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Directivity analysis of the muted trumpet

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The directivity function of a played musical instrument describes the angular dependence of its acoustic radiation and diffraction about the instrument, musician, and musician's chair. In this study, high angular resolution directivity data were acquired in an anechoic chamber of a muted trumpet being played by a seated musician. The chair height and horizontal displacement ensured that the geometric center of the instrument's radiating region fell at the circular center of a computer-controlled semi-circular array of 36 microphones positioned at 5-degree polar-angle increments. Azimuthal rotations progressed in 5-degree increments, such that the measurements involved 2,521 unique positions over a sphere. Additional measurements at a position within the rotating reference frame facilitated post-processing. The musician played chromatic scales at each rotation position, and this process was repeated for straight, cup, and wow wow mutes in order to draw comparisons in the directivity patterns of each mute to the unmuted trumpet. Radiation behind the musician increased as a result of the mute, and mute-dependent changes to the directivity patterns primarily occurred above 1 kHz.

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1. INTRODUCTION

Trumpet mutes are essential devices for players to modify their instrument timbres and diminish their presence in various musical settings and contexts. Usually, corks or metal clips affix mutes internally or externally to trumpet bells. The most common mutes include the straight, cup, and wow-wow (wah-wah), commonly known as the Harmon mute. Mutes are available in various shapes, sizes, and materials, including aluminum, copper, and plastic. "Stonelined" mutes, patented and manufactured by Humes and Berg, consist of a thin metal coated by a plaster-like substance.

The straight and cup mutes are standard for orchestral contexts. The straight mute gives a bright sound of diminished amplitude, whereas the cup mute produces a warmer or mellower sound. The Harmon mute occasionally appears in orchestral settings, but its more common use is for jazz. Its design includes a removable stem (a metal tube extending out of the mute with a cup-shaped bell), which changes the sound in a significant way. A player may cover the stem opening with a hand and then move it away to create a "wah" sound, which gives the mute its namesake. George Gershwin's *Rhapsody in Blue* provides notable examples of Harmon mutes used for trumpet and trombone solos.

Both cup and straight mutes use three corks perpendicular to the open end within the trumpet bell to hold themselves securely. The corks are about a centimeter thick, allowing sound to pass freely around the bell and between the corks. The Harmon mute has a thinner cork wrapped entirely around its opening, creating a better seal and forcing sound waves into the mute and stem.

Despite their common musical uses, many of the detailed acoustical characteristics of trumpet mutes remain obscure. Backus[1] observed changes in the input impedance curves with and without mutes. Ancell[2] studied the radiated spectrum at a single observation position away from the trumpet and showed that mutes primarily affect higher frequencies above 1 kHz. A relative increase in higher frequency energy is ostensibly the cause of the tonal shift between mutes and their "metallic" tones.

Because a sound source's directional characteristics lead to spectral colorations in playing environments,[3] it is paramount to understand the influence of trumpet mutes on directivity. While many works have considered trumpet directivities,[4–6] few outside of Ancell's have studied the impacts of mutes on general sound radiation. Additionally, single-capture measurement systems employed in previous studies limited the number of sampling positions to 13, 32, or other small numbers over a sphere.[4,7] Another effort has employed a multiple-capture transfer function method to study unmuted trumpet radiation with a 5° resolution, consistent with the AES directivity sampling standard,[8] to illustrate the benefits of increased sampling density.[9] This work explores muted trumpet directivities based on a similar system. The results show that the straight and cup mutes have minimal effect on the unmuted directivity below the 1.6 kHz one-third octave (OTO) band but have a more significant impact above it. In addition, the Harmon mute has more distinct differences compared to the other mutes at these higher frequencies.

2. METHODS

The directivity measurement system (DMS) included 36 free-field 12.7 mm (0.5 in) microphones spaced in 5° polar-angle increments on a semicircular array (Fig. 1). Acoustical treatments minimized undesirable scattering effects. The array structure was attached to a turntable, which rotated in 5° azimuthal steps to enable a multiple-capture measurement at 2,521 unique microphone positions over a sphere. Another fixed microphone within the sphere produced reference signals for post-processing via a transfer function method.[10]

A musician's chair attached to an adjustable stand positioned the musician within the microphone array. A head restraint stabilized the musician's head to keep its position consistent throughout the measurement sequence. A laser pointer attached to the trumpet also allowed the player to maintain its beam on a small roughly 2 cm square target on the chamber wall for further orientation and position consistency during the

