E-NEWSLETTER

September 2018 issue

THE SOCIETY OF ACOUSTICS SINGAPORE

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Year of Registration: 1989

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I.CONFERENCE NEWS

The 26th International Congress on Sound and Vibration(ICSV26) will be held in Montreal, Canada from 7 to 11 July 2019.

Woon Siong Gan will be organising three structured sessions on:

1. **Nonlinear acoustics and vibration**
2. **Acoustic metamaterials & phononic crystals: fundamentals and applications**
3. **Sound propagation in curvilinear spacetime**

Please visit www.icsv26.org for more informations.

The 13 th Western Pacific Acoustics Conferenc(WESPAC) will be held from 11-15 November ,2018 in New Delhi, India.

You are encouraged to attend even without presenting a paper. Our society organised the previous WESPAC in Singapore in Dec 2015. Sofar the number of abstracts submitted is 510.

Woon Siong Gan will be organising two structured sessions at this conference on:

1.Nonlinear acoustics & vibration

2.Acoustic metamaterials & phononic crystals: fundamentals and applications.

Please visit the website: www.wespac2018.org.in for more informations.

II.ANNONCEMENTS

The Society of Acoustics will be sending out invoices to members with outstanding membership subscriptions. Members are encouraged to make payment in support of the Society.

The E-Newsletters will be made available to industrial contacts in an effort to promote the activities of the Society.

The Society is also exploring the possibility of organising talks and other professional events in collaboration with acoustic societies of other countries.

Membership Certificates will soon be made available to all members who had made full payments of membership dues

The Society aims to increase membership by inviting all persons, including those from the institution of higher learning and other related societies such as the Institute of Architects, Singapore and the members of the mechanical engineering division of the Institution of Engineers, Singapore who are qualified in the various field of Acoustics to join our Society.

We are especially keen to invite students to join our society and we are establishing the Youth Chapter soon.

III.INTERNATIONAL ACOUSTICS NEWS

Woon Siong Gan was recently elected as a Director of the International Institute of Acoustics and Vibration(IIAV) for the period 2018 to 2022.

IV.MEMBERSHIP SUBSCRIPTION

Fellow	**S$70**
Member	**S$50**
Associate	**S$30**
Student	**S$15**
Corporate	**S$200**

FEE BASED ON ANNUAL RATE

FOR MORE INFORMATION PLEASE CONTACT: Dr. Woon Siong Gan at email: wsgan5@gmail.com

Membership application forms can be downloaded from the society website: www.acousticssingapore.com. Please complete and email to wsgan5@gmail.com

V.ARTICLE

Evaluation of Bookshelf Speaker Responses and Listener's Perceptions

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Singapore University of Technology & Design

Abstract

The goal of this project is to develop a better understanding of how the shape of the frequency response of each bookshelf speaker affects its appeal to listeners (which we define as 'quality' of the speakers) and the corresponding descriptors that listeners attribute to each speaker. The semantic descriptors explored were "warm", "bright", "muddy", "clear", "neutral", and "coloured". We were also interested to find out how these descriptors were linked to

perceived “quality” for both expert and amateur listeners. In general, we found that “muddy” and “clear” were two descriptors that had the best agreement. Counterintuitively, we found that spectral flatness measures were correlated to “warm/bright”, and also that none of the flatness measures strongly correlated to “neutral/coloured”, revealing a naïve understanding of these descriptors. Additionally, we found that while experts preferred speakers that were non-“muddy” while amateurs preferred “bright” speakers. Further, we observe that skew and kurtosis of the low frequency regions may be helpful to meaningfully quantify muddiness and clarity. We hope that this study helps to improve the objective understanding of these perceptual descriptor terms often used in the audiophile community.

Background

“Warm” and “bright” are semantic terms commonly understood to describe speakers which have speaker responses that either fall or rise towards higher frequencies respectively (Kisla, 2017; Rowe, 2016; Gabrielsson et al., 1990). “Muddy” is commonly understood to describe speakers with speaker responses having overly large sensitivities at low frequencies. “Clear” is the lack of “Muddy”-ness (Seydel, 2016; Mayzes, 2016; Teach Me Audio, 2018) or alternatively, an emphasis on midhigh to high frequencies (Gabrielsson et al., 1990). “Clear” and “bright” have been found to be associated with the same speakers (Gabrielsson, Lindström and Till, 1991). Lastly, “Neutral” and “Coloured” are largely understood to describe speakers with either high or low degree of spectrum flatness respectively (Inearmatters.net, 2008; Gowan, 2012).

