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Efficacy of an Arabic articulatory errors remediation software program in patients with velopharyngeal valve dysfunction: a quasi-experimental study

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Abstract

Background: Velopharyngeal dysfunction causes abnormal speech due to altered nasal resonance during the production of oral speech sounds. The development of computer-based speech therapy has been growing to make use of computer technology in providing an organized effective source for speech therapy and feedback. The development of a remediation software program that is specific for patients with velopharyngeal dysfunction in the Arabic language and testing its efficacy on patients' speech was the aim of this study.

Results: The study showed significant improvement in speech parameters after intervention with p value less than 0.05 for nasometer values and parameters of auditory perceptual assessment. The study proved a significant relation between nasometer values and auditory perceptual assessment.

Conclusion: The designed software program proved to be a good therapeutic tool in improving speech in patients with velopharyngeal dysfunction. The application of the program on a larger number of patients and in comparison with traditional methods of speech therapy and biofeedback is recommended.

Trial registration: The study was retrospectively registered at www.clinicaltrials.gov NCT04392817

Keywords: Velopharyngeal dysfunction, Hypernasality, Biofeedback, Articulation

Background

Normal speech production depends upon coordination between the four important physiological processes which are respiration, phonation, articulation, and resonance [1]. Velopharyngeal valve plays an important role in speech production through the regulation of acoustic energy to the nasal pathway when producing nasal speech sounds and to the oral pathway when producing oral speech sound [2, 3].

Inadequate function of the velopharyngeal valve leads to inadequate closure of the valve, which affects speech production. This is referred to as velopharyngeal dysfunction. This may be due to either structural defects, neurological affection, myopathic affection, or functional (with no apparent cause) [4].

Speech affection can be classified into (i) passive errors which occur due to a gap on velopharyngeal closure in the form of: hypernasality, weak imprecise consonants, and short utterance length; and (ii) compensatory articulatory errors when the articulatory movements for different phonemes change due to dysfunction. These errors include glottal stops and fricatives, pharyngealization, velar plosives, and nasal fricatives [5, 6].

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Assessment of VPD includes (a) adequate history taking to search for possible causes, (b) physical examination of the vocal tract, (c) auditory perceptual assessment of patient's speech (d) clinical diagnostic tests for nasal air emission and nasal tone, (f) examination and documentation of velopharyngeal valve closure by nasopharyngoscope, and (g) instrumental assessment by nasometer and aerodynamic measures [7].

Management of VPD differs according to the cause, size of the gap, and the function. The main lines include surgical, prosthetic, and speech therapy [3]. Determining the proper surgery depends on the size of the gap and the main contributors to closure (soft palate or lateral pharyngeal walls) [3]. Prosthesis are used in cases which are contraindicated or delayed surgery. Palatal lift is suitable for adequate length but immobile soft palate, while speech bulb for inadequate length soft palate [8–10].

Speech therapy cannot correct structural defects but is important for correcting functional (speech errors). Kummer A.W (2008) stated that indications of speech therapy in cases of VPD include compensatory articulation productions due to VPI, hypernasality which is phoneme specific, hypernasality due to apraxia of speech, and persistent hypernasality after surgical correction of velopharyngeal insufficiency [11]. Biofeedback methods can be used with speech therapy including simple methods as straw and air paddle or more advanced methods as nasopharyngoscopy and nasometer games [12, 13].

Designing software programs has been emerging as an advanced tool for speech and language therapy for speech sound disorders, dyslexia, prosody, and aphasia. These programs were designed in many languages as English, Romanian, Turkish, and other languages [14].

There is a lack of software programs in the Arabic language for speech therapy in VPD. So the aim of this study was to design a software program in Arabic language for correcting speech errors in VPD and to test if it was effective for Arabic-speaking patients with VPD.

Methods

Aim of the work

To design a remediation software program in Arabic language specific for articulatory errors in patients with velopharyngeal dysfunction and to test its efficacy on nasometer values, articulation, and auditory perceptual assessment of patient's speech.

Designing the program

The software program was first designed according to the phonetic approach in the following steps: (I)

discriminating incorrect production, (II) awareness of the correct production, (III) production of the correct phoneme in initial, middle, final position in words and sentences. This is done through (a) animated graphs of the vocal tract and (b) auditory feedback. The interface of the program includes seven main menus: patient data, glottalization, distorted R sound, nasalized phoneme, palatal dorsal production, pharyngeal fricatives, pharyngeal plosives, backing, nasalized vowels, and test yourself. The patient data menu includes personal data of the patients, their pre therapy evaluation, and follow-up evaluation. The "test your self" menu includes simple sentences and questions related to these sentences to be answered by the patient. The patient recorded his answer and listened back to evaluate if the errors were corrected or not. The remaining menus includes auditory discrimination menu, awareness menu, and production menu.