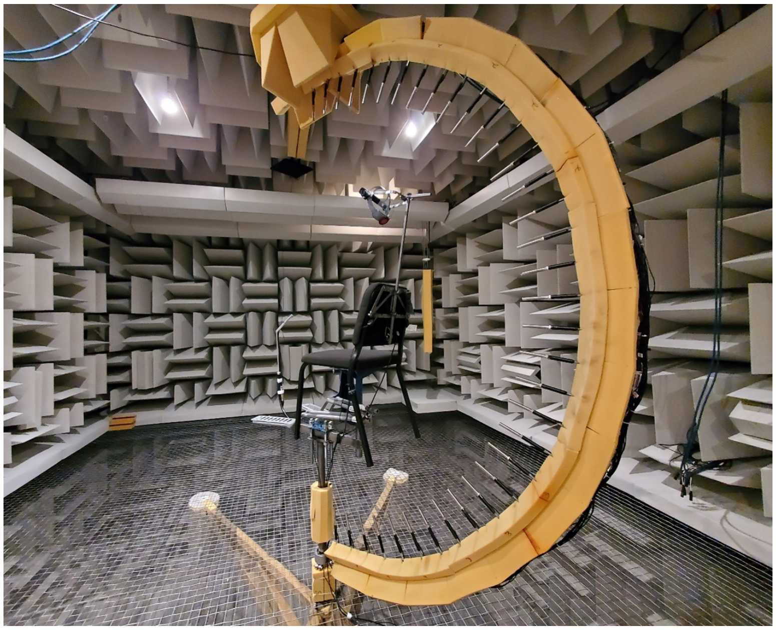

Figure 1: Setup of the DMS in an anechoic chamber.

measurement procedure. A small tuner also helped the musician maintain pitch stability during the session. Figure 2 shows the seated musician with the attached head restraint. The trumpet was a standard professional model, a Vincent Bach Model 43 Stradivarius B♭ trumpet. Figure 3 shows the trumpet with the tuner and laser pointer attached.

For each of the 72 azimuthal measurement angles, the musician played a chromatic scale from B♭3 to F5 at a mezzo-forte dynamic level. This range was well within the typically written range for the trumpet and provided a realistic representation. The musician played each scale note for 1 s with a 1 s pause between notes (i.e., one-quarter note per step with a quarter rest at 60 bpm). He repeated any notes that were not on pitch, consistent, or that "cracked."

Narrowband frequency response functions (FRFs), which compensated for differences between rotations, followed from auto and cross-spectral densities between the reference and array microphones.[10] Additionally, since architectural acoustics simulation packages commonly employ fractional octave band directivities, this work utilized the effective coherent output spectrum (ECOS) to calculate OTO band directivities.[10] An overall effective coherent output spectrum (OECOS) resulted by averaging the ECOS of each note together. As Figure 4 suggests, averaging more notes together fills each band with more spectral information. Broadband directivities then followed by summing the OECOS over the desired bandwidth. Coherence levels and balloons also facilitated detecting and analyzing problematic notes or microphone positions. Additionally, spherical harmonic expansions of the magnitude OTO band data allow smoothing to remove measurement noise by acting as a spatial filter.[11,12]

3. RESULTS

A. WITHOUT MUTE

Figure 5 plots the normalized directivity of the unmuted trumpet for select OTO bands, where balloon color and radius both indicate the relative levels on a 40 dB scale. For this and other plots, the musician faced the 0° azimuthal marker. Figure 5a-d shows the directivity from a front view, whereas Fig. 5e-h shows the directivity from a back view. At the 250 Hz OTO band (Figs. 5a and 5e), the radiation is nearly

Figure 2: Seated musician with the head restraint, clip-on tuner, and trumpet-mounted laser before the straight-mute measurements.

Figure 3: Bach Stradivarius Model 43 B♭ trumpet with a clip-on tuner and laser pointer attached.