Speakers

Index Number	**Speaker Name**
1	Heco Color 100
2	Heco Vitas
3	ELTAX Millenium 100
4	Audioengine HD5+
5	Audioengine HD6 walnut
6	MOREL SOLAN V2

Table 1: List of speakers and index numbers used in this study

We analysed the six bookshelf speakers from Table 1 above.

In a single recording session, the experiment was set up in the Academic Media Studio of the Singapore University of Technology & Design (SUTD), an acoustically treated room noted for excellent sound isolation (<20 dB re 20 μPa) and minimal reverberation (<0.23 seconds). Each speaker was located at a height of 1.2m, resting on a padded surface, in the middle of the room with at least 2.5 meter unobstructed clearance radius all around it. A Rode NT3 microphone was placed axially facing the speaker 1.5m away, and its signal output connected to a ProTools HDX interface. A broadband signal generated from Adobe Audition is sent to the speakers driven from a Marantz Micro Network Receiver MCR-611 amplifier. We also collected the data for the Adam A7X speaker as a reference speaker.

The volumes at the laptop and amplifier were accordingly adjusted to safely avoid signal distortion or clipping at any point, and this is checked using a TekTronix TBS2000 oscilloscope.

The speaker responses measured can be seen in Figure 1 below.

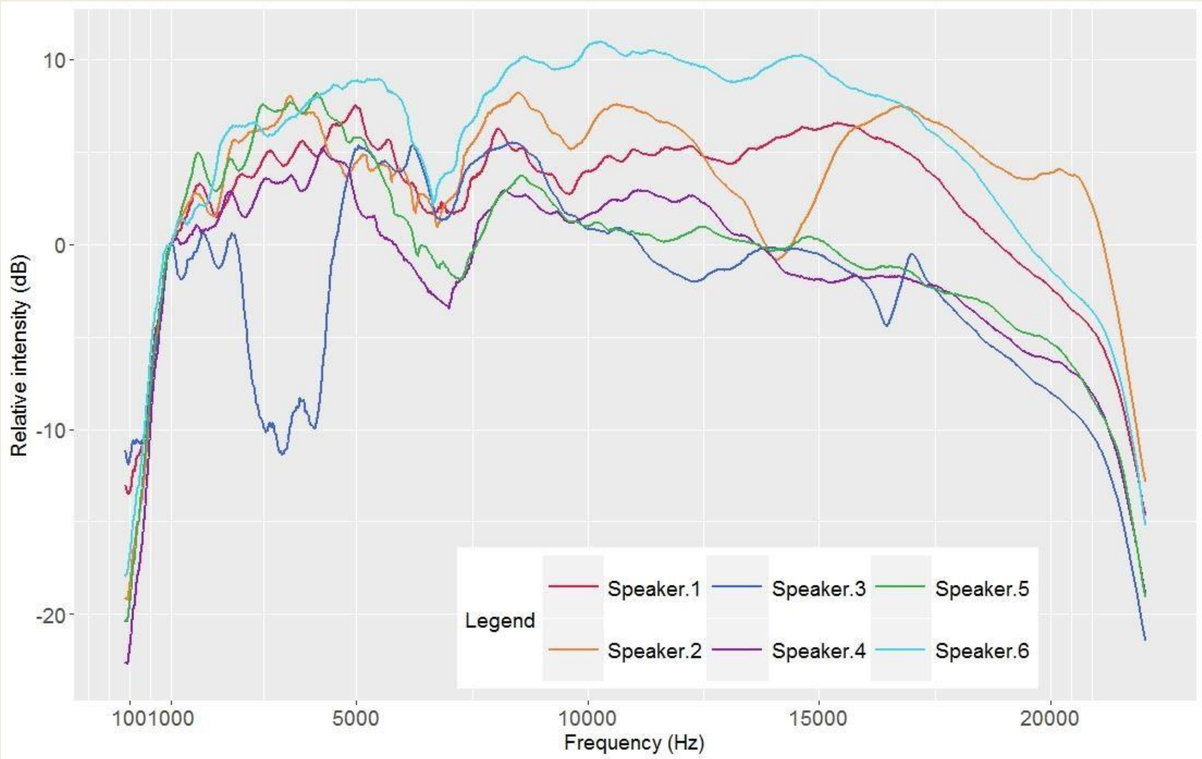

Figure 1: Frequency response of speakers anchored at 0dB at 1kHz

Listener Perception Test

We conducted listener surveys on 11 amateurs and 31 experts. The experts all had musical/audio backgrounds, defined as either having achieved significant musical expertise, having a vast experience in music editing, or having good knowledge of speakers (audiophiles). The amateurs were music lovers that did not consider themselves to be competent at speaker and audio equipment. While we only requested the amateurs to rate the perceived 'quality' of each musical excerpt heard, we further requested the experts to rate the perceived 'quality', as well as state which given semantic descriptors they would associate to each excerpt.

Similar to the earlier speaker analysis (Section 2), these tests were also conducted in the SUTD Academic Media Studio. The speakers were set in a row in front of the listeners (up to 6 simultaneously). We played the musical excerpt on the relevant speaker (and muted the rest of the speakers) while keeping the listeners blindfolded for the duration of the musical excerpt. Only after the excerpt ended did we let the listeners remove their blindfolds to answer the survey.

The musical excerpts used consists of 30-second excerpts from the 7 following songs: Bach Cello
Suite No.1 in G (solo instrumental), River Flows in You (solo instrumental), Take Five (jazz ensemble), Love Story (pop), The Scientist (pop), Great Gate of Kiev (orchestral *tutti*), Pirates of the Caribbean (orchestral *tutti*).

