The Effect of Source Location, Posture and Language on Speech Intelligibility in Goan Churches

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ABSTRACT

The results presented here are based on field measurements carried out in six Catholic churches (Goa, India). Rapid Speech Transmission Index (*RASTI*) and Subjective Speech Intelligibility (*SSI*) measurements were made in four different seating zones of a church for three speech source locations (altar, pulpit, high altar), two languages (English, Konkani) and two postures (standing, sitting). The effects of language and postures were not significant. The altar location and the sanctuary of the church were preferable for speech intelligibility. Although the altar location showed better averages than the other speech source locations, the best predictive relationship between RASTI and SSI was the exponential growth of RASTI for the *high altar* source location with SSI for the English language.

Keywords: Church acoustics; speech intelligibility; RASTI.

1. INTRODUCTION

Although speech and music have conflicting acoustical requirements in a worship space [1], intelligibility for both speech and music enhances the qualitative communion between the 'Word' [2,3] and the 'listener'. Intelligibility stimulates a resonance between the devotee and the worship space and facilitates *active, conscious* and *total participation* in community worship [4]. Research studies have shown a statistically significant relationship between speech intelligibility and the acoustical measures in a church [5,6,7]. This study is an effort to measure the difference in speech intelligibility due to the change of language of the speaker (English or Konkani), posture of the

listener (standing or sitting) and the source location (present altar, pulpit or high altar). The results presented are based on field measurements done in six Catholic churches of Goa, India (a former Portuguese colony from 1510 to 1961), a reasonable set of churches representative of this ambience in the world.

2. THE SAMPLE CHURCHES

The six selected churches vary in their architectural styles and represent the evolution of church architecture in Goa. A summary of these churches is provided in Table 1 and 2.

Table 1: Primary details of the churches surveyed

No	NAME	PLACE	YEAR BUILT	MAIN STYLE
CH1	Capela do Monte	Old Goa	1557	Mannerist
CH2	Bom Jesus Basilica	Old Goa	1594-1605	Jesuit Classic
CH3	Our Lady of Pilar	Pilar	1613	Mannerist
CH4	Divine Providence	Old Goa	1656-1661	Renaissance
CH5	Holy Spirit	Old Goa	1661-1668	Indo-Baroque
CH6	Holy Trinity	Benaulim	2005	Contemporary

Table 2: Descriptive statistics for the architectural measures of the six churches surveyed

	Minimum	Mean	Maximum	Median	Standard Deviation
$ABS_{TOT}\,(m^2)$	47.30	199	387	163	143
C_{ABS}	0.03	0.05	0.07	0.04	0.02
$A_{TOT}\,(m^2)$	250	755	1168	805	369
$A_{NV}\,(m^2)$	81	329	630	296	238
$H_{MAX}\,(m)$	15	21.17	30	21.50	5.71
$H_{NV}\,(m)$	9	18.67	30	18	7.28
$L_{MAX}\,(m)$	30	41.83	61	34.50	15.01
$L_{NV}\,(m)$	14	22.17	36	18	9.77
$V_{TOT}\,(m^3)$	2974	9382	18858	6726	7052
$V_{NV}\,(m^3)$	837	5657	13613	3556	5244
$H_{AVG}\,(m)$	8	11.67	16	10.50	3.61
$W_{NV}\,(m)$	9	13.67	23	11.50	5.85
$W_{AVG}\,(m)$	7	13	17	15	4.38
$W_{MIN\ NV}\,(m)$	9.20	11.77	18	10.10	3.58
$W_{AVG\ NV}\,(m)$	8.85	12.71	18	11.60	4.19
$H_{MIN\ NV}\,(m)$	9	13.10	16.50	14.05	2.97
$H_{AVG\ NV}\,(m)$	12.30	16.94	21.75	17.13	3.32
L_{NV}/H_{NV}	0.81	1.28	1.92	1.11	0.47
W_{NV}/H_{NV}	0.39	0.82	1.42	0.75	0.35

NAVE (NV) stands for the entire church excluding lateral chapels and main altar (apse)
TOTAL (TOT) stands for the entire church including lateral chapels and main altar (apse)

The tabulated architectural parameters measured or evaluated in the sample churches are: Total Absorption (ABS_{TOT}); Coefficient of Absorption (average value for all surfaces) (C_{ABS}); Total Surface Area of Church (A_{TOT}); Total Surface Area of Nave (A_{NV}); Maximum Height of the Church (H_{MAX}); Maximum Height of Nave (H_{NV}); Maximum Length of the Church (L_{MAX}); Maximum Length of Nave (L_{NV}); Total Volume of Church (V_{TOT}); Total Volume of Nave (V_{NV}); Total Average Height (H_{AVG}); Maximum Nave Width (W_{NV}); Average Width (W_{AVG}); Minimum Nave Width (W_{MIN_NV}); Average Nave Width (W_{AVG_NV}); Minimum Nave Height (H_{MIN_NV}); Average Nave Height (H_{AVG_NV}); Nave Proportions (L_{NV} / H_{NV}) and (W_{NV} / H_{NV}).

