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Acoustic characterization of sacred music rendered by a human whistle at the Divine Providence Church in Goa, India

Menino Allan S. M. Peter Tavares (1), S. Rajagopalan (1), Satish Jagannath Sharma (2) and António P. O. Carvalho (3)

(1) Department of Physics, Nagpur University, Nagpur – 440 033, India
(2) Department of Electronics, Nagpur University, Nagpur – 440 033, India
(3) Laboratory of Acoustics, Faculty of Engineering, University of Porto, 4200-465 Porto, Portugal

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ABSTRACT

The human whistle is a representation of the human vocal singing. Singing (solo and congregational) is an essential component of sacred music for collective worship in a Catholic church. The acoustic characterization of sacred music is defined in this paper through a derived Acoustic Comfort Impression Index (ACII) and several Acoustic Worship Indices (AWI), namely, Subjective Sacred Factor (SSaF), Subjective Intelligibility Factor (SInF) and Subjective Silence Factor (SSiF). In this study, live sacred music rendered by the human whistle is compared with that by the cello, clarinet, violins and the ensemble, in the Catholic church of the Divine Providence (Goa, India). Among the significant results, ACII for the human whistle was found to be better than ACII for the musical instruments ($F = 2.38$, $p = 0.08$); this difference was more significant at the nave of the church (music source) ($F = 2.94$, $p = 0.04$) and lower at the choir loft (music source) ($p = 0.21$). SInF for the ensemble music was found better than SInF for human whistle ($F = 3.07$, $p = 0.03$). At the nave of the church, the SInF was found better than SSaF and SSiF ($F = 4.17$, $p = 0.02$). SSaF and SInF were equally better than SSiF at the choir loft ($p = 0.02$). This study opens the possibility of optimized use of the human whistle in rendering sacred music in a church.

INTRODUCTION

A Worship Space needs all the factors of acoustics, namely speech, music, singing and silence to be well blended and purposefully used for an *active, conscious and total* communitarian experience of the Divine [1].

While speech is effectively used for an intellectual communion, music is a powerful catalyst and medium to communicate emotion. Singing is a marriage of speech and music that optimizes the animating and commissioning power of both music and speech while the moments of acoustic silence provide the ambience for in depth contemplation [2] [3].

The musical quality of a melody rendered by the human whistle is a symbolic representation of the human vocal singing. The results presented here, assess the subjective acoustic impact of a tune from sacred music rendered by a human whistle in comparison with the subjective acoustic effect of musical instruments (such as cello, clarinet, violins and ensemble) from different source locations (namely, the nave of the church and the choir loft of the church). The comparative subjective religious comfort triggered by the acoustic effect is assessed through a derived Acoustic Comfort Impression Index (ACII) [4] and several Acoustic Worship Indices (AWI), namely, Subjective Sacred Factor (SSaF), Subjective Intelligibility Factor (SInF) and Subjective Silence Factor (SSiF) [5][6][7].

PRELIMINARIES

Sample Church

The church of Our Lady of Divine Providence (1656-61) in Old Goa, India, was designed by Italian architects Carlo Ferrarini and Francesco Maria Milazzo, [8] as a miniature version of the Basilica of St Peter's at Rome, is the church of the monastery of St. Cajetan (Figure 1). The main body of the church internally manifests a Greek cross floor plan and is oblong externally. Four equal arms of the nave are flanked by aisles. The intersection of the arms is marked by four massive piers which form the supporting base of a lantern crowned circular dome resting on a drum. One of the arm of the nave ends in an apse. The coffered groin vaults of the nave and the aisles majestically entwine at different points due to their varying heights achieving a rare architectural fluidity which, along with the fine patterns of stucco spread out over the surface, are a treat to the eyes [9].

The ground floor plan of Our Lady of Divine Providence Church is shown in Figure 2 and its architectural main data are shown in Table 1.

Figure 1. Our Lady of Divine Providence Church.