The subjects and methods

The study was designed as a quasi-experimental comparing pre- and post-intervention outcomes. The ethics committee of the Faculty of Medicine approved the study (no. 0105440). The study was retrospectively registered at www.clinicaltrials.gov NCT04392817. The sample size included 40 patients chosen randomly from patients attending the Unit of Phoniatrics, Otorhinolaryngology Department, Alexandria University. Inclusion criteria: age of 5 years and above with articulation errors due to VPD, normal hearing, and vision. Exclusion criteria: unrepaired cleft palate or large fistula, patients with brain damage, and intellectual disability.

The patients were diagnosed through complete history taking, physical examination, clinical diagnostic tests, and instruments: nasopharyngoscopy to assess velopharyngeal valve closure during speech tasks: sentences loaded with oral and nasal phonemes, and automatic speech counting from 1 to 10. This procedure determines the cause of dysfunction whether structural deficiency or velopharyngeal mislearning.

Nasometer II model 6450 was used to assess nasalance score for vowels /a/, /i/, /u/, consonants /b/, /t/, /k/, nasal sentences, and oral sentences. Normative data for nasometer values were considered according to Kotby et al. [7] and Abou-Elsaad et al. [15]: /a/ $5 \pm 4\%$, /i/ $15 \pm 7\%$, /u/ $8 \pm 5\%$, /b/ $14 \pm 8\%$, /t/ $15 \pm 8\%$, /k/ $11 \pm 9\%$, nasal sentence 47%, and oral sentence 10%.

Articulation errors were diagnosed by the Arabic articulation test by Kotby et al. [16] which is descriptive for each phoneme in the Arabic language in the initial, middle, and final positions. Phonemes included are (/θ/, /s/, /z/, /š/, /f/, /h/, /ʔ/, /x/, /ʃ/, /ħ/, /b/,

/t/, /d/, /d⁻/, /t⁻/, /k/, /g/, /ʕ/, /ʁ/, /l/, /r/, /m/, /n/, /j/, /w/). The errors were labeled as the following: glottal stops, pharyngeal fricatives, backing, distorted /r/ sound, substitution of oral plosives /b/, /t/, and /k/ with nasal sounds (nasalized phonemes) [17, 12].

The speech of the patients was evaluated by auditory perceptual assessment and grading of the degree of nasality, glottalization, pharyngealization, consonant imprecision, and overall intelligibility through a 5-grade scale beginning from 0 (normal) to 4 (severe). Evaluation of automatic speech and specified sentences containing for each phoneme in initial, middle, and final positions [18].

The program was applied in the form of individual sessions in a duration ranging from minimum 1 month (in cases with phoneme specific hypernasality, velopharyngeal mislearning, who responded in a short time and did not need further sessions) to a maximum 6 months, about 2 sessions per week, 30 min each, according to the number of errors in each case. It was applied in the outpatient clinic.

The sessions start by (1) auditory discrimination of the articulatory error: the patient listened to a chosen word and recorded his production to listen back to his production and the correct word. (2) Awareness of the correct production. (3) Trial producing the correct phoneme in syllables, initial, middle, and final positions. (4) Trying to produce sentences and stories loaded with the phoneme. The patient was wearing headphones and using a recording icon on the program. This provides auditory feedback to the patient. (see the Appendix for screenshots of the program). We used visual and auditory stimulus. The patients were required to do some home exercises to increase practice. A CD containing some examples from the program was given to the patients who ha computers at home.

After finishing the therapy, the patients were reevaluated by nasometer II for nasalance scores, Arabic articulation test to assess the articulatory errors, if corrected or not, auditory perceptual assessment as previously mentioned. The data were blindly collected and analyzed.

Statistical analysis

Statistical analysis was carried out using SPSS statistics software version 23. Quantitative data were tested for normality using the Kolmogorov-Smirnov test. The variables which were normally distributed were described by mean ± SD. The variables which were not normally distributed were described by median (min–max). Qualitative data were expressed by numbers and percentages. The results were calculated at a level of significance of 5% or less.

Results

They were 55% males and 45% females, with mean age of 9.22 ± 3.02 years. Figure 1 shows that by nasopharyngoscopy, 47.5% had compensatory errors with repaired velopharyngeal insufficiency VPI with no gap on speech production (corrected either by primary repaired cleft palate, palatoplasty, or were secondary repaired by superiorly based pharyngeal flap). Thirty-five percent were found to have errors due to velopharyngeal mislearning, referring to functional or habitual VPD and 17.5% had compensatory errors due to unrepaired VPI with a gap on speech production (those include 5 patients who had primary repair of overt cleft palate and residual post-operative velopharyngeal insufficiency and 2 patients with deep pharynx).

