INTERNATIONAL SYMPOSIUM on MUSICAL and ROOM ACOUSTICS
ISMRA 2016
September 11-13, 2016
La Plata, Buenos Aires, Argentina

Physics of musical instruments and voice: Paper ISMRA2016-22

Proposed metrics for understanding how directional characteristics of assorted musical instruments change across musical passages

Lily M. Wang[a], Madeline A. Davidson[a]

[a] University of Nebraska – Lincoln, United States, lwang4@unl.edu

Abstract

In room acoustic computer modeling, directional characteristics of sound sources are often modeled based on the static directivity measured in each octave band. In reality, though, the directional characteristics of sources like musical instruments can change dramatically across a musical passage, and such changes may not be adequately captured in the current common computer modeling practice. This paper reviews proposed metrics developed to quantify how directional characteristics of musical instruments change in real-time. Application of these metrics to multi-channel recordings of a number of different musical instruments are described to indicate how these metrics can show differences in instrument behavior. Do violins demonstrate greater directional tone color than other instruments? Do these directional characteristics change across different musical excerpts? How do the proposed metrics vary based on the number of channels used for the recording? Findings and recommendations on using these metrics for quantifying time-varying directivity are presented.

Keywords: musical instrument directivity

Proposed metrics for understanding how directional characteristics of assorted musical instruments change across musical passages

1 Introduction

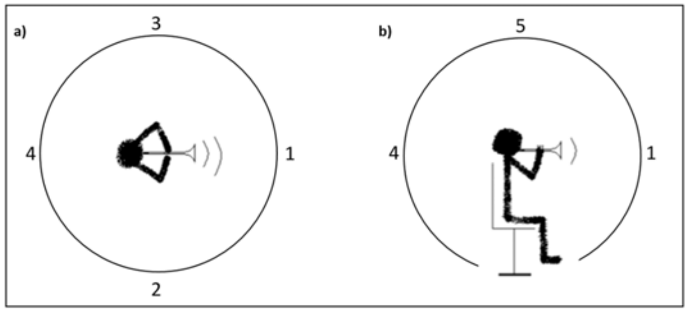
The directivity of a sound source refers to how its radiated sound energy varies with direction. Musical instruments demonstrate distinct directional sound radiation characteristics, and these have been recorded and analysed in a number of previous studies [1-3]. Typically, directivities have been investigated while the instrument maintains a given tone, so that a static directional pattern is produced. From such a static directivity pattern, one can calculate directivity factors in any given direction and convert those to the common metric, directivity index. Many of these static directivity patterns have been utilized in room acoustic computer modelling programs when predicting how sound will behave in a space, with a static directivity pattern assigned to each octave band for that instrument.

As a musician progresses through a musical piece and changes notes, dynamics, and articulations on an instrument, though, the directivity is constantly changing in time. Weinreich referred to the rapidly varying directional pattern of violins specifically, highlighting this particular instrument's 'directional tone color' [4]. Previous work has shown that the time-varying directional characteristics of real musical instruments can greatly impact the objective and subjective qualities associated with room acoustics [5-10]. There has been, however, far less work conducted on quantifying the time-varying aspect of directivity for sound sources.

In this paper, the authors propose metrics for quantifying the time-varying properties of directivity, calculated from simultaneous multi-channel recordings of musical instruments playing musical excerpts. Applying such metrics allows one to compare the degree to which different instruments exhibit the 'directional tone color' that Weinreich describes. Quantifying the directionally time-varying characteristics can also help one to understand better how musical sources may interact with a room.

2 Proposed quantifiers

There are five quantifiers proposed herein to describe a musical instrument's time-varying directional characteristics. They are calculated from simultaneous multi-channel recordings of individual instruments taken in an anechoic chamber. In this paper, the quantifiers are applied to five-channel recordings acquired at the Technical University of Denmark of every instrumental part from two symphony movements (Brahms' Symphony No. 4 in E minor, Op. 98: 3rd Movement, and Mozart's Symphony No. 40 in G Minor, K. 550: 1st Movement). For these recordings, the microphones were placed 1.5 m from the sound source, surrounding each player as shown in Figure 1, and a 44.1 kHz sampling rate and 24-bit quantization were used. More information on these recordings may be found in [9].



