Investigation into Voice Source of Monozygotic Twins using Formant based Inverse Filtering

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Abstract

Studying glottal flow gives potential benefit in many disciplines. Several methods have been developed for the estimation of the glottal flow. Glottal flow can be estimated from microphone pressure signal, or Inverse filtered signal. Inverse filtering (IF) has been used widely for the understanding of phonation type, intensity, voice quality, emotions and vocal loading. However there is a dearth of information about the effectiveness or reliability of IF techniques especially in the evaluation of individuals having similar voice and speech characteristics like monozygotic twins. Also, voice source through inverse filtering has not been investigated in twins so far. In this context, the present study investigated similarity of voice source in monozygotic twins using inverse filtering and the consistency of inverse filtered parameters. Two groups of females participated in the study. Group I had 6 monozygotic twins and Group II had 6, age and gender matched unrelated pairs. None of them had any voice disorders. Subjects Phonated vowel /a / three times at least for 5 seconds in comfortable pitch and loudness. Samples were audio-recorded at a sampling rate of 48 kHz and phase linear recording. Samples were inverse filtered using Vag_physio module of VAGHMI software in formant based method. Results showed that IF parameters were reliable over the repeated trials in all individuals. Also, ANOVA showed no significant difference between groups on voice source characteristics. The open quotient (OQ) and speed quotient (SQ) was significantly different across groups. However further investigation on twin pairs selection based on perceptual similarity and confirmed genetic analysis is warranted.

Key words: Glottal flow, Genetic similarity, Reliability.

The study of the glottal flow gives insight into the voice signal, which is of potential benefit in many disciplines such as speech synthesis, study of vocal expression of emotions, and clinical diagnosis and treatment of the voice. Due to the location of the larynx, (surrounded by many sensitive and vital organs and arteries), glottal flow is difficult to measure directly. Hence, several methods have been developed for the estimation of the glottal flow. They typically use the fundamental assumptions of Fant's source - filter theory. Although the source -filter theory was formally published in 1960 (Fant, 1960), Inverse filtering (IF) was already presented by Miller a year earlier (Miller, 1959). Using inverse filtering can be estimated the source of voiced speech and the glottal flow can be acquired by removing the effects of the estimated vocal tract and lip radiation from a measured air-flow or pressure waveform (Airas, 2008).

Two methods exist for the input signal in inverse filtering. Either a flow mask may be used to estimate the actual air-flow out of the mouth (Rothenberg, 1973) or microphone at a certain distance may be used to measure the speech pressure signal (Anathapadmanabha, 1984). If absolute flow value and measurement of the minimum flow are required, a calibrated flow mask has to be used. However, flow masks have poor frequency responses (linear only up to 1.6 kHz to 9 kHz), and positioning the mask tightly around the mouth and the nose poses restriction on natural production of speech (Rothenberg, 1977). In contrast, good low frequency response microphone placed at constant distance from the speaker may overcome disadvantages of mask.

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The amplitude and phase response characteristics of Condenser microphones are excellent and will not affect natural speech production. Due to these reasons, microphone recordings are widely used (Airas, 2008). Inverse filtering was used widely for different phenomena of voice production concentrating on issues like phonation type (Alku, Vilkman, 1996), intensity (Dromey, Stathopoulos, Sapienza, 1992), voice quality (Gobi, NiChasaide, 2003), emotions (Airas, Alku, 2006), pitch, (Price, 1989) and vocal loading (Vinnuri et al, 2001). In addition some studies have discussed inverse filtering from methodological point of view (Alku, Vilkman, Laukkanen, 1998). Given the prevalence of IF in the field of voice science, there is dearth of information about the effectiveness or reliability and sensitivity of the IF technique especially in the evaluation of individuals having similar voice and speech characteristics like monozygotic twins.