3. METHODOLOGY AND TERMINOLOGY

3.1 Listeners and Speech Sources

Nineteen normal listeners (age: 23 – 57 years) trained in the objectives of the work, were spatially separated by seating them in four seating zones within the church. Four listeners were seated in the sanctuary (labeled as listener zone 'A'). Five listeners were seated in the northern part of the nave (labeled as listener zone 'B'). Six listeners were seated in the middle section of the nave (labeled as listener zone 'C'). Four listeners were seated in the southern part of the nave (labeled as listener zone 'D'). Three locations in the church were chosen as speech sources. The first location, labeled as 'Speech Source A' (SA) is the altar location presently used for the Eucharistic celebration. The second location, labeled as 'Speech Source B' (SB) is the Pulpit. The third location is the high altar location, labeled as 'Speech Source C' (SC). The sources and the listener locations, for instance, in *Our Lady of Divine Providence church* (CH4) are shown in Figure 1.

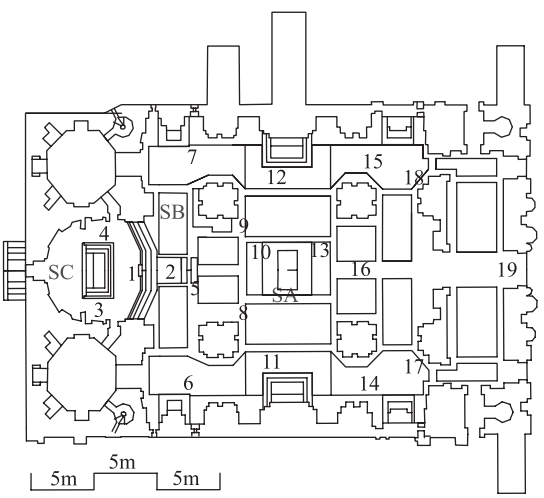

Figure 1. The locations of 19 listeners (1-19) and three speech sources (SA-C). The example shown is CH4, Our Lady of Divine Providence church.

3.2 Speech Types

The languages in which the speech tests were conducted in the churches were English (ENG) and Konkani (KON). The Konkani language is the mother tongue of Goa and is therefore the language that is predominantly used in the liturgy. The English language has good popularity mainly in urban areas.

3.3 Speech Tests: Methodology, Terminology and Calculations

The speakers chosen to read out the words form the test lists were a Catholic priest and a female theatre art professional. Words from the Modified Rhyme Test (MRT) [8] were used as the words and sounds conform to the parlance of the Christian liturgy. Both the speakers, who were trained in the art of oration, alternately read out 50 selected words in Konkani and English languages from the prepared MRT word lists, using a carrier sentence of the type *"… [PAUSE_5s]…ROW... (No.) ...THIS IS … (WORD).*" The Konkani MRT list was done by careful choice such that the distribution of syllables and the liturgical usage of the words corresponded with that of the English words. The listeners were instructed to encircle the word in the row which they thought they heard. The percentage of words understood and correctly noted by the listener on the evaluation sheet was calculated and averaged for each language and each speech source location and called the Subjective Speech Intelligibility (*SSI*). Results were averaged across sound sources and languages to obtain an *entire church* SSI value.

3.4 RASTI (Rapid Speech Transmission Index)

A standard *RASTI* [11] test signal (supplied by *Terrasonde Inc*. [9]) was uploaded on a PC and played through an amplified loudspeaker set up at the 'speaker' positions near the altar (SA) around 1.6 m above the floor, and on the pulpit floor (SB) and near the high altar (SC) at the same height to represent a standardized speech situation during a service. The ATB (*Audio Tool Box 2.0* [9]) microphone was set up at different heights (at the different 'listener' locations in the church) to simulate the sitting (SIT) and standing (STAND) posture of the listener respectively. The *RASTI* value at each listener location was averaged over at least three measurements. The averaged *RASTI* values for each 'listener' zone (i.e. *Sanctuary* - ZONE A, *Northern Nave* - ZONE B, *Middle Nave* -ZONE C and *Southern Nave* - ZONE D) were also obtained.

3.5 Background noise

In the six churches tested the background noise (LAeq) was from 35 dB to 53 dB as seen in Table 3, not affecting the results.

Table 3: Background noise LAeq for all the churches tested.

	CH1	CH2	CH3	CH4	CH5	CH6
LAeq (dB)	35	42	41	36	46	53

4. RESULTS

4.1 Inter-church Differences in Subjective Speech Intelligibility (SSI)

4.1.1 Experimental data

Descriptive statistics for the *SSI* data obtained for the different speaker locations and languages in each church are shown in Table 3.