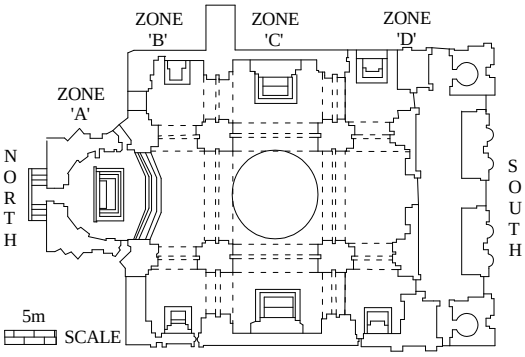

Figure 2. Ground floor plan of Our Lady of Divine Providence Church (Source: ASI, Goa)

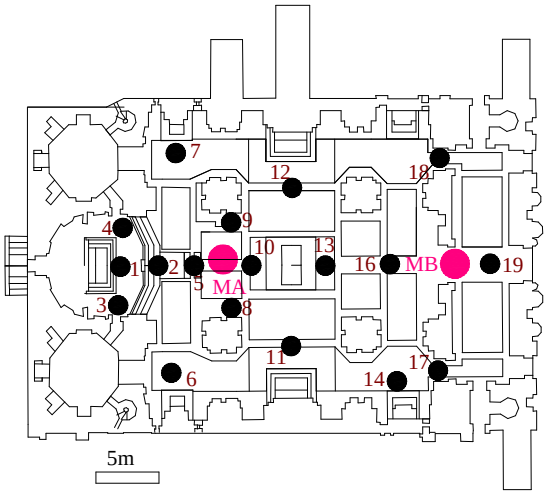

Figure 3. The locations of 18 listeners and two music sources (*MA* and *MB*) in Our Lady of Divine Providence Church

Table 1. Dimensional details of the church

DIMENSION	UNITS	VALUES
ABSTOT	m^2	203
CABS	(α)	0.04
ATOT	m^2	856
ANV	m^2	143
HMAX	m	30
HNV	m	30
LMAX	m	36
LNV	m	18
VTOT	m^3	7691
VNV	m^3	2512
HAVG	m	9
WNV	m	9
WAVG	m	16
WMIN_NV	m	9.2
WAVG_NV	m	8.85
HMIN_NV	m	13.5
HAVG_NV	m	21.75
LNV / HNV	(Ratio)	0.81
WNV / HNV	(Ratio)	0.39
LNV : WNV : HNV	(Ratio)	0.8 : 0.4 : 1.0

Music sources

Two locations were chosen as music sound sources. *Music source A* (MA) was on the floor of the north east/west nave – sanctuary corner of the church and *Music source B* (MB) was on the floor of the choir loft of the church.

Listeners and their seating locations

The church floor was divided into four zones:

- *Listener zone A* (The sanctuary or the main apse);
- *Listener zone B* (The northern floor of the nave);
- *Listener zone C* (The middle floor of the nave);
- *Listener zone D* (The southern floor of the nave).

Altogether nineteen listeners with an above average aptitude for music or acoustics, acquainted with the liturgy in a worship space were chosen and trained for the subjective acoustic tests. Some of the listeners had to be audiometrically tested (250 Hz – 8 kHz) to ascertain their hearing conditions. The locations of the music sources (MA and MB) and listeners seating for the subjective acoustic tests in Our Lady of Divine Providence Church are shown in Figure 3.

Music types

The human whistle as a very proximate simulation of the human voice (in singing) was compared with renditions by cello (designated as music type 'P'), ensemble of cello, clarinet, violins and guitar (designated as music type 'R') and violins in duet (designated as music type 'S').

The musical instruments for the subjective acoustic tests were chosen because of their popularity at different liturgical functions in Goa. The cellist played "Bach's Suite No. 2". The human whistle rendition was the tune of "Motet: Fera Pessima" a traditional Christian Lenten hymn. The ensemble and the violinists played "Piedade Saibinni" a Goan devotional classic, in minor and major. The music score of the rendition by the human whistle is given in Figure 4.