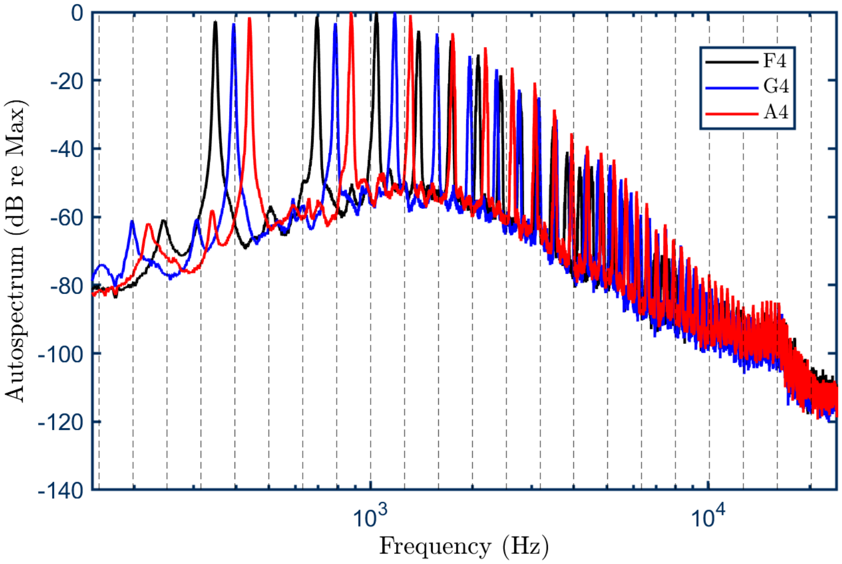

Figure 4: Spectra for three played notes, with dotted vertical lines indicating OTO band center frequencies.

omnidirectional, although some diffraction-related distinctions are evident behind the chair. Such effects are important features for musician-played instruments that artificial-excitation measurements often neglect.[13]

The radiated sound becomes more directional in higher-frequency bands, such as for 400 Hz (Figs. 5b and 5f), 800 Hz (Figs. 5c and 5g) and 1.25 kHz (Figs. 5d and 5h). The sound behind the musician also diminishes and small diffraction lobes appear more frequently.

B. WITH MUTE

Figure 6 presents directivity balloons for the trumpet with the cup mute while Fig. 7 presents directivity balloons for the trumpet with the straight mute. The shown frequency bands are the same as those in Fig. 5. As with the unmuted directivity, both the cup and straight mutes yield fairly omnidirectional radiation patterns in the 250 Hz band (Figs. 6a, 5f, 7a, and 7f), although the straight mute appears to exhibit stronger diffraction effects. The higher frequency balloons are also similar to those of the unmuted case, including the number and position of smaller side lobes. These results demonstrate that the cup and straight mutes produce few directional differences within these bands.

Significant directional differences begin to manifest themselves above the 1.6 kHz OTO band, so that similar trends do not hold for the cup or straight mutes. Figure 8 plots the directivity for the 3 kHz OTO band for the unmuted trumpet (Figs. 8a and 8e), trumpet with cup mute (Figs. 8b and 8f), trumpet with straight mute (Figs. 8c and 8g), and trumpet with the Harmon mute (Figs. 8d and 8f). Compared to the unmuted trumpet directivities, both the straight and cup mute directivities show more radiation to the sides and back of the instrument than for the unmuted trumpet. The Harmon mute in particular has a much broader primary radiation lobe than the other three cases. The difference in high-frequency radiation of the Harmon mute compared to the cup and straight mutes may be attributable to its lack of an annular opening and narrow mute aperture.

The influence of the cork placements appears in radiation patterns at very high frequencies for the cup and straight mutes. For example, Fig. 9 plots progressively higher OTO band directivities for the straight mute. Although at 4 kHz (Fig. 9a) the secondary lobe is roughly axisymmetric, by 8 kHz (Fig. 9d)