Table 3: SSI descriptive statistics for the six surveyed churches for sound sources (SA, SB and SC), languages (ENG, KONK) and the entire church (CH). CH values are derived by averaging across sources and languages. 'Confidence' refers to the 95% confidence intervals.

	SA	SB	SC	ENG	KONK	CH
Minimum	87.4	86.5	83.7	84.7	82.7	83.7
Mean	90.5	88.8	86.6	88.0	87.9	88.4
Maximum	92.6	91.8	89.5	91.6	92.3	92.2
Median	90.6	88.4	86.58	86.9	88.0	88.5
Standard Deviation	2.1	2.7	2.9	2.9	3.2	2.9
Confidence	1.7	2.2	2.3	2.3	2.6	2.3

The variation in mean *SSI* for the three different sources and two languages across churches is shown in Figure 2. Some columns in the figure are missing because SA was absent in CH5, SB was inaccessible in CH5 and absent in CH6 while SC locations of only CH2, CH4 and CH5 were tested for SSI.

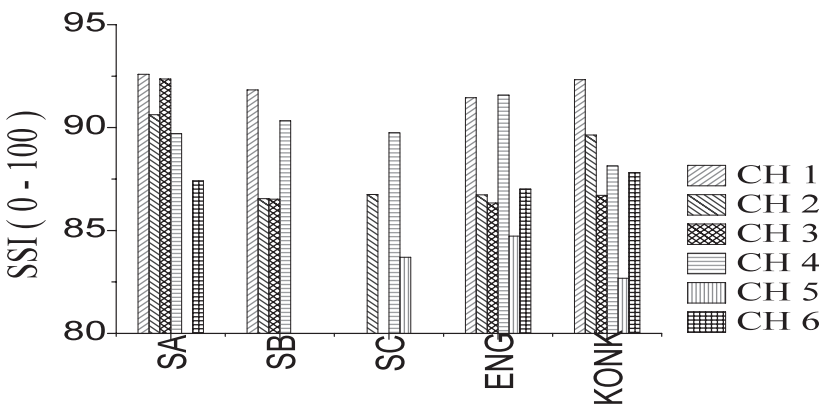

Figure 2. Differences in mean SSI values for each speech source location (SA-C) and language (ENG, KON) for the six churches (CH1 to CH6).

Mean values and standard deviation (SDev) of *SSI* for the three speaker source locations and the two languages in the different zones, averaged across the six churches, are shown in Table 4.

Table 4: Mean zonal values of SSI and their standard deviation values (SDev) for sound sources (SA, SB, SC), languages (ENG, KONK) and entire church (CH). CH values are derived by averaging across sources and languages.

	SA		SB		SC		ENG		KONK		CH	
ZONE	Mean	SDev	Mean	SDev	Mean	SDev	Mean	SDev	Mean	SDev	Mean	SDev
A	91.4	2.1	88.8	5.5	92.7	3.9	92.2	3.3	89.4	2.3	91.0	2.0
B	90.1	4.3	87.7	5.9	88.1	3.7	87.5	4.4	87.5	4.3	88.6	2.8
C	92.1	3.4	89.8	1.8	83.8	3.9	86.7	5.3	88.6	4.4	88.3	4.9
D	88.7	3.5	89.0	2.1	81.9	6.3	85.5	5.3	86.1	6.1	86.0	5.6

The effect of independent parameters (architectural style, different source locations within a church, different seating zones and languages) on *SSI* is assessed through the results of ANOVA tests on the means of *SSI* populations averaged across the tested churches (CHI, CH2, CH3, CH4, CH5 and CH6) as shown in Table 5. The architectural influence on the effect of source locations and languages on *SSI* is assessed through the results of ANOVA tests on the means of *SSI* populations shown in Tables 6-7.

Table 5: ANOVA test on means of *SSI* populations for: (A) six tested churches (CHI, CH2, CH3, CH4, CH5 and CH6); (B) three tested sources (SA, SB, SC); (C) two tested languages (ENG, KONK); (D) four tested zones (A, B, C, D).

