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EFFECT OF ARTIFICIAL MOUTH SIZE ON SPEECH TRANSMISSION INDEX

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Abstract

For this study a head and torso simulator was constructed with a variable mouth size. Directivity measurements confirmed that a larger mouth size yields a more directional radiation pattern. The effect of the mouth size on speech transmission index (STI) measurements was investigated for various azimuth angles around the simulator and various room acoustical contexts. In some circumstances source directivity does affect STI values.

1. INTRODUCTION

Speech transmission index (STI) is an objective method for rating speech intelligibility derived from the measurement of modulation transfer functions [1]. It yields a number between 0 and 1, which is primarily affected by room acoustical effects (reverberation, early reflections and echoes) and signal to noise ratio (while room acoustical effects can degrade intelligibility, they can also increase signal to noise ratio, and so in some circumstances enhance intelligibility). To use STI in architectural acoustics, the test signal must be generated by a loudspeaker, the radiation characteristics of which should be similar to those of a human talker. One way to achieve this is with a head and torso simulator. Head and torso simulators are commercially available (the most common one is the Brüel & Kjær HATS) based on a specification from the International Telecommunication Union [2], which is concerned with the testing of telephone handsets and headsets. The extent to which this simulates long term average human speech directivity was examined by Chu and Warnock [3], with results indicating that the simulator is slightly more directional than humans (conversational speech). Other head and torso simulators have been developed for various purposes by Flanagan [4], Olson [5], Kob [6] and Bozzoli *et al.* [7], which probably all have different properties in terms of directivity, frequency-dependent sound power and temporal response. Bozzoli *et al.* [8] provide a precursor to the present study by examining how STI measurements are affected by the directivities of three head and torso simulators – the Bruel & Kjaer HATS, a head-sized rectangular loudspeaker on a solid torso, and a shop mannequin with a small loudspeaker in the mouth position. Their study shows that STI can be substantially affected by the sound source in a car cabin (with an off-axis direct sound path), but there is very little effect in either a small or large classroom (with approximately on-axis direct sound paths).

The present study tests various head and torso simulator configurations by varying the mouth size of a mannequin based on the Brüel & Kjær HATS. This was done by building a new head from a casting of a Brüel & Kjær HATS (4128C), furnishing it with a loudspeaker, and making a collection of mouth inserts with a variety of orifice areas. We measured the directivity of these mouths in an anechoic chamber, along with that of the commercially produced HATS. Finally, we measured the STI produced by the various HATS mouths in two normal rooms as a function of rotation angle of the HATS.

2. CONSTRUCTION OF THE SIMULATOR

For this experiment a cast was made in plaster of a Brüel & Kjær 4128C HATS. Using the cast a new head was fashioned using plastic vehicle repair putty. A large aperture was cut into the finished head so as to allow the insertion of various mouth shapes formed from Perspex. The mouth sizes chosen were:

- "Regular":- 42mm x 16mm rectangular aperture – the same size of the mouth of the 4128C HATS
- "Small":- 42mm x 8mm rectangular aperture – the same mouth height, but half the width;
- "Round":- 12mm circular hole; and
- "Large":- A fourth larger aperture obtained by leaving the mouth insert cavity vacant, yielding a 60mm x 32mm rectangular mouth size.

Figure 1 shows the front section of the completed head with the "regular" sized mouth installed and the "small" and "round" mouths beside it. A 4-inch loudspeaker was installed directly behind the mouth and the new head was mounted on a Brüel & Kjær HATS torso. Figure 2 shows the completed new head along side the Brüel & Kjær HATS.