Results

speaker	warm	bright	muddy	clear	neutral	coloured	amateur score	expert score
1	0.38	0.32	0.52	0.31	0.37	0.29	2.98	2.90
2	0.23	0.47	0.22	0.52	0.35	0.34	3.02	3.15
3	0.46	0.23	0.37	0.41	0.38	0.30	2.85	3.01
4	0.41	0.28	0.34	0.38	0.42	0.30	2.95	3.07
5	0.39	0.26	0.37	0.39	0.32	0.37	2.88	3.16
6	0.37	0.30	0.33	0.39	0.34	0.31	3.14	3.14

Table 2: Association of descriptors and scores for each speaker

To obtain the final ‘quality’ of each speaker, we average all the ‘quality’ scores from all the excerpts of that speaker. We also obtain descriptor scores for each speaker based on the percentage of experts that associated the descriptor to excerpts from the speaker. In Table 2 above, the semantic descriptors (columns 2-7) are scored over a range of 0 to 1, with 1 being full agreement among experts that a speaker could be described in this way. The ‘quality’ scores (two right-most columns) are in a range of 1 to 7 with 7 being an extremely good speaker.

In general, “warm” is the opposite of “bright”, “clear” is the opposite of “muddy” and “neutral” is the opposite of “coloured” as we may expect. We also observe this trend well in Table 2. These negative correlations have p-values of 0.00077, 0.0040 and 0.082 respectively, which mean that the pairs of words tend to be used on different occasions.

In particular, we observe that the correlation between the “muddy” scores and expert scores are negative (correlation of −0.74 at a p-value of 0.090). This means that experts associate higher ‘quality’ scores to non-“muddy” speakers in general.

We notice that there is no strong correlation between the expert scores and amateur scores. Remarkably, there is no strong correlation observed between “warm”/ “bright” and “muddy”/ “clear” even though they are very similar in terms of their definition. Correlation between the clarity and brightness scores is 0.62 at a p-value of 0.19 and correlation between the muddiness and warmth scores is 0.71 at a p-value of 0.11, which means that while the trends are consistent with our expectations, they are not strong.

Speaker	**Amateur ranking**	**"Bright" ranking**	**Expert ranking**	**"Coloured" ranking**
1	3	2	6	6
2	2	1	2	2
3	6	6	5	4.5
4	4	4	4	4.5
5	5	5	1	1
6	1	3	3	3

Table 3: Rankings of speakers for quality from both surveys, brightness and colour

We examine the possible differences between the amateurs and experts and notice a strong correlation between brightness rankings of the speakers and the amateur scores. The data in Table 3 shows us a strong correlation of 0.83 with a p-value of 0.042. On the other hand, we notice a strong correlation between the colour of the speakers and the ranking of the expert scores. The data in Table 3 shows us a very strong correlation of 0.99 with a p-value of 0.00031. The p-values are low and are unlikely to have occurred due to chance.