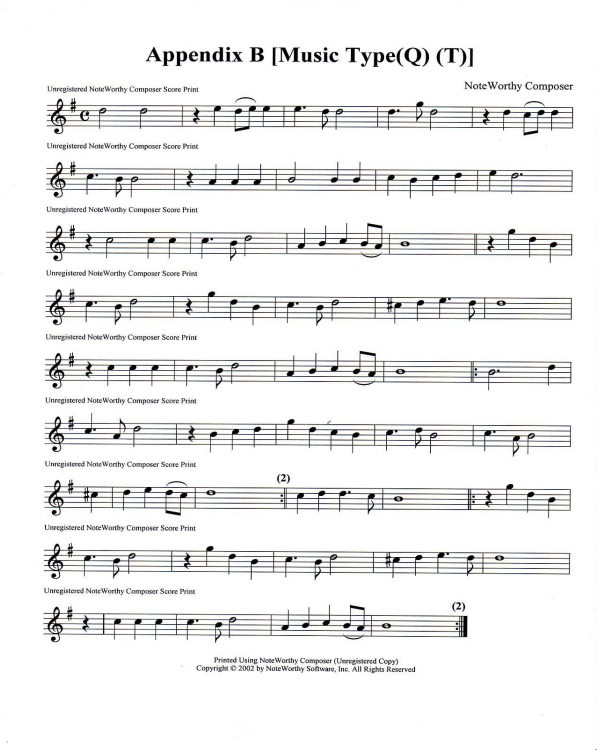

Figure 4. Music score of "*Motet: Fera Pessima*"

SUBJECTIVE ACOUSTIC EVALUATION OF SACRED MUSIC

Subjective acoustic Impressions

The listener, as guided before every test, judged to what degree the music played in the church was loud, clear, reverberant, well-directed, intimate, enveloping, tonally balanced, acoustically impressive and affected by echoes and background noise [10]. The averaged scores of the acoustic qualities for different music sources and types in different seating zones of the church could be considered as subjective impressions the sound registered on the listeners. Therefore, the averaged scores of the subjective acoustic qualities were called subjective acoustic impressions (SAI) and are listed as: Subjective acoustic impression of Loudness (SAI_{LOUD}); Subjective acoustic impression of Clarity (SAI_{CLAR}); Subjective acoustic impression of Directionality (SAI_{DIR}); Subjective acoustic impression of Balance (SAI_{BAL}); Subjective acoustic impression of Intimacy (SAI_{INT}); Subjective acoustic impression of Envelopment (SAI_{ENV}); Subjective acoustic impression of Reverberance (SAI_{REV}); Subjective acoustic impression of Echoes (SAI_{ECHO}); Subjective acoustic impression of Background Noise (SAI_{NOIS}) and Subjective overall acoustic impression (SAI_{OVER}).

Acoustic Comfort Impression Index

A difference was drawn between the desired subjective acoustic impressions (DSAI) in a worship space and the undesired subjective acoustic impressions (USAI) in a worship space in order to acoustically comprehend and optimize this 'religious feeling of comfort and solace'.

The desired and undesired subjective acoustic impressions (DSAI and USAI) were evaluated as averages of the eight desired $dSAI_i$ and the two undesired $uSAI_j$ respectively. The net difference score between the desired and the undesired was averaged and coded as the Acoustic Comfort Impression (ACI) of the worship space.

Finally, the acoustic comfort impression index (ACII) at each zone of the worship space was evaluated using Equation 1.

$$ACII = 1 - \left| \frac{ACI_x}{ACI_{ref}} \right| \quad \text{....(1)}$$

where,

ACI_{ref} is the reference value of ACI in the given worship space, $ACI_{ref} = 6$;
ACI_x is the difference between ACI_{ref} and the averaged value of ACI in the zone *x* (0 - 6).

ACII is a gross measurement of the subjective comfort induced by the acoustics inside the worship space. This subjective acoustic comfort enables the necessary disposition to worship.

Acoustic Worship Indices

The religious experience denoted by the *Sacred Factor* (SaF) was comprehensively constituted by the mix of the acoustical parameters SAI_{REV}, SAI_{INTI}, SAI_{ENV} and SAI_{OVER}, It was hypothesized that the perception of the overall subjective acoustic impression (SAI_{OVER}) has a tone of reverential awe and a subtle urge for the Divine when it is accompanied by a sufficient bonding with the source (SAI_{INTI}) and a sense of being immersed (SAI_{ENV}) into a vibrant ambience (SAI_{REV}). All the constituent parameters were normalized and (as it was hypothesized that no weighting of the constituents was required) the arithmetic mean of the normalized values of subjective acoustic impressions of reverberance ($nSAI_{REV}$), intimacy ($nSAI_{INTI}$), envelopment ($nSAI_{ENV}$) and the subjective acoustic overall impression ($nSAI_{OVER}$) was hypothesized to be the subjective sacred factor (SSaF).