Table 1 shows distribution of different articulatory errors in each group and their frequency is shown. The distribution of articulatory errors was similar in both repaired and unrepaired VPI groups. The

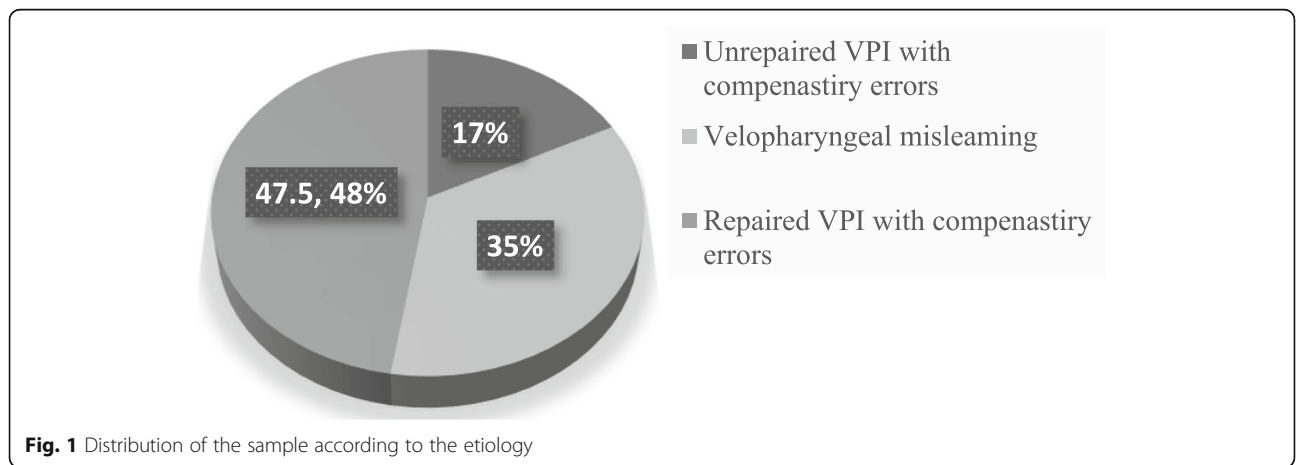


Fig. 1 Distribution of the sample according to the etiology

Table 1: Frequency of each articulatory error in each group

	Repaired VPI		Velopharyngeal mislearning		Unrepaired VPI	
	No.	%	No.	%	No.	%
Substitution errors (Nasalized phonemes)	20	35	10	34	11	55
Pharyngeal fricatives	18	31.5	8	27.5	5	25
Glottal stops	10	17.5	4	14	2	10
Backing	5	9	2	7	0	0
Lateral fricatives	2	3.5	4	14	1	5
Distorted /r/ sound	2	3.5	1	3.4	1	5
Total no. of defects	57	100	29	100	20	100

substitution errors (nasalized phonemes: oral sounds /b/, /t/, and /k/ replaced by nasal sounds) [12, 17], were the most common followed by pharyngeal fricatives then glottal stops.

Figures 2, 3, 4, 5, and 6 show post-intervention correction of articulatory errors regarding the results of the Arabic articulation test. These are described as percentages: completely corrected if all positions were pronounced correctly, partially corrected if one or two positions were pronounced correctly and not corrected if no position was correct.

Table 2 shows that there was statistically significant improvement between the medians of auditory perceptual assessment grades before and after therapy for degree of nasality, degree of glottalization, degree of pharyngealization, consonant imprecision, and overall intelligibility.

The subjective scores of auditory perceptual assessment of speech post-therapy were rated by 2 phoniatricians for 32 cases who complied till the end of the treatment program. While eight cases did not come for assessment by the second assessor. Table 3 shows that the agreement between the two raters ranged from good agreement for degree of nasality and glottalization, to moderate agreement for pharyngealization, consonant imprecision, and overall intelligibility.

Table 4 shows that there was no significant difference in the post-intervention degree of auditory perceptual assessment between patients with repaired and patients with unrepaired velopharyngeal insufficiency using Mann-Whitney test.

There was a statistically significant improvement in mean of post-intervention nasometer values when compared to pre-therapy values as shown in Table 5.