This suggests that while the amateurs preferred "bright" speakers, the experts preferred non-"muddy" speakers (already observed in the analysis of Table 2). This can be seen in Figure 2, where these quality scores are plotted against perceived "colour" and perceived "brightness": largely monotonic relationships can be observed in both the amateur scores in the perceived "brightness" plot (right) and the export scores in the perceived "colour" plot (left). However, because the range of values for the "coloured" variable is rather small when compared to the other variables, more data ought to be collected before making any firm conclusions here.

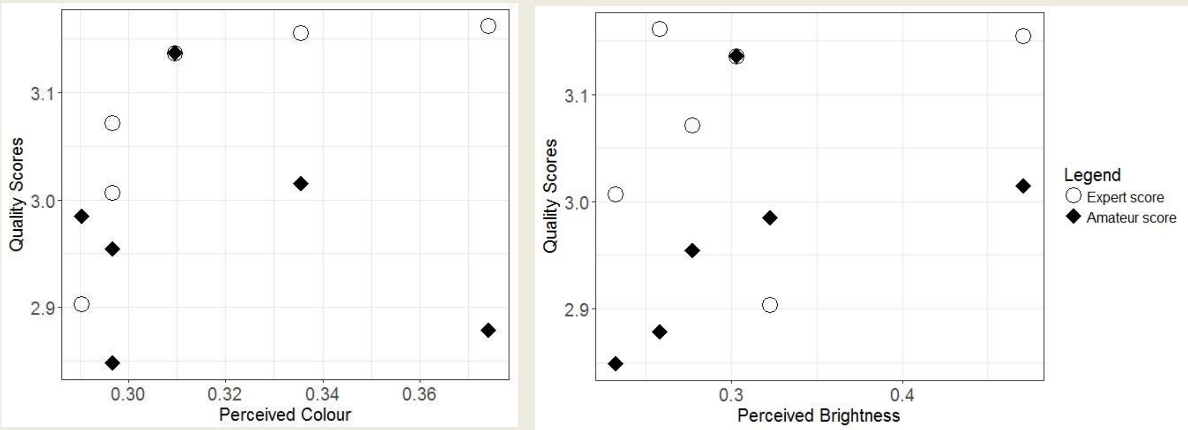

Figure 2: Plots of averaged 'quality' scores (range of 1-7) against perceived colour and perceived brightness (range of 0-1)

Analysis of variables

Variables

The performance parameters collected from each speaker are:

1) Total Harmonic Distortion[1] of the 9 sine wave samples played on the speaker: 100Hz, 500Hz and 1 kHz at three levels of volume which were 10dB apart.
2) Adjusted Autocorrelation value of the white noise in the time domain (G.M. Ljung and G.E.P Box, 1978): the higher the autocorrelation value, the less “white” the noise.
3) Spectral flatness measure of the white noise in the frequency domain according to N.Madhu (2009).
4) Area function characteristics of the frequency response such as normalized area, skew, kurtosis, taken from segments of the speaker response spectrum. The segments accordingly are the lowest, low, midrange and high frequencies, which have frequency ranges centred at 110Hz, 270Hz, 1125Hz and 11kHz respectively.

The full data set can be accessed at: http://bit.ly/SpeakerStatisticsData

Correlation between descriptors and speaker response characteristics

‘Quality’ score

We find that the skew and kurtosis of the low frequency region of the speaker response are most strongly correlated with expert’s score. Correlation with skewness of the low frequency region is −0.79 at a p-value of 0.063 which means that ‘quality’ increases when the low frequency region is left-skewed. Correlation with kurtosis of the low frequency region is −0.82 at a p-value of 0.045 which means that ‘quality’ increases when the low frequency region is gently-sloped. Overall, our experts prefer speakers with a left-skewed gentle-sloping low frequency region.

However, these variables are not strongly correlated with amateurs’ scores. Instead, correlation between the normalized area at high frequencies and amateur score is 0.82 with a p-value of 0.045. This means that amateurs liked speakers with good sensitivity/responsiveness at high frequencies.