Source: (Author, adapted from [6])

Figure 1: Microphone positions for five channel anechoic recordings

The directivity index at each channel is calculated from the multi-channel recordings over moving 10 ms time-windows throughout the excerpt, with a 5 ms overlap. A number of different time-window lengths were investigated, but the authors decided to move forward with 10 ms since a number of psychoacoustic studies have found that the temporal threshold for gap detection is in this range [11-12]. Because the musical passages for each instrument contained silences when the instrument was not being played (as each musician followed the score), silences longer than 10 ms were edited out of the multi-channel recordings prior to calculations.

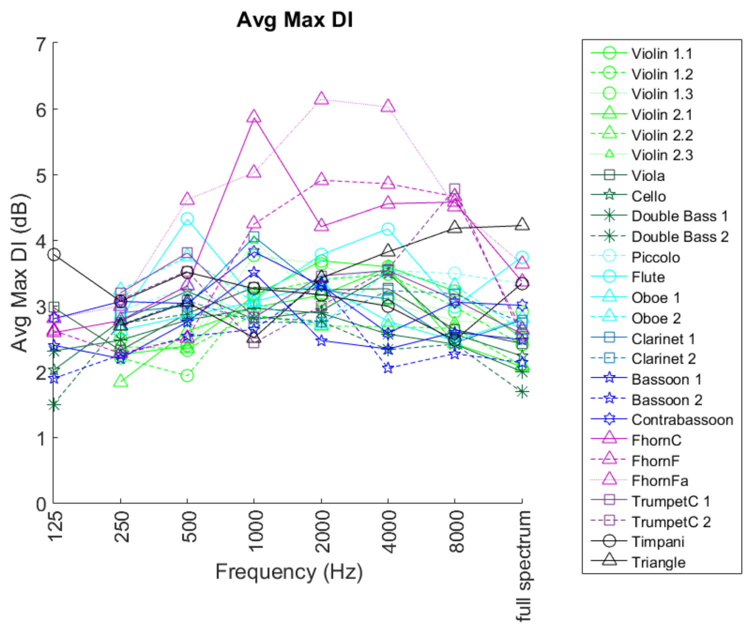
The five proposed quantifiers were then calculated from the directivity index data over time. First is the *average maximum directivity index (Avg Max DI)*, which is the average maximum directivity index of all 10 ms time windows over the entire excerpt. Higher values of Avg Max DI indicate that an instrument is generally more directional. Next is the *average change in maximum directivity index (Avg Chg Max DI)*, which is the average difference in maximum directivity index between consecutive 10 ms time windows. Higher values of Avg Chg Max DI potentially link to the 'directional tone color' that Weinreich discussed [4].

The final three provide information on how a source's directional characteristics change in space. *Location change ratio (L)* documents the number of times the channel of the maximum directivity index changed, normalized by the total number of time windows considered across the excerpt. Higher values of L are considered to be linked to instruments with greater 'directional tone color'. *Dominance ratio (D)* indicates how much the most prominently directional location dominates over the other directions, and is calculated by taking the number of time windows at which that location was dominant and dividing it by the total number of time windows considered across the excerpt. Higher values of D indicate an instrument whose primary directionality does not change location greatly. Finally, the *dominating channel* accompanies D, stating which channel (or direction) was dominant.

Now that the metrics have been introduced, they are applied to each instrumental part of both the Brahms and Mozart symphonies. Which has the greater impact on a musical instrument's time-varying characteristics: the characteristics of the instrument itself, or the musical excerpt? Two types of comparisons are made: first between orchestral families within one of the symphonies, and then between the two symphonies.

3 Results across instrument families

Figure 2 shows the average maximum directivity index results for all of the instruments in the Brahms symphony, across assorted octave bands as well as calculated across the full spectrum. The brass instruments are shown to have the highest directivity, while the other instrument families demonstrate more similar values.