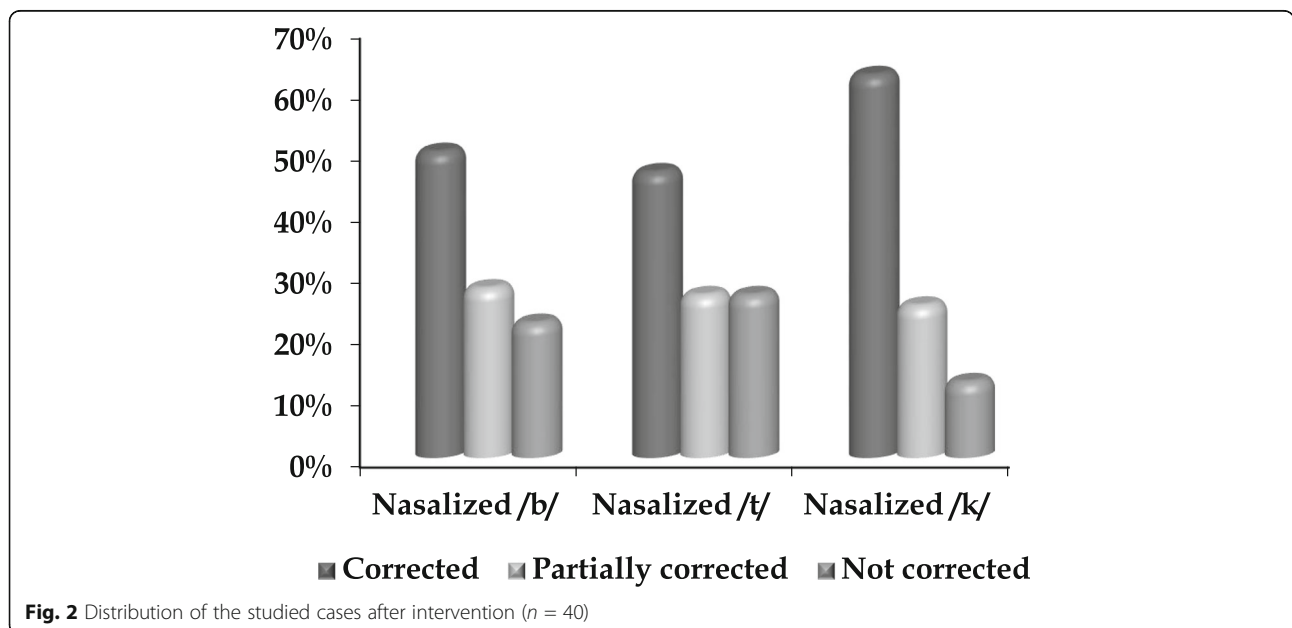


Fig. 2 Distribution of the studied cases after intervention (n = 40)

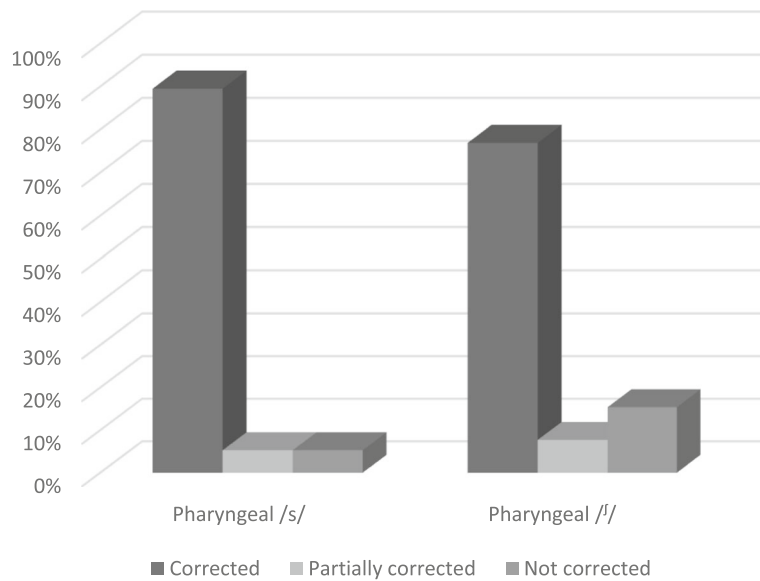


Fig. 3 Distribution of the studied cases after intervention (n = 40)

Studying relation of age to nasometer values pre- and post-therapy, there was a positive correlation between age and nasometer value of oral sentence only pre- and post-therapy but not for other nasometer values as shown in Table 6. That denotes that age was not a prognostic factor for improvement in nasality score by nasometer values except for oral sentence.

Comparing the group with compensatory errors following repaired VPI and compensatory errors with unrepaired VPI according to nasometer values post-therapy showed no statistically significant difference between the two groups as shown in Table 7.