Monozygotic twins resemble each other in many aspects like aptitude, habit, taste and style that constitute what we think of as human individuality (Gedda, Fiori & Bruno, 1960). It may be hypothesized that their voice also may sound similar at least to a certain degree. It is generally accepted that the physical characteristics of the laryngeal mechanism, such as vocal fold length and structure, size and shape of the supraglottic vocal tract, and phenotypic similarities elsewhere in the vocal mechanism are genetically determined (Sataloff, 1997). Several research groups have studied genetic similarities in monozygotic twins. Though voice is unique to individuals, studies involving listeners perception have showed the perceptive similarity in monozygotic twins (Decoster, Van Gysel, Vercammen & Debruyne, 2001). Also, several quantitative measures like fundamental frequency in phonation (Przbyla, Hori, & Crawford 1992; Decoster, Van Gysel, Vercammen, & Debruyne 2001; Kalaiselvi, Santhosh & Savithri 2005), speaking fundamental frequency (Debruyne, Decoster, Van Gysel, & Vercammen 2002), formants (Forrai, & Gordos 1983) and Dysphonia Severity Index (Van Lierde, Vinck, De Ley, Clement, & Van Cauwenberge 2005) show similarity in monozygotic twins. However, voice source through inverse filtering has not been investigated in twins so far. In this context, the present study investigated similarity of voice source in monozygotic twins using inverse filtering, and consistency of inverse filtered parameters.

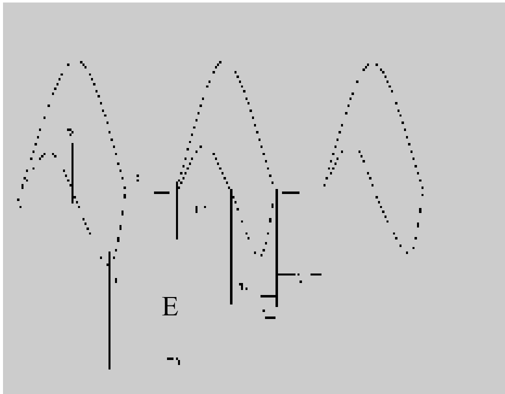
Method

Participants: Two groups of females participated in the study. Group I had 6 monozygotic twins and Group II had 6 age and gender unrelated pairs. All the subjects were between 19 to 25 years of age. Criteria for selecting the monozygotic twins included; (a) they should be same in gender, (b) should have the same blood group, and (c) should have approximately similar height and weight. Criteria for selecting the monozygotic unrelated pairs were: (a) non siblings of the same gender and (b) height should be approximately similar. None of the participants had any unstable voice, voice disorders, speech disorders, neuro-motor disorders, endocrinal disorders and/or hearing disorders.

Recordings: The recording was made in quiet room. Participants were instructed to phonate vowel /a / three times at least for 5 seconds at comfortable pitch and loudness. Before the actual recording the Speech pathologist demonstrated the phonation. All samples were audio-recorded using Sony portable mini disk recorder MZ-R3 (Sony Corporation, Tokyo, Japan) at a sampling rate of 48 kHz and phase linear recording. Recording was made using Alcom-unidirectional microphone (frequency range from 40 Hz to 12000Hz (± 2dB) placed at a distance of 10 cm from participants.

IF Procedure: The acoustic pressure waveforms were inverse filtered using Vag _ phsio module of VAGHMI software (Voice and Speech System, Bangalore, India). This program has two ways to obtain the glottal flow signal using IF- LPC analysis and formant frequency analysis. IF using Formant analysis gives clear glottal flow wave with out any high frequency ripples (ripples-free) compared to LPC based IF (Anathapadmanabha, 2008). Hence, in the present study, formant based IF was used to obtain the glottal flow wave. The edited downsampled phonation samples were fed in to IF. This software also has semiautomatic marking of the glottal flow wave to get the IF parameters. If semiautomatic marking fails to make decision user can switch to manual mode.