From these observations of variables correlated to quality, we can naively expect that experts dislike muddy speakers and amateurs prefer bright speakers. Our findings are consistent with this expectation.

[1] It is not easy to find correlations and relationships with THD. However, while other variables fail at predicting neutrality, THD actually has promising correlations with neutrality. However, this is out of the scope of our project.

Warmth/Brightness

There is no correlation between perceived brightness/warmth and measures of area of high/low regions. The linear plots (not shown here) also show no observable relationship.

Interestingly, they seem to both be correlated with both measures of flatness, the spectral flatness measure and adjusted autocorrelation. Warmth correlates to both at p-values of 0.072 and 0.047 respectively, while brightness correlate to both at p-values of 0.066 and 0.0048 respectively. This means that the flatter the frequency response, the higher the perceived brightness of the speaker will be. This is made even more interesting when we consider that the two measures themselves do not seem to be fully consistent with each other. We visually inspect our speaker responses in Figure 1, but we are still unable to explain this trend.

Muddiness/Clarity

Muddiness and clarity are both linked to the normalized area and skew of lowest and low frequency regions of the speaker responses. We see that the correlations in Table 4 are generally very strong and show that a large normalized area of low frequency regions and right-skewedness leads to “muddy” speakers. The opposite is true for “clear” speakers.

Correlated variable	**Normalized area of lowest freq**	**Normalized area of low freq**	**Skew of lowest freq**	**Skew of low freq**
“Muddy”	Correlation of 0.90 at p-value of 0.014	Correlation of 0.84 at p-value of 0.038	Correlation of 0.79 at p-value of 0.068	Correlation of 0.80 at p-value of 0.056
“Clear”	Correlation of −0.80 at p-value of 0.057	Correlation of −0.68 at p-value of 0.14	Correlation of −0.85 at p-value of 0.030	Correlation of −0.85 at p-value of 0.033

Table 4: Correlation between “muddy”/ “clear” and skew/normalized area of lowest/low frequency

regions

We do not find strong correlation between clarity and the variables at the midrange/high frequency regions or THD. This suggests that muddiness and clarity are perceived due to the shape and size of the low/lowest frequency regions.

Follow-up mini experiment

Although warmth/brightness and muddiness/clarity supposedly hold the same differences on the speaker response curves, we find (in Part 3.1) that they do not share the same correlated variables. We are also curious about the opposing warmth vs brightness and muddiness vs clarity relationships. Does a damping of low frequencies lead to brightness or does a boosting of high frequencies lead to brightness or both?

We then held a follow-up experiment that focused on testing a small group of 6 experts. We wanted to gain insights on how applying certain FFT filters to the sound sample affects the descriptors associated to them. The link to this survey is: http://bit.ly/DescriptorSurvey

	Warm	**Bright**	**Muddy**	**Clear**
Average	3.94	4.39	3.77	4.33
High-frequency damped	4.39	3.69	3.92	4
High-frequency normal	3.83	4.44	3.69	4.44
High-frequency boosted	3.61	5.03	3.69	4.56
Low-frequency damped	3.44	4.56	3.75	4.53
Low-frequency normal	4	4.19	3.58	4.19
Low-frequency boosted	4.39	4.42	3.98	4.28

Table 5: Average level of association of each descriptor to each FFT filter feature

In the top two quadrants of Table 5, we observe that when we vary the high frequencies, there is an inverse relationship between muddiness/clarity and warmth/brightness. As we boost the high frequencies, warmth decreases and brightness increases. Damping gives the inverse effect.

In the bottom two quadrants, we observe that when we vary the lower frequencies, the inverse relationships are not so clear. When we boost the lower frequencies, muddiness increases and when we damp the lower frequencies, clarity increases (bottom right quadrant). However, when we boost the lower frequencies, clarity does not decrease and when we damp the lower frequencies, muddiness does not decrease. This trend also holds for brightness, because when we boost the lower frequencies, brightness does not decrease.

We learn that a decrease in a characteristic (decrease in brightness, muddiness and clarity) might be harder to perceive than an increase the feature. However, we still do not gain further insight as to what is the key difference between warmth/brightness and muddiness/clarity.