	TYPE	Data	Mean	Variance	N	F value	p value
(A)	INTER CHURCH	CH1	92.3	2.3	4	2.44	0.074
		CH2	88.5	0.3	4		
		CH3	89.5	4.3	4		
		CH4	89.8	6.3	4		
		CH5	83.5	65	4		
		CH6	87.5	5.7	4		
(B)	INTER SOURCE	SA	90.7	12.0	20	3.20	0.050
		SB	88.8	14.4	16		
		SC	86.7	34.7	12		
(C)	INTER LANGUAGE	ENG	88.05	25.7	24	8.42E-5	0.99
		KONK	87.96	18.8	24		
(D)	INTER ZONE	ZONE A	91.0	3.6	6	1.45	0.26
		ZONE B	88.7	8.3	6		
		ZONE C	88.3	25.5	6		
		ZONE D	86	32	6		

Table 6: ANOVA tests on means of SSI populations (averaged across the four zones in a church) to compare the tested churches at three source locations in a church (SA, SB, and SC)

TYPE	Data	Mean	Variance	N	F value	p value
SA (ALTAR)	CH1	92.6	0.8	4	1.67	0.21
	CH2	90.8	22.3	4		
	CH3	92.5	1.7	4		
	CH4	90.0	22	4		
	CH6	87.5	5.7	4		
SB (PULPIT)	CH1	91.8	2.4	4	2.87	0.081
	CH2	86.5	17.7	4		
	CH3	86.5	11	4		
	CH4	90.5	11	4		
SC (HIGH ALTAR)	CH2	86.8	4.3	4	1.066	0.38
	CH4	89.8	36.9	4		
	CH5	83.7	61.8	4		

Table 7: ANOVA test on means of SSI populations (averaged across the four zones in a church) to compare the six tested churches for two languages (ENG, KONK)

TYPE	Data	Mean	Variance	N	F value	p value
ENG (ENGLISH)	CH1	91.5	4.6	4	1.35	0.29
	CH2	86.5	9.0	4		
	CH3	86.5	12.3	4		
	CH4	91.5	7.0	4		
	CH5	84.7	88.5	4		
	CH6	87.0	22.0	4		
KONK (KONKANI)	CH1	92.3	2.8	4	3.22	0.030
	CH2	89.8	2.3	4		
	CH3	87.0	20.7	4		
	CH4	88.0	6.0	4		
	CH5	82.7	43.0	4		
	CH6	88.0	1.3	4		

4.1.2 Observations

Capela do Monte church (CH1) had a 79% significantly better overall SSI score from the altar (SA) (Table 6). *SSI* from the pulpit (SB) was 92% significantly better in *Capela do Monte church* (CH1) (Table 6). The high altar (SC) of *Our Lady of Divine Providence church* (CH4) gave only 62% significantly better score of *SSI* (Table 6). *Capela do Monte church* (CH1) and *our Lady of Divine Providence church* (CH4) had equivalent *SSI* scores for the English language however their scores were only 61% significantly better than those of other churches (Table 7). *Capela do Monte church* (CH1) had a 97% significantly better SSI score for the Konkani language (KON) (Table

7). The altar source location (SA) was 95% significantly better than the pulpit (SB) and the high altar (SC) for SSI (Table 5B). The SSI scores for the two languages (ENG, KONK) were equivalent (only 1% significant difference) (Table 5C). Among the different zones in a church (A, B, C, D), the sanctuary (zone A) was 76% significantly better than other zones for the SSI score (Table 5D). Overall, *Capela do Monte* (CH1) had the highest mean SSI score 93% significantly better than the SSI scores in other churches (Table 5A).

The percentages shown are derived from the significance values (p-values) of the ANOVA tests on means of SSI populations.

4.2 Inter-church Differences in Rapid Speech Transmission Index (RASTI)

4.2.1. Experimental data

The descriptive statistics for the RASTI values for different signal sources: altar position (SA), pulpit position (SB), high altar position (SC) and different recording postures: standing (STAND) and sitting (SIT) in comparison with the mean value in the church (CH) are shown in Table 8. The mean values for the RASTI measurements for different source locations and postures in the different zones of a church are shown in Table 9.

Table 8: Descriptive statistics for RASTI measurements. 'Confidence' refers to the 95% confidence intervals.

	STAND	SIT	SA	SB	SC	CH
Minimum	0.26	0.31	0.29	0.34	0.22	0.29
Mean	0.39	0.38	0.43	0.36	0.38	0.39
Maximum	0.48	0.42	0.52	0.41	0.48	0.48
Median	0.39	0.41	0.45	0.34	0.43	0.40
Standard Deviation	0.08	0.05	0.09	0.04	0.13	0.06
Confidence	0.06	0.04	0.07	0.03	0.11	0.05

Table 9: Mean zonal values of RASTI and their standard deviation values (SDev) for sound sources (SA, SB, SC), postures (STAND, SIT) and entire church (CH). CH values are derived by averaging across sources and postures.