Parameterization: The glottal flow waveforms estimated by the formant based IF were parameterized based on temporal [Open quotient (OQ), Speed quotient (SQ), Leakage quotient (LQ) and Pitch Period (T0)] and spectral [Roll-off, First Harmonic (H0), Harmonic ratio (H0-H1), EI/EE, & Dynamic leakage (AR)] measurement. Figure 1 shows the modeled volume –velocity glottal pulse and its derivative in the time domain and figure 2 shows the log spectrum of voice source.



0 – glottal Onset, P – peak flow, E – Epoch, C – Closure, T0-Pitch period, TP-Opening Interval, TN-Closing Interval, TL -Leakage Interval, TC-Closed Interval.

Figure 1: Modeled glottal pulse and its derivative in time domain.

Open quotient is defined as the ratio between the duration of glottal opening and the fundamental period (OQ = (TP+TN+TL) / T0. Speed quotient is defined as the ratio between the duration of for opening and closing of the glottis (TP/TN). Leakage quotient is defined as the ratio between TL and T0, here TL is the time taken for the voice source signal to return from epoch (E) to the baseline.

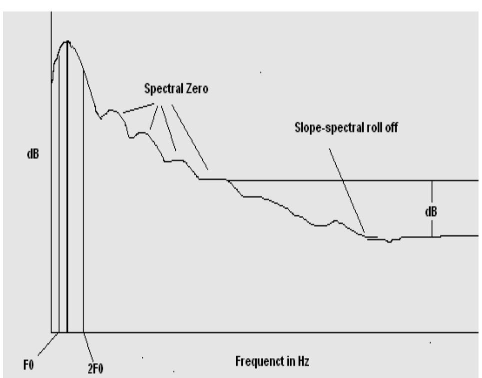


Figure 2: Log Spectrum of single voice source.

Spectral roll-off indicates the smoothness of the glottal closure or the change in the spectral level over an octave change in the frequency. Harmonic ratio (H1-H0) is the ratio of energy at first harmonic and fundamental frequency. EI/EE- is the mean ratio value of positive area and the negative area in each derivate cycle. Dynamic leakage (AR) is the residual flow during the return phase, which occurs from the time of excitation to the time of complete closure.

Analyses: Phonation signals were recorded at a sampling rate of 48 kHz. To make the signal compatible with VAGHMI software Program (Voice & Speech Systems, Bangalore, India), signals were downsampled to 16 kHz using Wavesurfer software. The middle 3 second of each phonation sample was subjected to IF analysis. Vag _ phsio module of VAGHMI software Program was used for IF analysis. Each parameter was extracted 180 times each for group I and group II (6 * 2subjects * 3 trails * Five times): All analyses were made using semi-automatic marking methods. Whenever software failed to make mark, manual mode was selected for marking the glottal cycles. Ten present of the samples were subjected to test-re test reliability, which showed 89 % reliability.

Statistical analysis: SPSS 10 was used to make the statistical calculations. Pearson product correlation was used to find the relation between the three trails measured within the subject. One way ANOVA was used to find the difference between the twin and co-twin as well as in unrelated pairs. Also the Absolute difference between the twin and co-twin as well as between the two participants in the unrelated group was calculated. From these values the statistical difference were made using one way ANOVA. Similarly the over all parameter difference was found.

Results

Reliability over repeated trails

To check the reliability of repeated trails the mean value of three trails was correlated over group I and group II. Tables 1 and 2 shows the r-values of groups. r values suggest that there was not much variability among trails, except in few parameters.

Parameters	Trial		
	1 & 2	1 & 3	2 & 3
T0	0.892**	0.977**	0.948**
OQ	0.924**	0.891**	0.850**
SQ	0.704*	0.838**	0.871**
LQ	0.768**	0.716**	0.938**
EIEE	0.727**	0.916**	0.741**
AR	0.874**	0.785**	0.798**
H0	0.380	0.429	0.892**
H0-H1	0.803**	0.875**	0.751**
Roll-off	0.979**	0.865**	0.924**

Table 1: r- values of group I. (** p< 0.01, * p< 0.05).