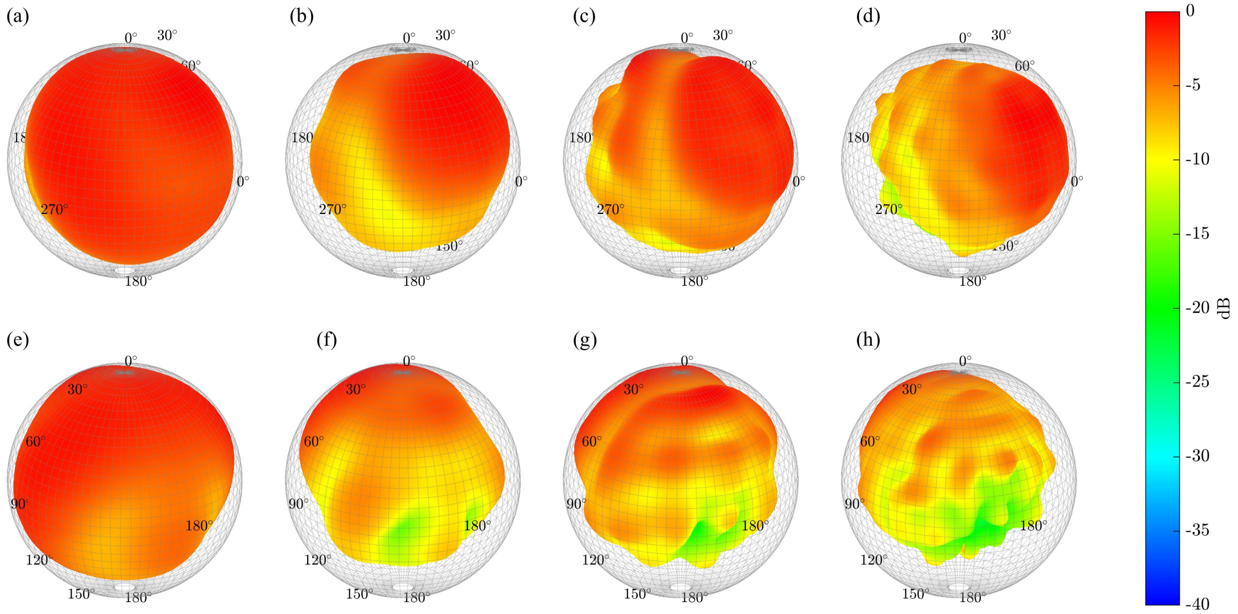

Figure 5: Normalized OTO band directivity patterns for the unmuted trumpet smoothed with an $N = 17$ spherical harmonic expansions from an (a)-(d) front view and an (e)-(h) back view. (a),(e) 250 Hz. (b),(f) 400 Hz. (c),(g) 800 Hz. (d),(h) 1.25 kHz.

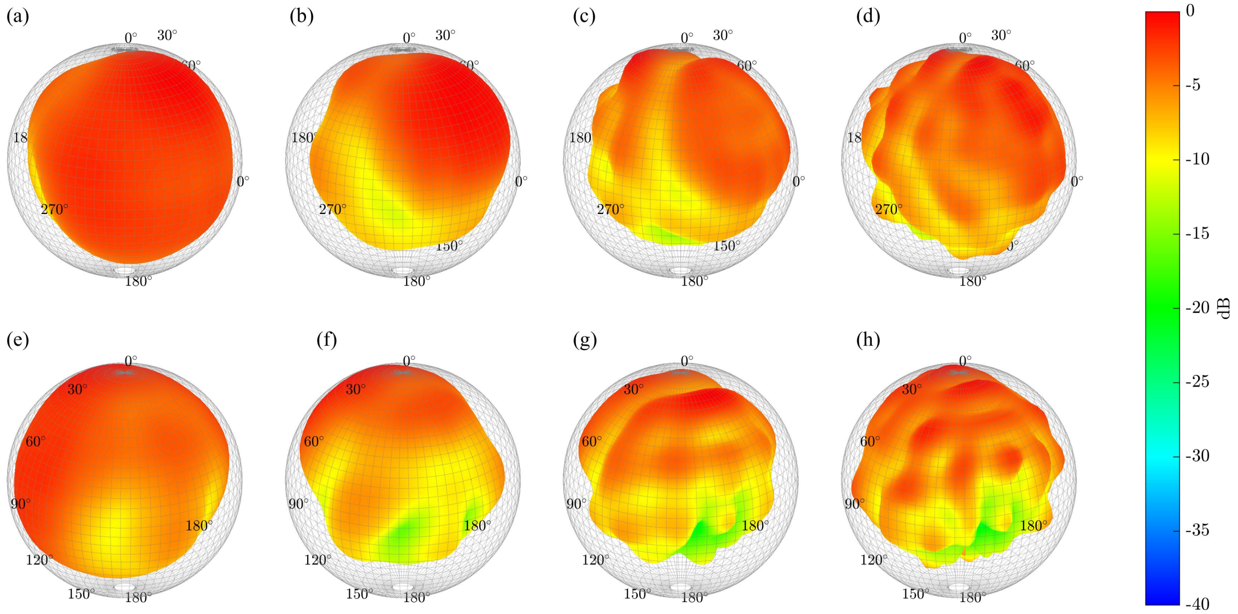

Figure 6: Normalized OTO band directivity patterns for the cup mute smoothed with an $N = 17$ spherical harmonic expansions from an (a)-(d) front view and an (e)-(h) back view. (a),(e) 250 Hz. (b),(f) 400 Hz. (c),(g) 800 Hz. (d),(h) 1.25 kHz.