ZONE	SA		SB		SC		STAND		SIT		CH	
	Mean	SDev	Mean	SDev	Mean	SDev	Mean	SDev	Mean	SDev	Mean	SDev
A	0.44	0.18	0.32	0.26	0.71	0.02	0.48	0.19	0.41	0.15	0.47	0.17
B	0.52	0.21	0.35	0.09	0.34	0.14	0.40	0.12	0.42	0.15	0.41	0.12
C	0.38	0.14	0.47	0.14	0.32	0.10	0.37	0.10	0.39	0.14	0.38	0.11
D	0.39	0.21	0.29	0.07	0.30	0.05	0.32	0.09	0.31	0.09	0.32	0.09

Differences in mean *RASTI* values for the three speech sources and two recording postures in each church are shown in Figure 3. Only the standing posture (STAND) was tested in CH 5; SB was inaccessible in CH5 and absent in CH6 while SC locations of only CH2, CH4 and CH5 were tested for RASTI hence some values (bars) are missing.

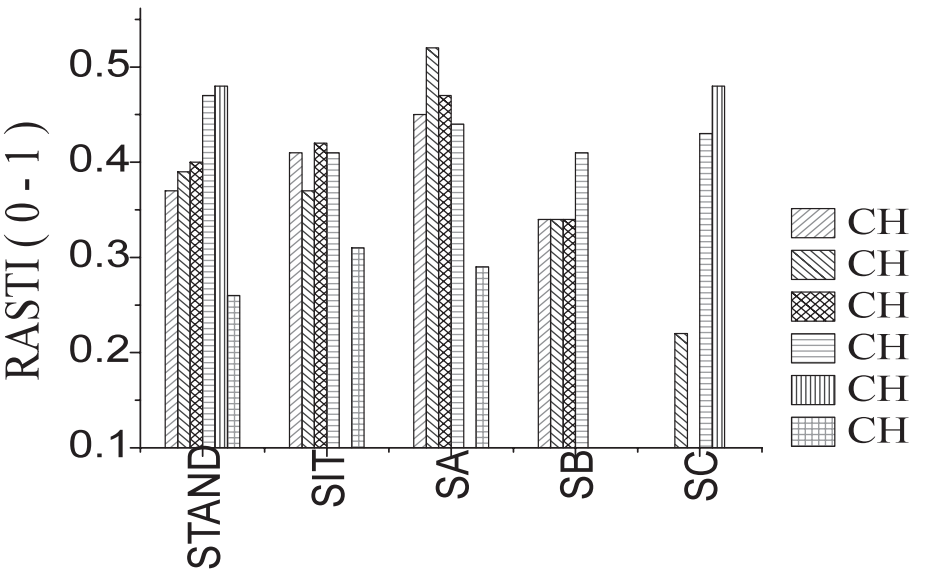

Figure 3. Mean RASTI values for each sound source location and posture in the six churches.

The effect of independent parameters (architectural style, different source locations within a church, different seating zones and recording (listening) postures) on RASTI is assessed through the results of the one way ANOVA tests on the means of *RASTI* populations averaged across the tested churches (CHI, CH2, CH3, CH4, CH5 and CH6) as shown in Table 10. The architectural influence on the effect of source locations and the recording (listening) postures on RASTI is assessed through the results of the one way ANOVA tests on the means of *RASTI* populations shown in Tables 11-12.

Table 10: ANOVA test on means of *RASTI* populations for: (A) six tested churches (CHI, CH2, CH3, CH4, CH5 and CH6); (B) three tested sources (SA, SB, SC); (C) two tested postures (STAND, SIT); (D) four tested zones (A, B, C, D).

TYPE	Data	Mean	Variance	N	F value	p value
(A) INTER CHURCH	CH1	0.39	0.025	4	0.95	0.48
	CH2	0.38	0.002	4		
	CH3	0.41	0.011	4		
	CH4	0.43	0.010	4		
	CH5	0.48	0.026	4		
	CH6	0.28	0.030	4		
(B) INTER SOURCE	SA	0.43	0.033	20	0.85	0.43
	SB	0.36	0.025	16		
	SC	0.39	0.032	11		
(C) INTER POSTURE	STAND	0.39	0.019	24	0.07	0.79
	SIT	0.38	0.017	20		
(D) INTER ZONE	ZONE A	0.47	0.029	6	1.44	0.26
	ZONE B	0.42	0.015	6		
	ZONE C	0.38	0.013	6		
	ZONE D	0.33	0.008	6		

Table 11: ANOVA tests on means of RASTI populations (averaged across the four zones in a church) to compare to compare the tested churches at three source l

TYPE	Data	Mean	Variance	N	F value	p value
SA (ALTAR)	CH1	0.45	0.056	4	1.00	0.44
	CH2	0.53	0.025	4		
	CH3	0.47	0.009	4		
	CH4	0.44	0.044	4		
	CH6	0.28	0.030	4		
SB (PULPIT)	CH1	0.34	0.016	4	0.17	0.91
	CH2	0.34	0.044	4		
	CH3	0.35	0.013	4		
	CH4	0.41	0.047	4		
SC (HIGH ALTAR)	CH2	0.23	8.33E-4	3	2.28	0.16
	CH4	0.43	0.042	4		
	CH5	0.48	0.026	4		

Table 12: ANOVA test on means of RASTI populations (averaged across the four zones in a church) to compare the tested churches for the standing (STAND) and the sitting (SIT) posture.