Figure 1. Various mouth shapes and sizes

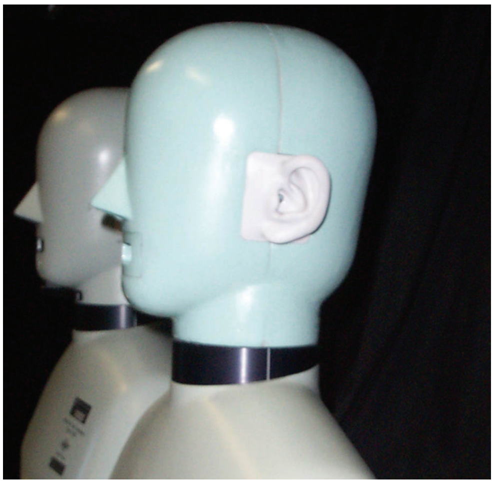

Figure 2. Modified head and torso simulator

3. DIRECTIVITY MEASUREMENTS

Firstly the directivity patterns of the various mouth configurations of the head and torso simulator were measured along with a Brüel & Kjær Type 4128C HATS. These patterns were measured using both a swept sinusoid impulse response technique and a steady state response technique using a computer controlled Brüel & Kjær "Pulse" electro-acoustic audio analysis measurement system. The Pulse software was set up to control a turntable Type 9640, generate a logarithmic sine-sweep tone into a Type 3560 D-A converter and through a Type 2716C amplifier present the tone as a signal to the loudspeaker of the HATS under test. A half inch, free field measuring microphone Type 4189 was positioned in the horizontal plane of the HATS mouth centre and 2 metres directly in front with the HATS facing forward. The microphone returned a signal through the Type 3560 input A-D converter, through a one-third octave band filter to record a decibel level for each centre frequency. After each measurement the turntable was set to rotate 10 degrees after which another measurement would be taken until completing the full 360 degrees. The measurements were conducted in a large anechoic room. Measurements were taken in the horizontal plane, as well as for elevation angles of 90 degrees, 60 degrees, 30 degrees and –30 degrees to the horizontal plane at a distance of 2 metres. The horizontal directivity patterns of every third 1/3-octave band are show in Figure 3.

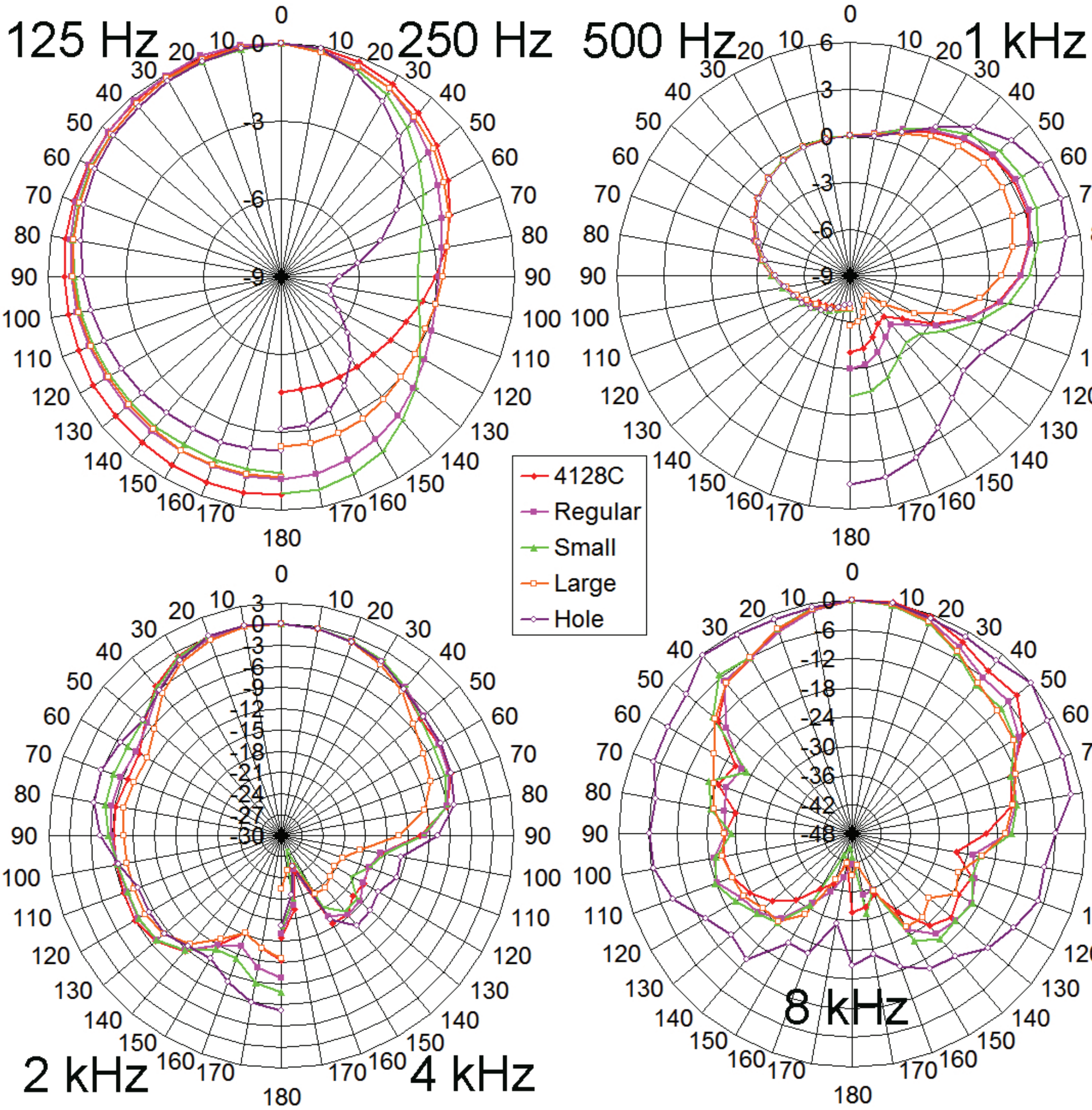

Figure 3. 1/3-octave band horizontal directivities centred on 125 Hz, 250 Hz, 500 Hz, 1 kHz, 2 kHz, 4 kHz and 8 kHz. Values are in decibels relative to 0 degrees.