The religious experience denoted by the *Intelligibility Factor* (InF) was comprehensively constituted by the parameters SAI_{LOUD}, SAI_{CLAR}, SAI_{DIR} and SAI_{BAL}. It was hypothesized that the music played in a church had to be perceived as loud (SAI_{LOUD}), clear (SAI_{CLAR}), well-directed (SAI_{DIR}) and balanced (SAI_{BAL}) in its bass and treble tones, in order to satisfy the conditions of intelligibility of sacred music. Again, it was hypothesized that no weighting of the constituents was required as explained in the case of the SaF, hence the arithmetic mean of the normalized values of SAI_{LOUD}, SAI_{CLAR}, SAI_{DIR}, SAI_{BAL} and SSI was hypothesized to be the subjective intelligibility factor (SInF).

It was hypothesized that in order to optimize the effect of music in the sacred liturgy an ambience of "silence" was necessary; therefore, subjective impressions of echoes (SAI_{ECHO}) and background noise (SAI_{NOIS}) were undesirable. These subjective parameters when normalized were converted and construed as positive determinants of the silence ambience and as such constituted the religious experience denoted by the *Silence Factor* (SiF). As, no weighting of the constituents was required, the arithmetic mean of the normalized values of subjective silence from echoes (SS_{ECHO}) and subjective silence from noise (SS_{NOIS}) was hypothesized to be the subjective silence factor (SSiF).

The subjective acoustical measures were evaluated on a semantic differential rating scale with seven points (1 to 7) [9]. For instance, loudness (overall loudness of the sound) was scaled from 1 (extremely weak) to 7 (optimally loud); Therefore, for the normalization of the DSAI the optimal reference limit value was taken as 7 and their normalized values calculated using Equation 2,

$$nX_{DSAI} = 1 \qquad \forall\ X_{meas} = X_{ref}$$
$$nX_{DSAI} = 1 - \frac{\Delta X}{X_{ref}} \qquad \forall\ X_{meas} < X_{ref} \qquad \ldots.(2)$$

where,

X_{meas} is the measured value of the subjective acoustic impression,
nX_{DSAI} is the normalized value of the DSAI,
$X_{ref} = 7$ is the optimal reference limit value of the subjective acoustic impression,
$\Delta X = |X_{meas} - X_{ref}|$

The USAI were also given an optimal reference value equal to 7 considering the latter to be the maximum value that can be scored on the semantic scale used for the evaluation of the subjective acoustic parameters. However, these undesirable subjective impressions of echoes and noise were expressed as their respective equivalents in terms of subjective silence from echoes (SS_{ECHO}) and subjective silence from noise (SS_{NOIS}). Consequently, the normalized values of SS_{ECHO} and SS_{NOIS} were calculated using Equation 3,

$$nSS = \frac{\Delta X}{X_{ref}} \ \forall\ X_{meas} \qquad \ldots.(3)$$

where,

X_{meas} is the measured value of the subjective acoustic impression;
nSS is the normalized value of the subjective silence impression (SS_{ECHO} and SS_{NOIS});
$X_{ref} = 7$ is the optimal reference value of the subjective acoustic measures (SAI_{ECHO} and SAI_{NOIS});
$\Delta X = |X_{meas} - X_{ref}|$

The subjective data was analysed using *Excel* and *Origin 6.1*.

RESULTS

Subjective acoustic Impressions

A comparison of the mean values of different desired subjective acoustic impressions (DSAI) and undesired subjective acoustic impressions (USAI) evaluated inside Our Lady of Divine Providence Church is assessed through the results of the ANOVA tests on the means of their populations averaged across 18 listener locations at the nave (source MA) and the choir loft (source MB) of the church as shown in Tables 2 and 3.

Table 2. ANOVA tests on the means of DSAI and USAI populations in the church (averaged across 18 listener locations in the church) to compare the different subjective acoustic impressions for the human whistle rendition from the nave of the church (source MA)

TYPE	Data	Mean	Variance	N	F value	p value
DSAI	SAI_{LOUD}	5.11	1.05	18	1.53	0.16
	SAI_{CLAR}	5.83	1.09	18		
	SAI_{DIR}	5.94	0.76	18		
	SAI_{BAL}	5.56	1.32	18		
	SAI_{INT}	5.44	1.08	18		
	SAI_{ENV}	5.44	1.44	18		
	SAI_{REV}	5.28	1.15	18		
	SAI_{OVER}	5.89	0.69	18		
USAI	SAI_{NOIS}	2.17	2.38	18	0.09	0.77
	SAI_{ECHO}	2.33	3.41	18		

Table 3. ANOVA tests on the means of DSAI and USAI populations in the church (averaged across 18 listener locations in the church) to compare the different subjective acoustic impressions for the human whistle rendition from the choir loft of the church (source MB)