Parameters	Trial		
	1 & 2	1 & 3	2 & 3
T0	*0.980***	*0.973***	*0.968***
OQ	*0.773***	*0.831***	*0.752***
SQ	*0.774**	*0.637**	*0.671**
LQ	*0.482*	*0.706**	*0.438*
EIEE	*0.414*	*0.724**	*0.747**
AR	*0.774***	*0.725***	*0.768***
H0	*0.732***	*0.711**	*0.705**
H0-H1	*0.933***	*0.904***	*0.836***
Roll-off	*0.879***	*0.865***	*0.784***

Table 2: r- value of group II. (** p< 0.01, * p< 0.05).

Comparison with in group I & group II

Results of one-way ANOVA revealed no significant difference within twins in all pairs in various parameters. Table 3 show mean, standard deviation of group I and Table 4 show mean, and standard deviation in group II.

	T0	OQ	SQ	LQ	EI/EE	AR	H0	Ho-H1	Roll-off
Pair 1	3.81(.01)* 4.08(.02)	**.75(.01)** **.74(.02)**	**1.31(.06)** **1.35(.25)**	.25(.04)** .19(.06)	**.67(.02)** **.65(.07)**	1.70(.29)* 1.96(.15)	**110.1(1.5)** **108.6(4.6)**	**9.7(3.21)** **11.5(6.33)**	7.03(1.36)* 5.62(.09)
Pair 2	4.02(.06)* 4.83(.02)	72(.03)* .75(.01)	**1.81(.24)** **1.81(.17)**	.23(.03)** .19(.05)	.61(.04)* .57(.01)	2.21(.14)* 1.70(.38)	108(1.4)** 102 (7)	**15.5(6.28)** **13.8(4.44)**	5.53(.16)* 5.65(.09)
Pair 3	4.53(.03)* 4.48(.05)	.89(.07)* .97(.01)	**1.29(.16)** **1.26(.06)**	**.22(.05)** **.24(.02)**	.54(.02)* .61(.05)	1.35(.17)* 1.26(.07)	108.8(1.6)* 101.3(.6)	11.07(1.40)* 13.55(2.55)	14.33(1.3)* 12.36(.63)
Pair 4	4.54(.25)* 4.17(.06)	.86(.04)* .94(.06)	**1.88(.32)** **1.74(.09)**	.11(.03)* .13(.03)	.39(.04)* .58(.06)	1.96(.29)* 1.71(.21)	101.(1.5)** 107.(1)	5.6(.59)** 9.0(.83)	7.17(.35)** 12.47(2.50)
Pair 5	**4.02(.03)** **4.0(.02)**	.93(.03) .81(.01)	1.57(.16)** 2.16(.10)	.20(.03)** .16(.01)	.50(.02)* .45(.01)	1.56(.15)* 2.33(.10)	100.3(.53)* 98.3(.22)	**9.47(.48)** **3.85(.18)**	15.36(.82)* 15.92(.48)
Pair 6	4.58(.08)* 4.46(.09)	.63(.05)* .77(.04)	1.41(.17)** 2.10(.34)	**.03(.01)** **.05(.02)**	**.61(.04)** **.56(.09)**	**1.86(.11)** **1.92(.18)**	**101.5(.53)** **103.1(3.1)**	3.6(.51) ** 8.3(1.2)	**6.54(.74)** **6.30(.58)**

Table 3: Mean and SD of 1-3 twin pairs. (** p< 0.01, * p< 0.05)