Correlations between the degree of severity of auditory perceptual assessment (degree of nasality, glottalization, pharyngealization, consonant imprecision, overall intelligibility) before intervention and degree of improvement after intervention using Pearson coefficient showed moderately positive correlation for the degree of open nasality and glottalization. Correlation for the degree of pharyngeal fricatives was weakly positive. Correlation for degree of consonant imprecision and overall intelligibility was strongly positive as shown in Table 8.

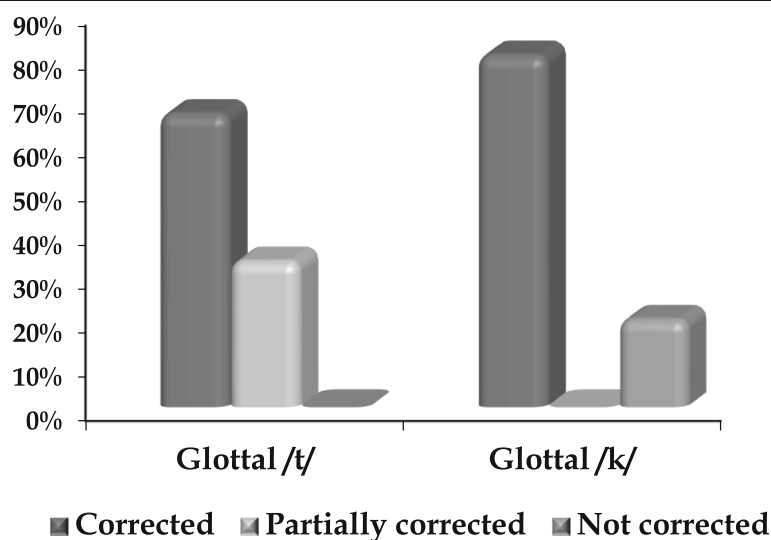


Fig. 4 Distribution of the studied cases after intervention (n = 40)

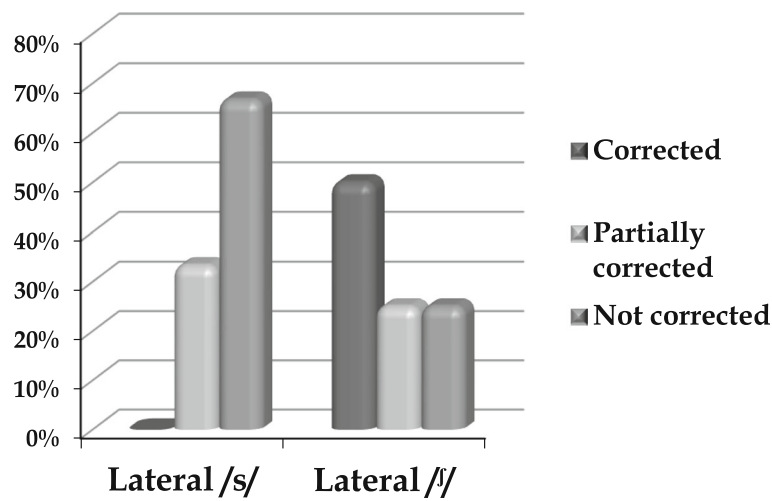


Fig. 5 Distribution of lateral fricatives errors after intervention

There was a moderately positive correlation between the degree of nasality and nasometer values for /i/, /u/, and oral sentence before the intervention and there was a weak positive correlation between the degree of nasality and nasometer values for /k/ and oral sentence after intervention as shown in Table 9.

Discussion

Patients with VPD usually have passive and/or active speech errors that necessitate speech therapy. Designing and testing the efficacy of a software program for speech therapy in Arabic-speaking patients with VPD were the aims of this study.

Regarding the age factor, the patients’ mean age was 9.02 years and the standard deviation of 3.22 years. There were 4 cases aged 14–15 years with 3 of them showed good response, needed less number of sessions, and they showed also low compliance to therapy.

There was a significant relationship between age and some nasometer values including /i/, /u/, and oral sentence before therapy. This denotes that nasometer values were higher with older ages rather than lower age. This finding could be attributed to some anatomical changes that occur with aging suggested by Siegel-Sadewitz and Shprintzen which include involution of adenoid, decrease in lateral pharyngeal walls movement and change in the closure pattern [19].