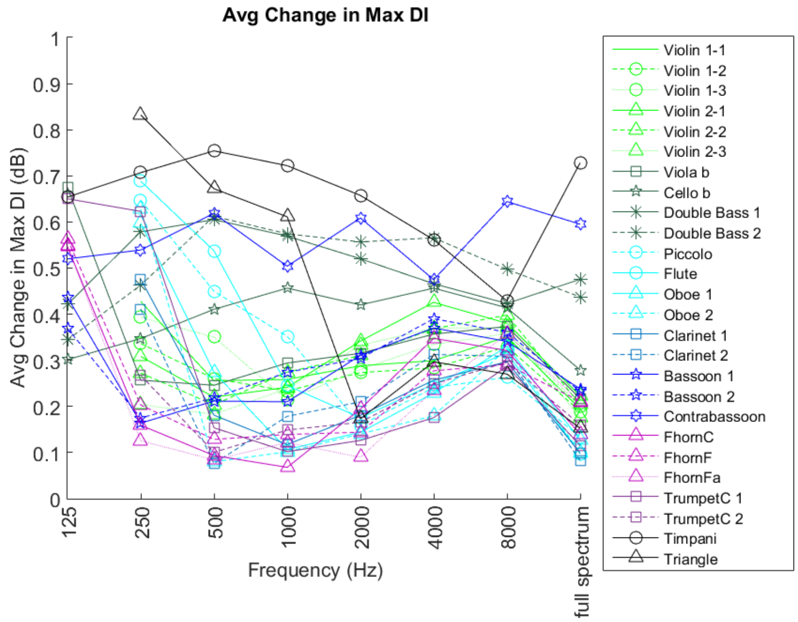


Source: (Author, 2016)

Figure 2: Average maximum directivity index results for each instrument of the Brahms symphony

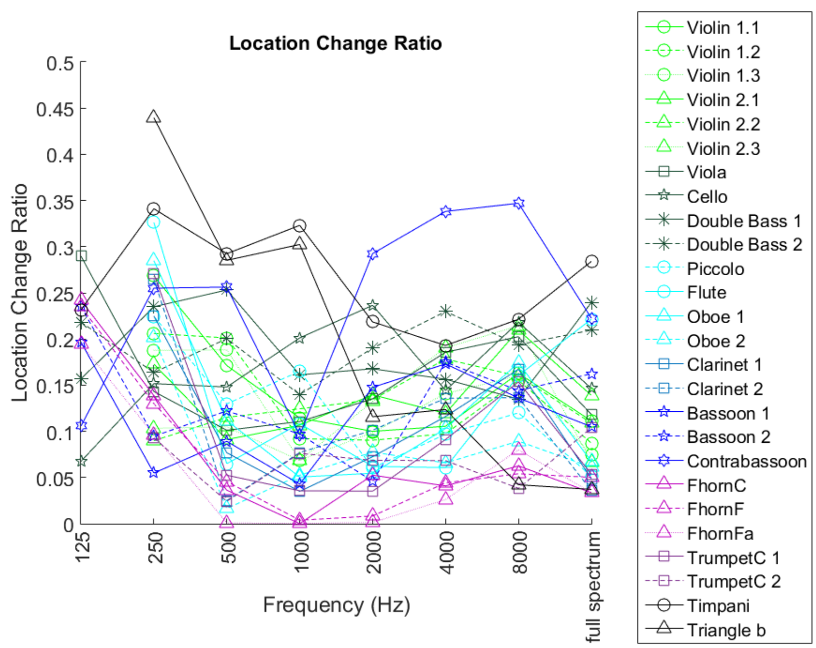
The average change in maximum directivity index results are given in Figure 3 for all of the instruments in the Brahms symphony, across assorted octave bands as well as calculated across the full spectrum. In this case, the strings and woodwinds have greater values than the brass, indicating that their directional characteristics change more dramatically than brass instruments.

Figure 4 plots the location change ratio results for all of the instruments in the Brahms symphony, across assorted octave bands as well as calculated across the full spectrum. These results mirror those from the average change in maximum directivity index, with the strings and woodwinds demonstrating a greater number of times that the channel with maximum directivity changes in comparison to the brass instruments.



Source: (Author, 2016)