TYPE	Data	Mean	Variance	N	F value	p value
STAND (Standing)	CH1	0.37	0.020	4	1.37	0.28
	CH2	0.39	0.005	4		
	CH3	0.40	0.007	4		
	CH4	0.47	0.026	4		
	CH5	0.48	0.026	4		
	CH6	0.26	0.019	4		
SIT (Sitting)	CH1	0.41	0.033	4	0.46	0.77
	CH2	0.37	0.002	4		
	CH3	0.42	0.015	4		
	CH4	0.41	0.006	4		
	CH6	0.31	0.043	4		

4.2.2. Observations

The altar location (SA) of *Bom Jesus Basilica* (CH2) (as compared to those of other churches) was only 56% significantly better for its RASTI score (Table 11). *RASTI* from the pulpit (SB) was not significantly different in the tested churches (p = 0.91) (Table 11). The high altar (SC) was 84% significantly better for *Holy Spirit church* (CH5) (Table 11). The mean RASTI value for the standing posture was 72% significantly better in *Holy Spirit church* (CH5) however, RASTI did not significantly favor any of the tested churches for the sitting posture (p = 0.77) (Table 12). Among the sources, the altar source location (SA) was only 57% significantly better for RASTI (Table 10B). The mean RASTI for the standing (STAND) and the sitting (SIT) posture showed little significant difference (p = 0.79) (Table 10C). Among the different zones in a church, the sanctuary (zone A) was 74% significantly better than other zones for the RASTI score (Table 10D). Overall, *Holy Spirit church* (CH5) had only 52% significantly better RASTI score than other churches (Table 10A).

4.3 Comparisons, Correlations and Regressions

4.3.1. Data

The effect of the architectural styles on *SSI* and *RASTI* was assessed by examining variations in mean *SSI* and *RASTI* (for the church) in the different churches as shown in Figure 4.

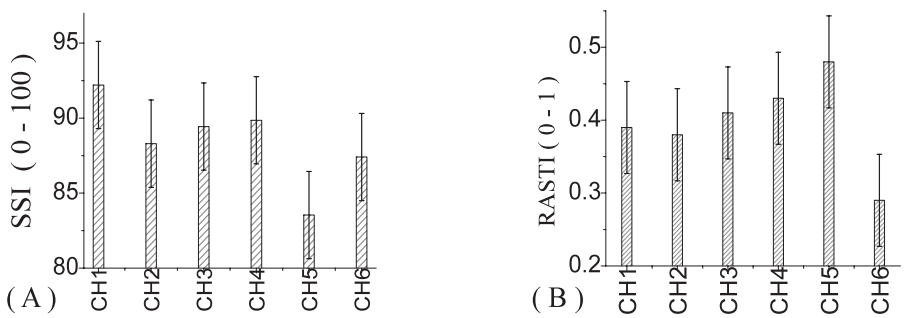

Figure 4. Interchurch differences in: (A) mean SSI values (B) mean RASTI values. [Architectural style: CH1 – Mannerist; CH2 - Jesuit Classic; CH3 – Mannerist; CH4 – Renaissance; CH5 - Indo – Baroque; CH6 – Contemporary]

The Pearson's coefficients of correlation (*R*) for the relationships between *RASTI* and Subjective Speech Intelligibility (*SSI*) are shown in Table 7.

Table 7: Correlations (R) between RASTI and SSI values.

		SS I					
		CH	SA	SB	SC	ENG	KONK
RAST I	CH	0.41	0.37	0.33	0.60	0.54	0.19
	SA	0.19	0.51	-0.34	-0.61	0.22	-0.02
	SB	0.48	-0.31	0.62	0.56	0.22	0.38
	SC	0.36	-0.16	0.73	0.60	0.59	0.15
	STAND	0.38	0.30	0.29	0.65	0.53	0.16
	SIT	0.67	0.37	0.37	0.62	0.57	0.31

The best fits between RASTI and SSI for different factors are shown in Figure 5. When graphically representing these fits, the standard error of estimates (computed by *Origin* [10] as a square root of the mean of squared deviations) was also plotted.

These figures are important to check the relationships between subjective and objective intelligibility parameters and to find equations to relate them.