	T0	OQ	SQ	LQ	EI/EE	AR	H0	Ho-H1	Roll-off
UPair 1	4.21(.04)** 4.31(.06)	.84(.01)* .89(.07)	1.95(.09)** 1.55(.39)	.14(.01)** .14(.06)	.49(.03)* .55(.16)	1.46(.10)** 1.67(.44)	111.9(.72)** 106.1(2.5)	7.52(.49)** 10.7(1.04)	6.11(1.03)** 10.5(.71)
UPair 2	4.33(.10)** 4.43(.07)	.81(.04)* .86(.05)	2.93(.72)** 1.82(.14)	.06(.03)** .10(.03)	**.49(.16)** **.50(.08)**	2.41(.71)* 1.85(.13)	101.3(4.5)** 105.8(1.5)	4.87(1.57)** 7.66(.89)	6.07(.74)** 9.23(3.22)
UPair 3	5.18(.11)** 4.87(.06)	.63(.08)** .74(.04)	**2.31(.67)** **2.24(.16)**	.09(.06)** .02(.01)	.37(.03)** .52(.05)	2.55(.64)** 2.09(.13)	99.(2.04)** 103.(1.06)	1.75(1.4)** 6.06(.45)	5.66(.44)** 6.24(.24)
UPair 4	4.57(.04)** 4.23(.11)	.79(.10)** .92(.08)	1.81(.33) 1.63(.33)	.09(.04)** .19(.06)	.39(.05)** .64(.08)	2.08(.53)** 1.45(.18)	**101.4(1.53)** **101.2(2.19)**	6.55(1.80)** 13.15(2.34)	9.47(2.36)** 9.88(.83)
UPair 5	4.42(.07)* 4.66(.03)	.94(.02)** .80(.05)	2.13(.22)* 2.39(.26)	.16(.03)** .10(.01)	**.35(.04)** **.35(.02)**	1.96(.21)* 2.19(.14)	105.5(.86) 102.3(1.0)	6.71(1.24) 6.0(.50)	7.23(1.23) 8.27(.89)
UPair 6	5.18(.11) 4.29(.04)	.63(.08)** .84(.01)	2.31(.67) 1.95(.09)	.09(.06)** .14(.01)	.37(.03)** .49(.03)	2.55(.64) 1.46(.10)	99.5(2.0) 111.9(.72	1.75(1.4) 7.52(.49)	5.66(.44) 6.11(1.03)

Table 4: Mean and SD of 1-3 group II. (** p< 0.01, * p< 0.05)

Comparison of IF parameters between the groups

Absolute difference between twin, and co-twin was used to perform one way ANOVA. Twin, co- twin difference is the arithmetic differences between the two members of twin members. Similarly, pair, co-pair differences values where calculated for unrelated members. Appendix I shows mean and standard deviation of difference values of twin pairs and unrelated pairs.

Using the difference of twin, co twin and pair, co-pair values group comparison was made between group I and group II. Results indicated significant differences between groups on OQ, SQ, LQ EI/EE, AR, and H0. Table 5 shows the mean and SD in both groups.

	Unrelated	Twins
T0	0.33 (.28)	.28 (.29)
OQ	**0.12 (.09)**	**0.08 (.06)****
SQ	**0.62 (.47)**	**0.36 (.29)****
LQ	**0.06 (.05)**	**0.05 (.04)***
EI/EE	**0.14 (.10)**	**0.08 (.06)****
AR	**0.60 (.52)**	**0.38 (.28)****
H0	**5.79 (3.6)**	**4.88 (3.6)***
Ho-H1	4.52 (2.35)	4.05 (3.27)
Roll-off	2.18 (1.95)	1.78 (2.14)

Table 5: Mean and SD of difference values in two groups. (** p< 0.01, * p< 0.05)

Discussion

Very few studies have investigated the consistency of inverse filtering parameters either in subjects with normal voice or in pathological voice. Few studies investigated the voice source but none of the published work had been done on analysis of IF parameters in monozygotic twins.

Current study investigated the inverse filtering parameters of six monozygotic twins comparing with age and gender matched unrelated pair. The coefficient value suggested that there was good consistency between trails of individuals in both groups, and a good consistency of IF parameters over repeated trials.