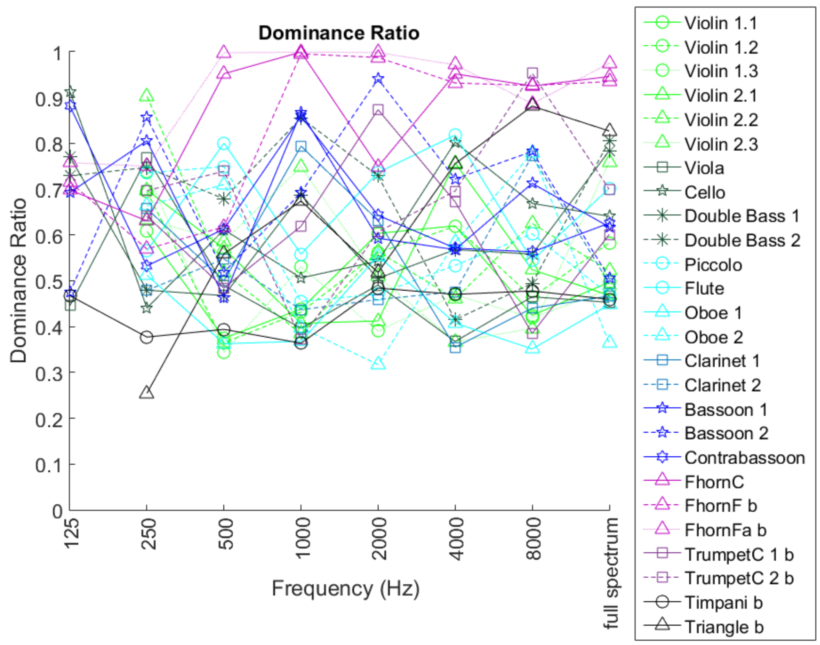
Figure 3: Average change in maximum directivity index results for each instrument of the Brahms symphony



Source: (Author, 2016)

Figure 4: Location change ratio results for each instrument of the Brahms symphony

The dominance ratio results are shown in Figure 5 for all of the instruments in the Brahms symphony, across assorted octave bands as well as calculated across the full spectrum. The brass instruments have high dominance ratios, indicating that the location of the maximum directivity did not change greatly over the excerpt. The strings, woodwinds, and percussion demonstrate lower values but span quite a wide range across their own families.

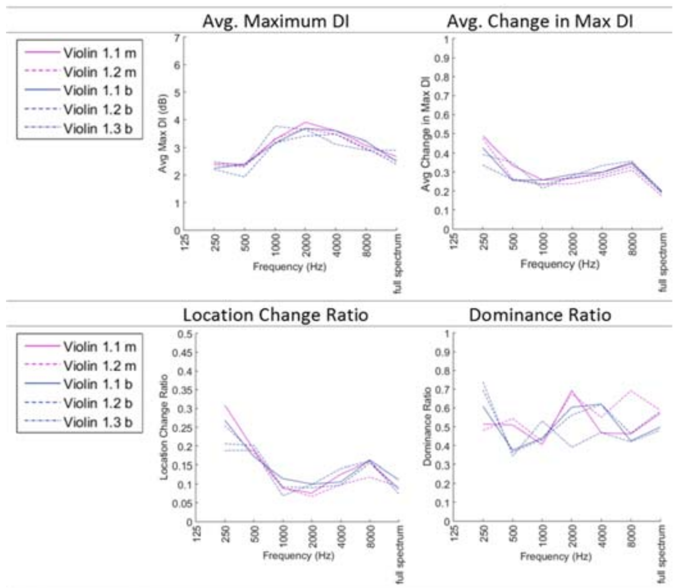


Source: (Author, 2016)

Figure 5: Dominance ratio results for each instrument of the Brahms symphony

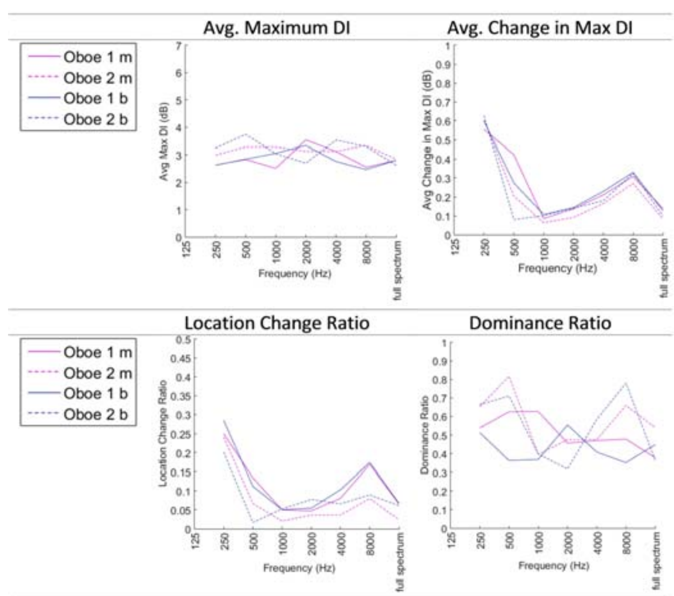
4 Results across excerpts

Figures 6-8 show how these metrics vary between the Brahms and Mozart symphonies, for three instruments found in both of these pieces: violin, oboe, and French horn. The behaviors of the instruments appear to be very similar between these two excerpts. Based on the analyses presented in this paper then, more significant differences in time-varying directional characteristics exist between instrument families than between excerpts. However, the two excerpts utilized may not be different enough; additional excerpts should be investigated.