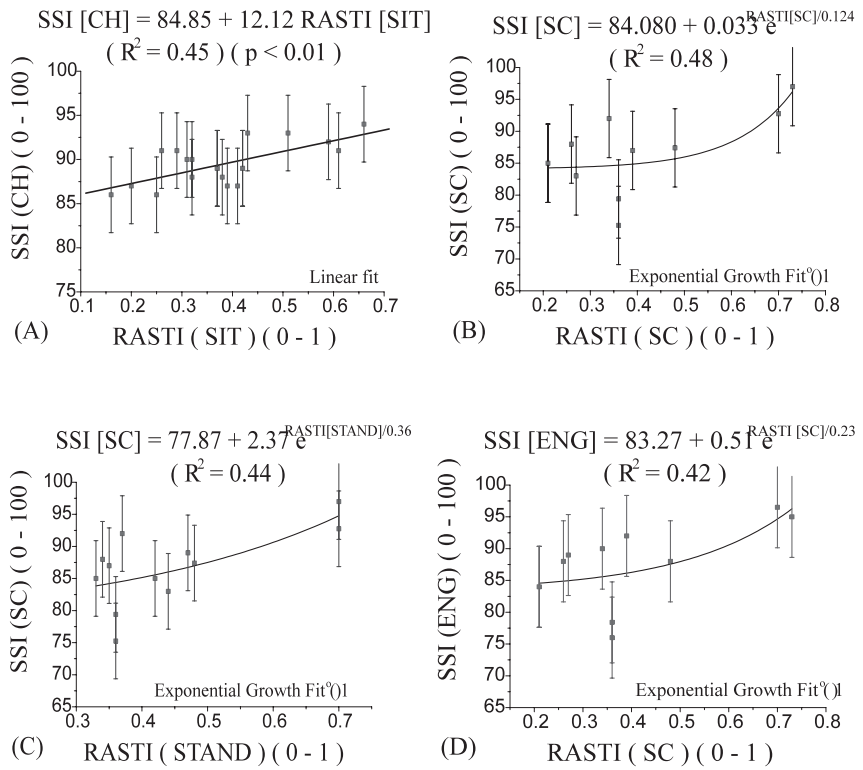

Figure 5. Best fits for SSI versus RASTI.
Linear Fit of SSI [CH] on RASTI [SIT]
Exponential Growth Fit of SSI [SC] on RASTI [SC]
Exponential Growth Fit of SSI [SC] on RASTI [STAND]
Exponential Growth Fit of SSI [ENG] on RASTI [SC]

4.3.2. Observations

Only the high altar location (SC) was available for tests in *Holy Spirit church* (CH5) hence the comparatively low score of mean SSI and the comparatively high score of mean RASTI in *CH5* are a reflection of the subjective and objective speech intelligibility for the high altar source location (SC). The *SSI* and *RASTI mean values* gradually increase as the architectural style chronologically evolves from *CH2* to *CH4* (Figure 4).

The overall church averages for RASTI and SSI values are not strongly correlated. The church average for SSI significantly correlates ($p < 0.01$) with RASTI (SIT), but only 45% of the variance between them is explained by this correlation ($R^2 = 0.45$). Amongst the sound source locations, RASTI for SC shows correlation with its subjective counterpart. The SC location shows better correlation for SSI versus RASTI for the standing posture. SSI values for the English language show a moderate correlation with RASTI values for the source SC. Among the available best fits, the exponential relationship between RASTI [SC] and RASTI [STAND] with SSI [SC] and RASTI [SC] with SSI [ENG] are robust and statistically significant.

5. DISCUSSION

One of the purposes of this study was to determine if the independent variables (source, language, zone, posture, and church) affect SSI and RASTI. The following conclusions are drawn based on the averages across the six tested churches,

- Among the different architectural genres, the mannerist style Capela do Monte church (CH1) is best for Subjective Speech Intelligibility (SSI) ($p \leq 0.10$) but none of the churches show a significant difference in their RASTI values ($p < 0.30$). Overall, all the older churches (CH 1-5) were better than the contemporary Holy Trinity church (CH6) for speech intelligibility.
- Among source locations, the altar (SA) is better than the pulpit (SB) and the high altar location (SC) for subjective speech intelligibility (SSI) ($p \leq 0.10$). However, the source locations show no significant difference in their RASTI scores $p > 0.30$).
- Among the zones, ZONE A seems to be the favorable zone for RASTI and SSI ($p < 0.30$). This implies that the sanctuary of the church (ZONE A) is the best place to sit in a church for speech intelligibility.
- Regarding the postures, neither sitting (SIT) nor standing (STAND) show a significant effect on objective speech intelligibility (RASTI) ($p > 0.30$).
- Similarly for the languages, neither English (ENG) nor Konkani (KONK) shows any significant difference in their SSI values ($p > 0.30$).

  The following conclusions regarding the architectural influence on the effect of the independent parameters (language, source location, and listening posture) on speech intelligibility are based on the averages within the six tested churches,
- SSI scores for Konkani language (KONK) are better in Capela do Monte church (CH1) ($p \leq 0.10$) and the SSI scores for English language (ENG) are better in Our Lady of Providence church (CH4) ($p \leq 0.30$).This implies that language does matter for subjective speech intelligibility in architecturally different worship spaces.