Secondly, within each twin (Group I), no significant difference was found on several parameters rather voice source similarity was very few in group II. Speed quotient was more similar in monozygotic twin's pair compares all other inverse filtering parameters. These results were in hand with Van Lierde et al (2005). They investigated voice quality of 45 monozygotic twins using qualitative and quantitative assessment. The results showed similarity in laryngeal, aerodynamic measurement. The voice source similarity in group I can be attributed to would be physical characteristics of the laryngeal mechanism, such as vocal fold length and structure, size and shape of the supraglottic and vocal tract. Since twins are similar in genetically they have high similarity on voice source characteristics (Sataloff, 1997). Variability that is seen in the voice source of twins group can be due to variation in genetic similarity. That is some pairs have more genetically similar component than others.

Using the absolute difference value the group comparison made between twin pairs and unrelated pairs. OQ, SQ, LQ, EI/EL, AR, HO were significantly different between groups. Open quotient and speed quotient are parameter which is more similar in monozygotic twin's pair compares all other inverse filtering parameters. It shows the opening phase and speed of vocal fold movement is similar in monozygotic group. OQ & SQ value gives the overall morphology of the glottal wave.

In conclusion, IF parameters was reliable over the repeated trials in all individuals. Monozygotic twins showed considerable similarity in voice source on inverse filtering. Also majority of the parameters, specially OQ and SQ were sensitive enough to differentiate monozygotic twin's voice. Further investigation on twin pairs based on perceptual and genetic analysis is warranted.

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Appendix 1 – Mean and SD of absolute difference values in both groups.

(U-unrelated pair, Pair – twin pair)

	U 1 & Pair 1	U 2 & Pair 2	U 3 & Pair 3	U 4 & Pair 4	U 5 & Pair 5	U 6 & Pair 6
T0	.09(.05) .27(.03)	.13(.10) .81(.07)	.31(.14) .06(.05)	.33(.12) .37(.23)	.23(.06) .03(.03)	.88(.12) .13(.11)
OQ	.07(.04) .02(.01)	.05(.03) .04(.02)	.10(.06) .08(.06)	.15(.14) .11(.04)	.14(.05) .12(.04)	.21(.09) .14(.05)
SQ	.50(.26) .20(.21)	1.11(.72) .24(.15)	.68(.38) .16(.09)	.44(.24) .25(.19)	.32(.30) .59(.16)	.67(.37) .71(.33)
LQ	.05(.03) .07(.04)	.03(.03) .07(.04)	.07(.07) .07(.03)	.10(.09) .03(.02)	.05(.03) .04(.03)	.08(.02) .02(.01)
EI/EE	.15(.10) .06(.05)	.16(.14) .05(.03)	.15(.04) .07(.04)	.24(.10) .18(.07)	.04(.04) .05(.02)	.12(.04) .09(.06)
AR	.34(.36) .27(.20)	.79(.38) .49(.18)	.75(.38) .16(.12)	.68(.53) .39(.29)	.26(.26) .79(.18)	1.5(.10) .17(.11)
H0	5.85(2.29) 3.49(1.61)	5.75(1.03) 6.87(6.58)	4.32(1.73) 7.54(2.09)	3.18(1.19) 6.39(1.30)	3.19(1.70) 2.09(.70)	12.44(2.21) 2.93(1.86)
Ho-H1	3.18(1) 4.72(6.03)	2.90(1.50) 6.14(4.15)	4.30(1.51) 2.63(1.75)	6.60(2.53) 3.42(1.07)	1.37(.93) 5.61(.51)	5.76(1.46) 4.75(.96)
Roll-off	4.40(.98) 1.41(1.35)	3.58(2.9) .16(.11)	.62(.13) 2.27(1.46)	2.19(1.01) 5.31(2.39)	1.23(.68) .91(.75)	1.03(.77) .62(.52)