Neutrality/Colour

We find that neutrality and colour are not strongly related to the flatness measures (spectral flatness measure and adjusted autocorrelation). They are also not found to be strongly related to the skewness or kurtosis of the speaker response spectrum.

This shows that perceived neutrality and perceived colour have very little to do with actual flatness and deviation from flatness.

Clustering of the listeners

We also tried to gain a deeper insight on certain habits of word usage or preferences among our listeners. To achieve this, we decided to conduct some clustering analysis on the data, first on the full data set, then on each individual/pair component: “quality”, “warm + bright”, “clear + muddy” and “colour + neutral”. For the purposes of this clustering analysis, we combined the pairs of descriptors because the experts only picked a maximum of one out of the pair of words at any one question.

We conduct hierarchical clustering of the listener responses using complete linkage and Manhattan distance, as described in Müllner (2013). After finding possible clusters using hierarchical clustering, we then use the gap statistic to test the clusters for their quality. The gap statistic tells us if the clustering is better than random. We employ the "One SE" approach taken from (Tibshirani, Walther and Hastie, 2001). In this approach, we observe if there is a significant increase in the gap statistic should we add in one extra cluster.

There is no point where the gap statistic increased with an additional cluster. This shows that the clustering was no better than clustering of a random data set.

Although we have no special findings in this analysis, we would like to repeat this process on groups of listeners with a common preference for music and check if listeners who prefer similar types of music have the same tendencies to use similar descriptors using this procedure.

Discussion

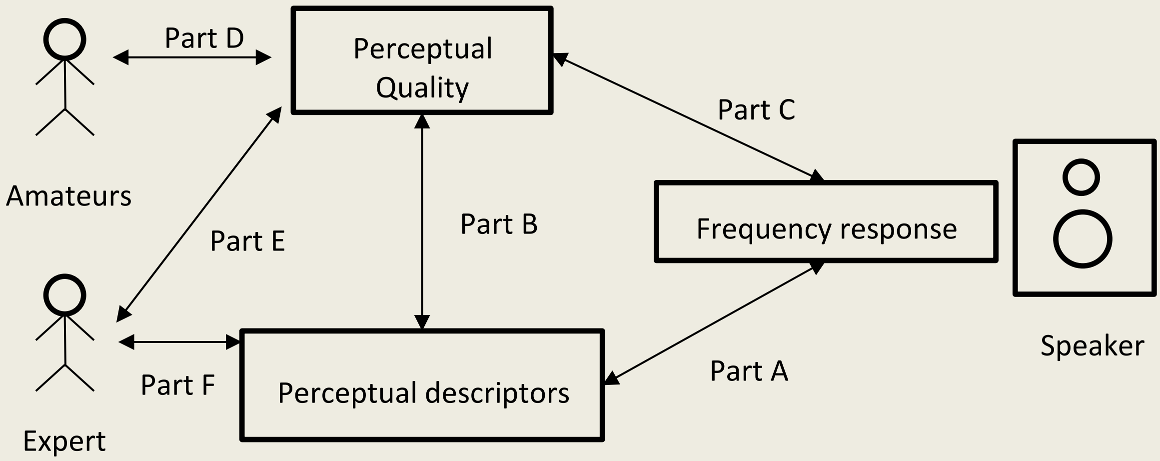

Figure 3: Overview of relationships

Figure 3 is a schematic showing the complex relationships between listeners and speakers and the elements involved: the relationships are not simple (nor symmetrical) and allow us to appreciate the difficulty in objective discussions regarding speaker response, perceptual descriptors and perceptual quality.

We start off the discussion with the analysis of the relationship between the descriptors and the speaker response characteristics (Part A in Figure 3).

Among our hypotheses, we found that perceived muddiness and clarity are strongly related to the normalized area and skew of the lower frequencies. However, warmth and brightness are not strongly related to the area of the high and low frequencies in the speaker response. Interestingly, they are both strongly linked to measures of flatness instead. We set out to match the listener's perception of neutrality to the flatness of the speaker's frequency response. However, upon analysis, perceived neutrality and colour were not strongly related to any of the flatness measures of the frequency response. How well humans can discern flat spectrums and what humans perceive as neutral are interesting questions that require further study, such as work by Agus et al (2018).