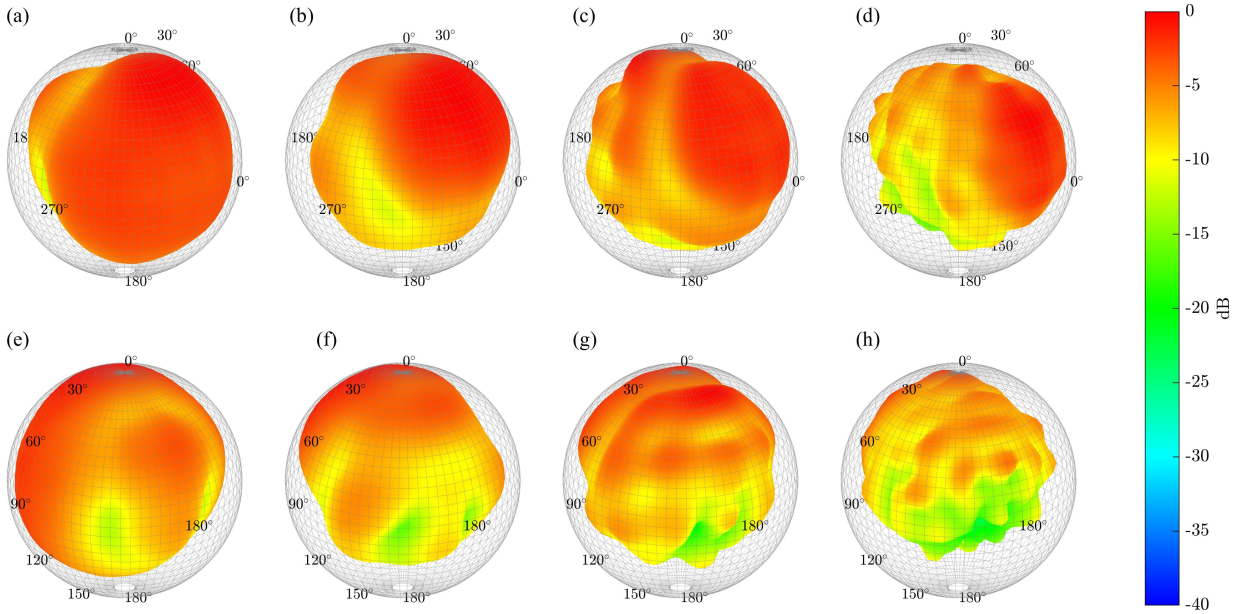

Figure 7: Normalized OTO band directivity patterns for the straight mute smoothed with an $N = 17$ spherical harmonic expansions from a (a)-(d) front view and a (e)-(h) back view. (a),(e) 250 Hz. (b),(f) 400 Hz. (c),(g) 800 Hz. (d),(h) 1.25 kHz.