- SSI scores for the pulpit (SB) ($p < 0.10$) and for the altar (SA) ($p < 0.30$) are better in Capela do Monte church (CH1) but the RASTI averages for the pulpit (SB) and for the altar (SA) do not show any significant difference across the churches ($p > 0.30$). Though, SSI scores for the high altar (SC) do not significantly differ ($p > 0.30$), RASTI scores for high altar (SC) are better in Holy Spirit church (CH5) ($p < 0.30$). Thus overall, the effect of the source locations on speech intelligibility significantly varies in architecturally different worship spaces.
- RASTI scores for the standing posture (STAND) are better in Holy Spirit church (CH5) ($p \leq 0.30$) which implies that speech intelligibility for the standing posture significantly differs while RASTI scores for the sitting posture (SIT) do not significantly vary ($p > 0.30$) in architecturally different worship spaces.

Although the listening posture has no general effect on RASTI, however, the significant effect of the standing posture (STAND) on RASTI coupled with the fact that RASTI for the standing posture (STAND) is a significantly predictable speech intelligibility counterpart to SSI for high altar (SC) justifies the testing of two recording modes for RASTI (simulating the sitting and the standing posture of a listener). The relationship between RASTI and SSI is best for high altar (SC) as RASTI for high altar (SC) is a significantly predictable speech intelligibility counterpart to SSI for high altar (SC) and to SSI for English language (ENG). The good correlation of RASTI and SSI for the high altar (SC) supports the liturgical need of the high altar being a location of optimum speech intelligibility considering that at this location the priest used to utter the prayers and communicate with his back to the congregation.

6. CONCLUSIONS

From the inter-church comparisons the following conclusions can be drawn. Subjective Speech Intelligibility (SSI) is best for the Capela do Monte church while Holy Spirit church and our Lady of Divine Providence church show better RASTI scores. Speech intelligibility in the tested churches does not significantly favor either of the two tested languages (English, Konkani) nor did the two test listening postures (standing, sitting). Speech intelligibility favors altar source (SA) over the pulpit (SB) in the tested churches. The sanctuary of the church seems to be the favorable zone for speech intelligibility since the means of RASTI and SSI in the sanctuary (ZONE A) are significantly different from the means in Zone D of the church.

From the correlations and regressions of RASTI and SSI, it can be inferred that RASTI vs SSI [for SC], RASTI [SC] vs. SSI [ENG], and RASTI [STAND] vs. SSI [SC] are the best found pairs of speech intelligibility counterparts. It is preferable to predict SSI in terms of RASTI (since it is easier to measure RASTI than SSI).

In terms of the Subjective Speech Intelligibility (SSI), the six churches showed 93% significant difference ($p = 0.07$), whereas the speech intelligibility scores as indicated by RASTI were only 52% significantly different ($p = 0.48$). The mean SSI score (= 88 on a scale of 0 - 100) suggests that the churches are subjectively sufficiently good for speech intelligibility although the mean RASTI score (= 0.39) indicates a less than satisfactory conditions for speech intelligibility in the tested Goan Catholic churches.

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REFERENCES

[1] D. Lubman and E. A. Wetherill (1985) ed., *Acoustics of Worship Spaces*, American Institute of Physics for the Acoustical Society of America, x-xii.

[2] Pope Benedict XVI (1995), *Liturgy and Church Music, A New Song for the Lord*, Crossroad NY.

[3] Cf. John 1:13.

[4] Vatican II, Sacrosanctum concilium, 4 Dec. 1963, article 14, 34.

[5] A. P. O. Carvalho, A. E. J. Morgado and L. Henrique (1997), *Speech Intelligibility in Churches. How it relates with objective acoustical parameters and architectural features.* 133rd Acoustical Society of America Meeting, PennState USA.

[6] T. Zamarreno, S. Giron and M. Galindo (2008), *Assessing the Intelligibility of Speech and Singing in Mudejar-Gothic Churches*, Applied Acoustics, Vol. 69, Number 3, pp. 242-254.

[7] M. A. P. S. Tavares, S. Rajagopalan and S. J. Sharma (2007), *Comparative Acoustical Studies of Two Goan Churches*, Proceedings of 19th ICA, paper rba-16-009, 2007, Madrid, Spain.

[8] A. House, C. Williams, M. Hecker and K. Kryter (1965). Articulation testing methods: Consonantal differentiation with a closed response set. *J. of the Acoust. Soc. of Am.,* **37**: 158-166.

[9] http://www.terrasonde.com, accessed on July 2009.

[10] http://www.originlab.com, accessed on July 2009.

[11] IEC 60268-16 (1998), *Sound system equipment - Part 16: Objective rating of speech intelligibility by speech transmission index.*