In our mini follow-up experiment where FFT filters were applied to the sound samples to elicit expert semantic preferences, we found that generally, the expected relationships between “warm”/“bright”/“muddy”/“clear” and the strengths of high/low frequency responses were observed. However, the reverse relationships were not as clear-cut when the low frequencies were varied. As we only had a small sample size for this mini experiment, we hope that the trends will become clearer with more data to be collected.

In Part B, we found of the three semantic descriptor terms expected to be positively correlate to quality (“clear”, “warm” and “neutral”), only the preference for “clear” is presented. “Warm” and “neutral” was less appealing than “bright” and “coloured” for our listeners as shown by the relative scores.

We have a hypothesis for the preference of “bright” speakers: In Part A, we found out that “bright” speakers correlated to speaker responses that were flatter. As we understand that experts generally prefer flat spectrums, it then makes sense that “bright” speakers were perceived to be of higher quality, even though the wrong descriptor is attached to the feature of flatness.

We also found that amateurs and experts preferred different speakers, indicating that Part D and E were not in agreement. We found significant evidence that they were looking for different speaker characteristics, such that Part B is different for each group. In particular, we showed that amateurs place more emphasis on the brightness of the sounds while experts prioritize non-muddy sounds. However, it must be noted that reference for brightness is a two-edged sword, as although the bright speakers can sound more ‘defined’ initially, it can also quickly give rise to listener fatigue subsequently (Hall and Denison, 2018; Heyne, 2012).

Part C supports this: ‘quality’ is related to the skewness and kurtosis of the woofer frequency region for experts but was related to the area of the tweeter frequency region for amateurs. This supports the notion that experts avoided muddiness while amateurs preferred brightness.

Lastly, we tried to find relationships between our experts’ usage of descriptors, which is Part F. Unfortunately, no similar or consistent responses could be elicited; whether it be on the full dataset, or on individual descriptors, the listeners all had rather different responses from each other. This was rather disappointing. We understand that listening is a very subjective experience. However, we did not expect that even the [seemingly simple] words “muddy” and “clear” held so much subjectivity, such that no groups of listeners that had the same interpretations of these descriptors.

Conclusion

In this study, we have looked at how speaker responses, listeners and the descriptors listeners use to describe speakers are related. While we were able to quantify the speaker’s response in a laboratory setting, there was no agreement among the listeners’ perceptions of the different speakers.

We found differences between our two listener populations that we surveyed: experts and amateurs. Our amateurs seemed to prefer “bright” speakers, but experts tended to choose non-“muddy” speakers. This is not surprising, as the consumer market has already known this, as evidenced by them producing speakers catering to these two populations, whether it be for amateurs with more straightforward expectations or for experts having more nuanced preferences. Importantly, we show, for the first time, that skew and kurtosis of the low frequency regions may be helpful to meaningfully quantify muddiness and clarity.

Interestingly, measures of spectral flatness were found to be useful in predicting whether the speakers were perceived as “warm” or “bright”. Rather counter-intuitively, we also found that *actual* neutrality (as measured) and *perceived* neutrality (as surveyed) were in fact not strongly correlated and this invites further study.

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VI.REPORT ON CONFERENCES

The Regional Conference on Acoustics and Vibration (RECAV) organised by the Society of Acoustics(Singapore) and the Association of Acoustics and Vibration Indonesia(AAVI) was successfully held in Bali,Indonsia from 27 to 28 Nov 2017. There were 110 presentations from 14 countries with 60% of them from Indonesia. There were also some 18 exhibition booths. This reflected strong local participation and the international nature of the conference.

VII. BID FOR FUTURE INTERNATIONAL CONFERENCES

Riding on the success of Wespac 2015, the society is bidding to host the International Congress on Acoustics(ICA) in Singapore in 2025 and to host the International Congress on Sound and Vibration(ICSV) in Singapore in 2021

Government Bodies

www.mom.gov.sg

www.nea.gov.sg

www.lta.gov.sg

Technical and Research Sites

Corporate Sites

www.metaultrasound.com

www.noisecontrols.com

(The Society welcomes interested parties to contribute relevant websites to the above e useful links. For more information, please contact us. Thank you.)

President: **Woon Siong Gan**
E-Newsletter compiled by: **Woon Siong Gan**