TYPE	Data	Mean	Variance	N	F value	p value
DSAI	SAI_{LOUD}	5.00	0.59	18	1.79	0.09
	SAI_{CLAR}	5.78	0.89	18		
	SAI_{DIR}	5.78	0.89	18		
	SAI_{BAL}	5.50	1.32	18		
	SAI_{INT}	5.33	1.18	18		
	SAI_{ENV}	5.28	0.80	18		
	SAI_{REV}	5.22	1.71	18		
	SAI_{OVER}	5.89	0.69	18		
USAI	SAI_{NOIS}	2.39	2.02	18	0.099	0.75
	SAI_{ECHO}	2.22	3.01	18		

ACII, SSaF, SInF and SSiF

The effect of independent parameters (church architecture, different source locations within the church, different seating zones and music types) on *ACII, SSaF, SInF* and *SSiF* is assessed through the results of the ANOVA tests on the means of their populations averaged across 18 listener locations in the church as shown in Tables 4 to 6.

The effect of independent parameters (different source locations within the church) on *ACII, SSaF, SInF* and *SSiF* of the human whistle is assessed through the results of the ANOVA tests on the means of their populations averaged across 18 listener locations in the church for the two different source locations as shown in Tables 7 and 8.

Table 4. ANOVA tests on the means of ACII and AWI populations in the church (averaged across 18 listener locations in the church) to assess the tested church for different music types (P, R, S, and T)

TYPE	Data	Mean	Variance	N	F value	p value
ACII	P	0.42	0.04	18	2.38	0.08
	R	0.39	0.03	18		
	S	0.44	0.04	18		
	T	0.54	0.03	18		
SSaF	P	0.81	0.02	18	0.46	0.71
	R	0.83	0.01	18		
	S	0.81	0.01	18		
	T	0.78	0.01	18		
SInF	P	0.86	0.01	18	3.07	0.03
	R	0.87	0.00	18		
	S	0.86	0.01	18		
	T	0.79	0.01	18		
SSiF	P	0.75	0.02	18	1.20	0.32
	R	0.76	0.02	18		
	S	0.73	0.02	18		
	T	0.68	0.03	18		

Table 5. ANOVA tests on the means of ACII and AWI populations at the nave of the church (averaged across 18 listener locations in the church) to assess the tested church for different music types (P, R, S, and T)

TYPE	Data	Mean	Variance	N	F value	p value
ACII	P	0.41	0.05	18	2.94	0.04
	R	0.35	0.02	18		
	S	0.44	0.05	18		
	T	0.54	0.04	18		
SSaF	P	0.81	0.02	18	0.62	0.60
	R	0.84	0.01	18		
	S	0.81	0.02	18		
	T	0.79	0.01	18		
SInF	P	0.87	0.01	18	3.61	0.02
	R	0.89	0.01	18		
	S	0.86	0.01	18		
	T	0.80	0.01	18		
SSiF	P	0.75	0.02	18	1.36	0.26
	R	0.78	0.01	18		
	S	0.73	0.03	18		
	T	0.68	0.03	18		

Table 6. ANOVA tests on the means of ACII and AWI populations at the choir loft of the church (averaged across 18 listener locations in the church) to assess the tested church for different music types (P, R, S, and T)

TYPE	Data	Mean	Variance	N	F value	p value
ACII	P	0.42	0.04	18	1.53	0.21
	R	0.43	0.04	18		
	S	0.45	0.04	18		
	T	0.55	0.04	18		
SSaF	P	0.81	0.02	18	0.34	0.80
	R	0.81	0.01	18		
	S	0.80	0.01	18		
	T	0.78	0.01	18		
SInF	P	0.84	0.01	18	1.89	0.14
	R	0.84	0.01	18		
	S	0.85	0.01	18		
	T	0.78	0.01	18		
SSiF	P	0.76	0.02	18	1.02	0.39
	R	0.74	0.02	18		
	S	0.73	0.03	18		
	T	0.67	0.03	18		

Table 7. ANOVA tests on the means of ACII and AWI populations in the church (averaged across 18 listener locations in the church) to compare the human whistle at the nave (MA) and at the choir loft (MB)

TYPE	Data	Mean	Variance	N	F value	p value
ACII	MA	0.54	0.04	18	0.02	0.90
	MB	0.55	0.04	18		
SSaF	MA	0.79	0.01	18	0.12	0.74
	MB	0.78	0.01	18		
SInF	MA	0.80	0.01	18	0.58	0.45
	MB	0.78	0.01	18		
SSiF	MA	0.68	0.03	18	0.04	0.84
	MB	0.67	0.03	18		