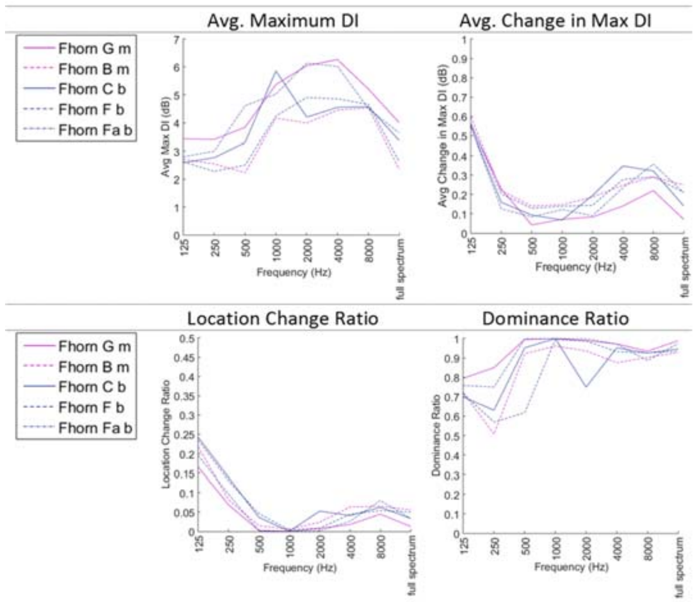
Source: (Author, 2016)

Figure 6: Comparison of time-varying characteristics for the violin across the two symphonies



Source: (Author, 2016)

Figure 7: Comparison of time-varying characteristics for the oboe across the two symphonies



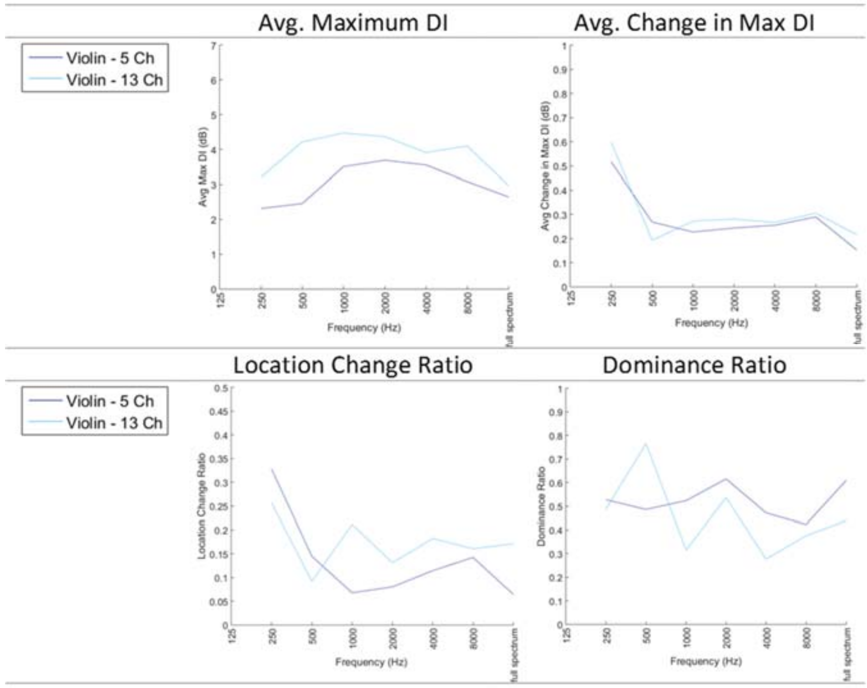
Source: (Author, 2016)

Figure 8: Comparison of time-varying characteristics for the French horn across the two symphonies

5 Increasing the number of channels

The authors understand that having only five channels of directional data does not sufficiently sample a source's radiation pattern, so the results presented above primarily serve to demonstrate the utility of the metrics proposed rather than to make definitive statements about the values of the metrics for each instrument. Having more channels of directional data would provide more accurate sampling of the true radiation pattern. The values of the proposed metrics are expected to change as well, so that values can only be compared when calculated from similar multi-channel recording setups. The Avg Max DI could potentially be greater, due to better sampling of the actual peaks. The Avg Chg Max Di could also increase, due to higher sampling accuracy. The location change ratio would produce higher values due to the additional number of microphone channels, while the dominance ratio would produce lower values for the same reason. One would expect the dominant location to be in a similar spatial location.