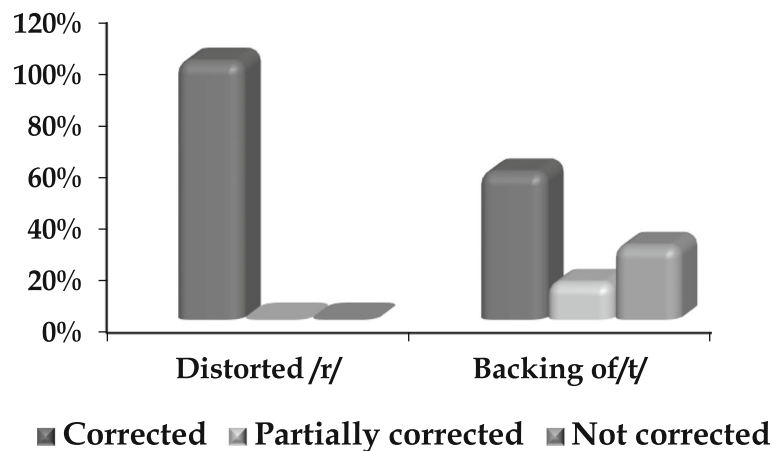


Fig. 6 Distribution of the studied cases after intervention (n = 40)

Table 2 Comparison between medians of degree of auditory perceptual assessment of speech before and after intervention

	Before intervention (n = 40)	After intervention (n = 40)	Test of significance (p)
Degree of nasality			
Median (min–max)	1.5 (0–3)	1(0–2)	(z = - 4.2, p < .0001**)
Glottal			
Median (min–max)	0 (0–3)	0 (0–3)	(z = (z = - 2.8, p < .004 *)
Pharyngeal fricative			
Median (min–max)	1.5 (0– 3)	0 (0– 3)	(z = - 4.1, p < .0001**)
Consonant imprecision			
Median (min–max)	1 (0– 2)	0 (0– 2)	(z = - 4.03, p < .0001**)
Overall intelligibility			
Median (min–max)	1 (0– 3)	0 (0– 2)	(z = - 3.64, p < .0001**)

Z Wilcoxon test

*Statistically sig < .05

**Highly significant < .001

Also, this finding agrees with a study by Abou-Elsaad et al. which showed that increased nasalance scores tends to occur in Egyptian-speaking adults [15]. Also, a study on Korean speakers by Seunghee and Seong-Hyeon revealed that adults had significantly higher nasalance scores than children group [20].

As for the effect of etiology, patients who had compensatory errors after repaired velopharyngeal insufficiency by pharyngeal flap represented 45% of the sample. Also, 17.5% of the sample was due to VPI not repaired by pharyngeal flap which include four cases had primary palatoplasty for cleft palate

and needed secondary repair. Another two cases with deep pharynx and/or high arched palate, and the size of gap improved after the application of software program. Phua and de Chalain stated that about 20 to 30% of children with cleft palate will still have VPI resulting in abnormal speech after primary repair [21].

Regarding the auditory perceptual assessment of speech, there was a statistically significant improvement in auditory perceptual assessment after applying the program. Also, there was a positive correlation between the degree of auditory perceptual assessment before therapy and improvement after therapy. So, the higher pre-therapy grades were associated with better improvement after intervention. This finding suggests that a higher degree of auditory perceptual assessment was associated with high patient awareness, good auditory discrimination of correct articulation, and a better chance for correcting these errors. Auditory perceptual assessment is particularly an important criterion in the assessment of speech errors and consequently the effectiveness of speech therapy [22].

The proposed program was effective in decreasing nasometer values. This finding suggests that correcting abnormal articulatory placement decreased the abnormal high nasometer values, which may be explained by changing the abnormal tongue position, thus facilitating the oral direction of sounds. Also, working on discriminating nasal production of vowels and correcting them was effective in decreasing their nasalance scores.

There was a positive correlation between nasometer values for the oral sentence and the degree of open nasality. Also, there was a positive correlation between nasometer values for vowels /i/ and /u/. This

Table 3 The inter rater agreement between the two raters regarding the post therapy parameters of auditory perceptual assessment of speech (n = 32)

	Rater 1 vs rater 2	
	k (p)	LOA
Degree of nasality	0.683*(< 0.001*)	Good agreement
Glottal	0.692*(< 0.001*)	Good agreement
Pharyngealization	0.472*(< 0.001*)	Moderate agreement
Consonant imprecision	0.522*(0.001*)	Moderate agreement
Overall intelligibility	0.531*(< 0.001*)	Moderate agreement
	Value of K	Strength of agreement
	< 0.20	Poor agreement
	0.21–0.40	Fair agreement
	0.41–0.60	Moderate agreement
	0.61–0.80	Good agreement
	0.81–1.00	Very good agreement

k KAPPA test, LOA level of agreement, p p value for comparing between rater 1 and 2

*Statistically significant at p ≤ 0.05

Table 4: Comparison between repaired and unrepaired velopharyngeal insufficiency regarding post-intervention degree of auditory perceptual assessment of speech