Table 8. ANOVA tests on the means of SSaf, SInF and SSiF populations in the church (averaged across 18 listener locations in the church) to compare the AWI for the human whistle at the nave (MA) and at the choir loft (MB)

TYPE	Data	Mean	Variance	N	F value	P value
MA	SSaF	0.79	0.01	18	4.17	0.02
	SInF	0.80	0.01	18		
	SSiF	0.68	0.03	18		
MB	SSaF	0.78	0.01	18	4.04	0.02
	SInF	0.78	0.01	18		
	SSiF	0.67	0.03	18		

OBSERVATIONS AND CONCLUSIONS

Subjective acoustic impressions (SAI)

At the nave of the church, the subjective acoustic impression of directionality (SAI_{DIR}) of the human whistle is found 84% significantly better than the other desired subjective acoustic impressions (DSAI) whereas at the choir loft, the overall subjective acoustic impression (SAI_{OVER}) was found to be the significantly best DSAI ($p = 0.09$). The difference between the undesired subjective acoustic impressions (SAI_{NOIS} and SAI_{ECHO}) is not significant at the nave of the church nor at the choir loft of the church (Tables 2 and 3).

This indicates that when sacred music is whistled from the nave of this church the subjective directionality of its rendition stands out from the other subjective acoustic impressions. The same rendition from the choir loft impinges a strong overall acoustic impression than any specific DSAI. The undesired subjective effects of background noise and echoes individually do not stand out for the same rendition from both the music sources.

Acoustic Comfort Impression Index (ACII)

In general, ACII of the human whistle is found significantly better than that of the musical instruments ($p = 0.08$). The difference is even more significant at the nave of the church ($p = 0.04$). At the choir loft, the difference between the ACII means for the different music types is not impressively significant ($p = 0.21$) (Tables 4 to 6).

The results imply that subjective experience of acoustic comfort (as characterized by ACII) significantly favours the human whistle when the sacred music is rendered from the floor of the nave of the church. The choir loft seems to significantly level the subjective effect of the sacred music by the human whistle.

Acoustic Worship Indices (SSaF, SInF and SSiF)

The means of the SInF in the church show the overall scores of the musical instruments to be 97% significantly better than that of the human whistle. The effect is seen to be more prominent at the nave of the church ($p = 0.02$) than at the choir loft ($p = 0.14$) (Tables 4 to 6).

This indicates that in terms of subjective intelligibility required to let sacred music deliver the message and meaning (as characterized by SInF) the musical instruments are preferred over the human whistle, especially when the rendition of the sacred music is from the floor of the nave of the church.

The overall impact of the church and the impact of the music source locations on the SSaf and SSiF do not show a significant difference between the musical instruments and the human whistle (Tables 4-6).

The subjective reverential awe elicited by sacred music (as characterized by SSaF) and the subjective silence leading to worship (as characterized by SSiF) thus seem to preferentially favour neither sacred music from musical instruments nor the rendition by the whistle, irrespective of whether the music is rendered from the floor of the nave or from the choir loft of the church. Perhaps the very sacredness of sacred music impinges the desired effect independent of whether it is played from musical instruments or whistled.

The two music sources do not show any significant difference in the ACII, SSaF, SInF and SSiF scores for the human whistle (Table 7). *The results could imply that the human whistle is effective in inducing the subjective mood for worship (as characterized by ACII, SSaF, SInF, and SSiF) while rendering the sacred melody both from the floor of the nave of the church and from its choir loft respectively.*

Among the derived acoustic worship indices (AWI), SInF was 98% significantly better than SSaF and SSiF for the human whistle at the nave of the church (MA) while for the same rendition at the choir loft (MB) both SSaF and SInF are equally better than the SSiF ($p = 0.02$) (Table 8).

Subjective silence thus seems not to be the favourite effect of the human whistle (while rendering sacred music in the Divine Providence Church) as compared to subjective experience of intelligibility and reverential awe.

The results in Our Lady of Divine Providence Church not only reveal the possibility of using the human whistle to render sacred music in the church but also indicate the possibility of knowing whether to use the musical instruments or the human whistle, when a particular location in the church is chosen for rendition (floor of the nave or the choir loft of the church).

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