this moment?

Effortful

Effortless

How comfortable is phonation at this moment?

Uncomfortable

Comfortable

Post-experimental questionnaire

How does your voice sound at this moment?

Bad

Good

How effortful is phonation...

During the therapy session?

Effortful

Effortless

After the therapy session?

Effortful

Effortless

How comfortable is phonation...

During the therapy session?

Uncomfortable

Comfortable

After the therapy session?

Uncomfortable

Comfortable

What is your experience with the used vocal technique?

Unpleasant

Pleasant

Would you practice these exercises at home?

- Yes
- No