An example of how these metrics can vary due to different microphone channel numbers is shown in Figure 9 for the violin. Data from the five-channel recording setup described in Section 2 are compared against similar data (from a different solo musical passage) taken from the same facility using a 13-channel recording setup [6]. Results tend to behave as expected, particularly in the upper frequency bands.



Source: (Author, 2016)

Figure 9: Comparison of metrics for the violin between two different microphone channel setups

6 Conclusions

This paper presents a set of proposed metrics for quantifying the time-varying directional characteristics of musical instruments and demonstrates how they can be applied to understand differences between instrument families as well as between musical excerpts. The quantifiers appear to be suitable for comparing between instruments when using available five-channel data, but the limited data lead to less conclusive results when comparing between different classical musical excerpts. Using recordings taken from a higher number of microphone channels is suggested, as additional channels improve the sampling accuracy of the instrument’s sound radiation pattern.

Other suggestions for future work are to consider what the optimal number of channels would be to reliably use the proposed metrics, depending on the wavelengths of interest. Further comparisons between more contrasting musical excerpts are also recommended.

The authors believe that better quantification of the time-varying behavior of musical instruments can aid in understanding and better modeling of how these sources interact with the built environment.

Acknowledgments

Many thanks to Adam Buck and Kristin Hanna who worked on this project in its earlier phases.

References

[1] Meyer, J. The sound of the orchestra, *Journal of the Audio Engineering Society*, Vol 41 (4), 1993, pp 203-213.

[2] Meyer, J. *Acoustics and the Performance of Music: Manual for Acousticians, Audio Engineers, Musicians, Architects and Musical Instrument Makers*. Springer Science & Business Media, 2009.

[3] Patynen, J.; Lokki, T. Directivities of symphony orchestra instruments, *Acta Acustica united with Acustica*, Vol 96 (1), 2010, pp 138-167.

[4] Weinreich, G. Directional tone color, *Journal of the Acoustical Society of America*, Vol 101 (4), 1997, pp 2338-2346.

[5] Prince, D.; Talaske, R. Variation of room acoustic measurements as a function of source location and directivity, in *W. Clement Sabine Centennial Symposium*, Cambridge, MA, 1994, pp 5-7.

[6] Otondo, F.; Rindel, J. The influence of the directivity of musical instruments in a room, *Acta Acustica united with Acustica*, Vol 90 (6), 2004, pp 1178-1184.

[7] Martin, R.; Witew, I.; Arana, M.; Vorländer, M. Influence of the source orientation on the measurement of acoustic parameters, *Acta Acustica united with Acustica*, Vol 93 (3), 2007, pp 387-397.

[8] Chiang, W.; Lin, W.; Lin, Y. Optimizing the seats surrounding the platform in a recital hall when considering source directivity, *Applied Acoustics*, Vol 69 (12), 2008, pp 1176-1188.

[9] Vigeant, M.; Wang, L.; Rindel, J. Investigations of orchestra auralizations using the multi-channel multi-source auralization technique, *Acta Acustica united with Acustica*, Vol 94 (6), 2008, pp 866-882.

[10] Vigeant, M.; Wang, L.; Rindel, J. Objective and subjective evaluations of the multi-channel auralization technique as applied to solo instruments, *Applied Acoustics*, Vol 72 (6), 2011, pp 311-323.

[11] Moore, B.; Glasberg, B.; Plack, C.; Biswas, A. The shape of the ear's temporal window, *Journal of the Acoustical Society of America*, Vol 83 (3), 1988, pp 1102-1116.

[12] Lister, J.; Koehnke, J.; Besing, J. Binaural gap duration discrimination in listeners with impaired hearing and normal hearing, *Ear and Hearing*, Vol 21 (2), 2000, pp 141-150.