	Repaired VPI (n = 18)	Unrepaired VPI (n = 7)	Test of significance (p)
Degree of nasality			
Median (min–max)	1 (0–2)	1(0–2)	(U = 61.5, p = .93)
Glottal			
Median (min–max)	0 (0–2)	0 (0–0)	(U = 56, p = .7)
Pharyngeal fricative			
Median (min–max)	0 (0–2)	0 (0–1)	(U = 57.5, p = .745)
Consonant imprecision			
Median (min–max)	0 (0–1)	1(0–2)	(U = 42, p = .22)
Overall intelligibility			
Median (min–max)	0 (0–2)	0 (0–2)	(U = 50, p = .46)

U Mann-Whitney test

finding goes with a study by Brunnegård, Lohmander [23], who stated that there was a positive correlation between nasalance scores and hypernasality ratings. This proves that a nasometer is an important part of the initial evaluation of speech in cases of VPD and follow-up. Also, it helps to confirm the rating of hypernasality especially for inadequately trained phoniatrics [23].

The comparison of the post-intervention nasometer values between the group with repaired VPI and the group with unrepaired VPI shows no significant difference between these groups. As mentioned before, the group of unrepaired VPI in this study included was divided into cases with a need for secondary repair and cases improved without need for repair, and this group was small in number so that this study could not prove that speech therapy in repaired VPI is successful more than unrepaired VPI. Further studies are needed to study the actual difference between the two groups.

The program was effective in correcting pharyngeal fricatives completely in 89.5% of pharyngeal /s/ sound and 76.9% of pharyngeal /ʃ/ sound.

For glottal stops, the program was effective in complete correction of 66.7% of glottalized /t/ and 80% of glottalized /k/ sound.

Complete correction of lateral fricatives was obtained in 50% of lateral /ʃ/.

Yet, complete correction of lateral /s/ could not be obtained; partial correction was only noticed in

Table 5 Comparison between mean of nasometer values before and after the intervention

Nasometer values	Pre	Post	Test of sig.	p
/a/	(n = 40)	(n = 40)		
Min.–max.	7.0–93.0	3.0–99.0	Z = 3.999*	< 0.001*
Mean ± SD	42.03 ± 20.0	24.65 ± 21.03		
Median	44.50	22.0		
/i/	(n = 40)	(n = 40)		
Min.–max.	5.0–96.0	7.0–98.0	t = 5.438*	< 0.001*
Mean ± SD	66.0 ± 25.78	46.40 ± 21.96		
Median	76.0	45.0		
/u/	(n = 40)	(n = 40)		
Min.–max.	6.0–87.0	2.0–98.0	Z = 3.636*	< 0.001*
Mean ± SD	45.23 ± 25.19	30.35 ± 23.24		
Median	44.50	28.50		
/b/	(n = 40)	(n = 40)		
Min.–max.	7.0–95.0	0.0–98.0	Z = 3.979*	< 0.001*
Mean ± SD	60.90 ± 30.27	29.95 ± 30.36		
Median	75.50	16.50		
/t/	(n = 38)	(n = 39)		
Min.–max.	10.0–91.0	0.0–92.0	Z = 4.112*	< 0.001*
Mean ± SD	50.18 ± 28.94	27.05 ± 27.13		
Median	43.50	16.0		
/k/	(n = 32)	(n = 40)		
Min.–max.	7.0–94.0	0.0–98.0	Z = 2.674*	0.007*
Mean ± SD	46.50 ± 27.15	30.63 ± 25.17		
Median	41.0	20.0		
Nasal sentence	(n = 40)	(n = 40)		
Min.–max.	42.0–92.0	37.0–97.0	t = 3.864*	< 0.001*
Mean ± SD	71.83 ± 13.01	60.98 ± 12.15		
Median	71.0	60.50		
Oral sentence	(n = 40)	(n = 40)		
Min.–max.	8.0–87.0	9.0–99.0	Z = 3.623*	< 0.001*
Mean ± SD	48.78 ± 19.11	35.25 ± 18.80		
Median	52.0	34.0		

t paired t test, Z Wilcoxon signed ranks test
 p p value for comparing between pre and post
 *Statistically significant at p ≤ 0.05
 **Highly significant < .001

33.3% of errors. This finding was observed in patients who have retrognathia accompanying VPD which affected correct production of sound /s/. Lastly, the software program could completely cure 100% of distorted /r/ sound and 57.1% of backing /t/. A study that critically appraised many computer programs for speech therapy and did systematic review stated that level of evidence for CBST was moderate, and it can be complementary to