Chu and Warnock [3] have previously measured the directivity of the Brüel & Kjær HATS. Figure 4 provides a graph of deviations comparing of our measurements from their measurements (in every third 1/3 octave band). Deviations are within ±1 dB up to 1 kHz. The variation, which is more prominent in the higher frequencies, could be partly due to different axial centre zero alignments of the HATS with respect to the placement of the microphone, to minor reflections in one or the other measurement situation, and to differences in the centre of rotation.

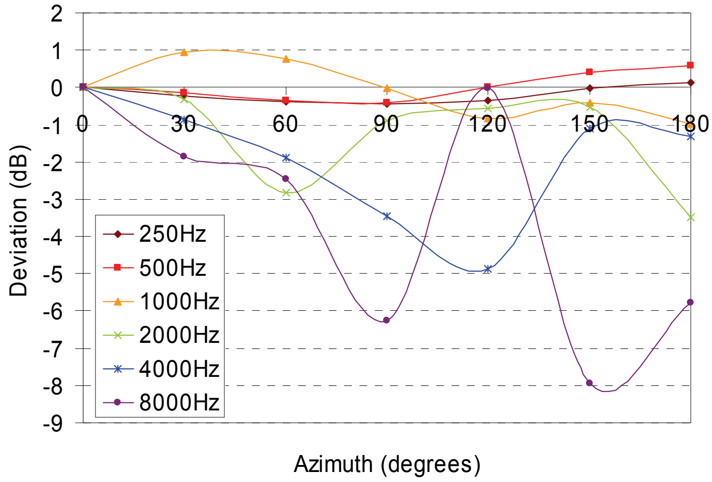

Figure 4. Deviations in HATS directivity to Chu & Warnock measurements

4. STI MEASUREMENTS

In order to check that the mouth fittings did not compromise STI values, STI was measured in the anechoic room for horizontal angles around the dummy head. The resulting STI was 1.00 in every case, meaning that the STI was not degraded by the measurement system itself.

The five mouth size configurations were employed in three different room acoustical conditions to compare STI measurements. Two rooms were used – a small conference room shown in Figure 5 and a lecture theatre. The conference room is approximately 108 cubic metres (6 x 5 x 3.6 m) and is dominated by a 2.4 metre diameter round table which has a laminated top. All the surfaces are hard and reflective and the STI was expected to be quite low for a room of this size. The measurement was recorded from one side of the table to not quite the other maintaining a distance of 2 m between source and receiver. STI measurements were taken at 20 degree rotations of the HATS using a swept sine tone convolved into an impulse response. The measurement excluded background noise (it was only sensitive to room acoustical effects). The STI values ('male' weighting) were then assessed through the full rotation of the HATS (Figure 6).