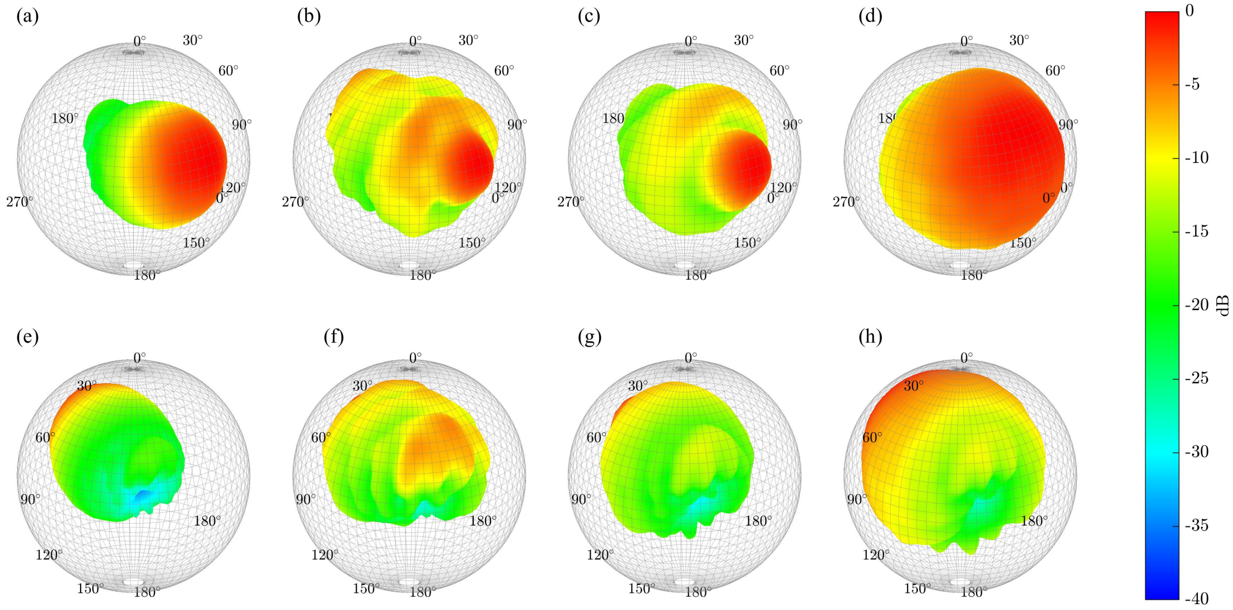

Figure 8: Normalized directivity patterns for 3.15 kHz OTO band smoothed with an $N = 17$ spherical harmonic expansions from an (a)-(d) front view and an (e)-(h) back view. (a),(e) Unmuted trumpet. (b),(f) Cup mute. (c),(g) Straight mute. (d),(h) Harmon mute.

three lobes spaced around a primary lobe in the center appear. In examining reference images, the lobes correspond to the cork placements inside the bell, indicating potential diffraction effects due to the corks.

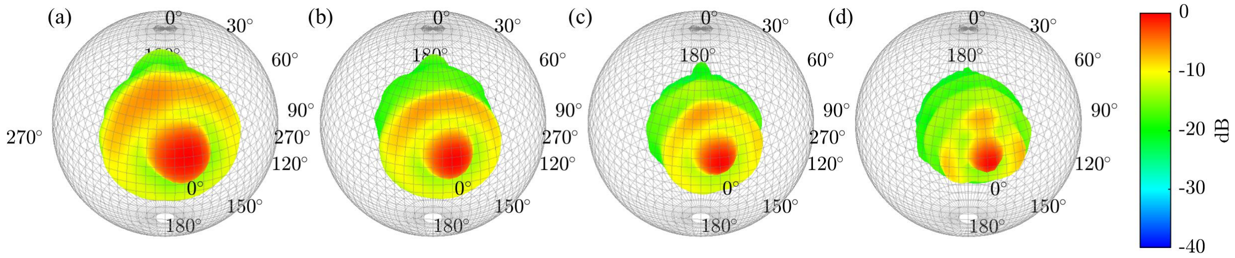

Figure 9: Directivity patterns for the straight mute for the (a) 4 kHz (b) 5 kHz (c) 6.3 kHz and (d) 8 kHz OTO bands.

4. DISCUSSION

The unmuted results of this work agree with those of previous high-resolution, unmuted trumpet directivity measurements made by Bodon.[9] They demonstrate roughly omnidirectional radiation at low frequencies and increasing directionality at higher frequencies. The cup and straight mute directivities produced in the present work appear to minimally affect trumpet directivity below the 1.6 kHz OTO band. At higher frequencies, differences between directivities with and without mutes are attributable to mute geometries, locations, and trumpet bell attachments via corks.

The directivity patterns reflect the attenuation and diffraction around the trumpet, musician, and mutes. Radiation patterns with relatively large beamwidths arise for cup and straight mute above 1.6 kHz. This directional behavior indicates that less of the total sound radiating from the trumpet is directed forward in comparison to the unmuted trumpet. This broadened beam width would likely result in a diminished direct sound perceived by audience members.

5. CONCLUSIONS

Acoustically, the trumpet cup and straight mutes have little differences between unmuted directivities below the 1.6 kHz OTO band. At higher frequencies, these mutes cause the trumpet to radiate more to the sides and back of the instrument and musician. Because this work has only considered directional characteristics, explorations of the impact of trumpet mutes on radiated sound power spectra as well as further analysis on directional characteristics remain for future work. Additional research could also consider other types of mutes and investigate the impacts of mutes on optimal microphone placements for audio recordings and sound reinforcement.

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