Table 6 Correlation between age and nasometer values

Nasometer values	N	Age (years)		
		R	P	
/a/	Pre	40	0.168	0.301
	Post	40	0.238	0.140
/i/	Pre	40	0.346*	0.029*
	Post	40	0.300	0.060
/u/	Pre	40	0.157	0.333
	Post	40	0.325*	0.041*
/b/	Pre	40	0.249	0.121
	Post	40	0.042	0.795
/t/	Pre	38	0.105	0.530
	Post	39	0.007	0.967
/k/	Pre	32	0.420*	0.017*
	Post	40	0.177	0.275
Nasal sentence	Pre	40	0.217	0.178
	Post	40	0.052	0.750
Oral sentence	Pre	40	0.326*	0.040*
	Post	40	0.397*	0.011*

r Pearson coefficient
*Statistically significant at $p \leq 0.05$

Table 7 Comparison between repaired and unrepaired velopharyngeal insufficiency regarding post-intervention nasometer values

	Repaired VPI (n = 18)	Unrepaired VPI (n = 7)	Test of significance (p)
/a/			
Median (min-max)	20 (5-99)	11 (5-37)	(U = 51, p = .495)
/i/			
Median (min-max)	42.5 (13-98)	53 (12-72)	(U = 56, p = .7)
/u/			
Median (min-max)	30.5(2-90)	17 (3-57)	(U = 52, p = .534)
/b/			
Median (min-max)	16 (5-92)	15 (4-75)	(U = 54, p= .615)
/t/			
Median (min-max)	17(3-92)	23 (11-87)	(U = 50, p = .82)
/k/			
Median (min-max)	20 (4-98)	26 (7-73)	(U = 54.5, p = .757)
Nasal sentences			
Median (min-max)	60.5(37-97)	57 (52-69)	(U = 43, p = .914)
Oral sentences			
Median (min-max)	29 (14-88)	32.5 (19-55)	(U = 50, p = .82)

U Mann-Whitney test, p p value, significance < 0.05

Table 8 Correlation between degree of auditory perceptual assessment of speech before intervention and degree of improvement after intervention

	r	p
Degree of nasality	0.558*	< 0.001**
Glottalization	0.683*	< 0.001**
Pharyngealization	0.382*	0.015*
Consonant imprecision	0.727*	< 0.001**
Overall intelligibility	0.728*	< 0.001**

r Pearson coefficient
*Statistically significant at $p \leq 0.05$

traditional therapy, can increase the frequency of training outside the session, and ease delivery of the service. Also, this study stated that there were factors that assist the success: stimulable phonemes, good auditory discrimination, training for poor auditory discriminated sounds, and auditory and visual feedback [14].

In conclusion, the program was effective in correcting articulatory errors and improving nasality scores, and there is a need for further research about its effects of the other speech sound disorders other than VPD.

Yet, there were some limitations of this study, these included

- Drop out before completing the therapy and poor compliance of some patients.
- Not all the patients had facilities to do home exercises using this program.

Conclusion

Speech therapy is an important intervention strategy for cases with VPD with speech errors either alone or

Table 9 Correlation between degree of nasality and nasometer values before and after the intervention

Nasometer values before	Degree of nasality before		Nasometer values "post"	Degree of nasality "post"	
	r _s	p		r _s	p
/a/	0.269	0.093	/a/	0.137	0.399
/i/	0.419*	0.007*	/i/	0.190	0.241
/u/	0.340*	0.032*	/u/	0.196	0.225
/b/	0.233	0.148	/b/	- 0.046	0.779
/t/	0.070	0.676	/t/	0.160	0.330
/k/	0.231	0.203	/k/	0.316*	0.047*
Nasal sentence	0.282	0.078	Nasal sentence	- 0.033	0.840
Oral sentence	0.467*	0.002*	Oral sentence	0.317*	0.046*

r_s Spearman coefficient
*Statistically significant at $p \leq 0.05$

with surgery or prosthesis. This study proved that the designed Arabic software program was effective for correcting both speech errors and nasality scores.

Supplementary information

Supplementary information accompanies this paper at <https://doi.org/10.1186/s43163-020-00036-y>.

Additional file 1: Auditory discrimination window. Awareness window. Production window for syllables

Abbreviations

VPD: Velopharyngeal dysfunction; VPI: Velopharyngeal insufficiency; CBST: Computer-Based Speech Therapy

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Authors' contributions

RM: supervision, established the concept of the research, designed the work, validation and visualization of the results. EE: role in supervision, role in revising the results, writing the original draft, reviewing and editing. AR: role in collecting data, applying the intervention, analyzing the data. RE: designing the software program. All authors read and approved the final manuscript.

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Availability of data and materials

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Ethics approval and consent to participate

The ethics committee of the Faculty of Medicine approved the study (no.0105440). Informed consent to participate in the study was provided by the parent or legal guardian of the cases as they were all children under 16 after explaining the intervention.

Consent for publication

Not applicable.

Competing interests

The authors declare that they have no competing interests.

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