Figure 5. Modified HATS in the conference room

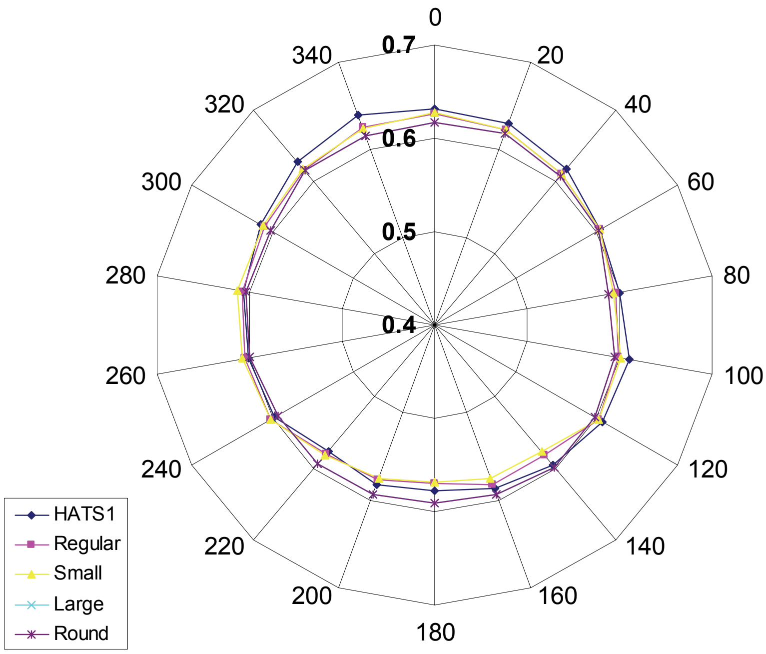

Figure 6. STI in conference room

The next measurements were taken in a moderately large (100 seat) lecture theatre with a volume of approximately 560 cubic metres. The first sets of measurement (Figure 7) were taken at a distance of 2 m in the horizontal plane, directly in front of the speaker which was situated in the front of the room. The second set (Figure 8) was made with the microphone moved into the centre of the seating area, approximately 7 m from the source. In each case the speaker was rotated through 360 degrees.

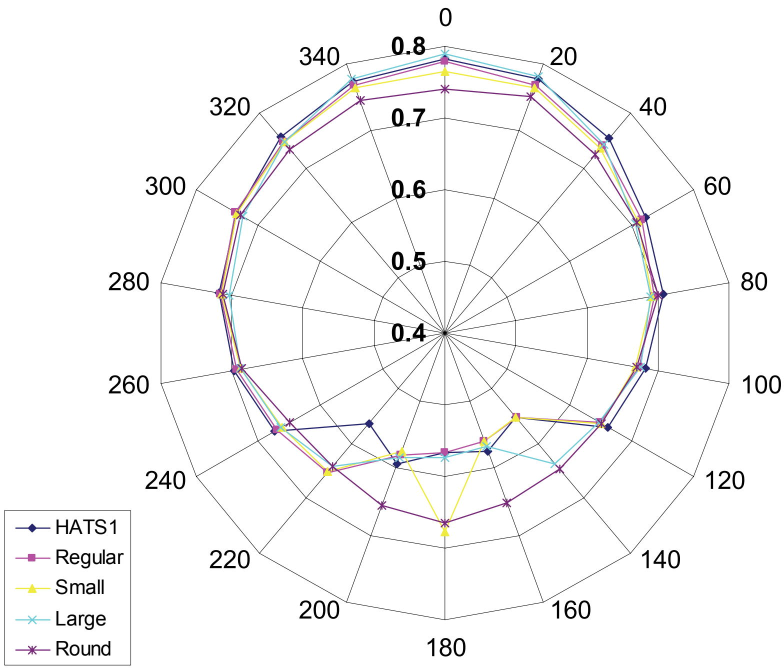

Figure 7. STI at 2 m distance in the lecture theatre

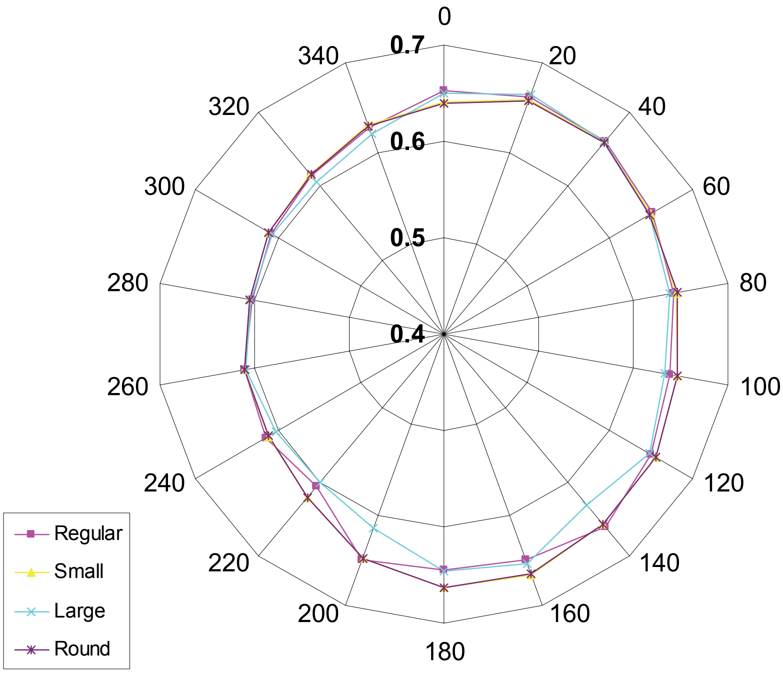

Figure 8. STI in the lecture theatre audience area

The STI measurements show little variation between the mouth configurations with source rotation. The only variation occurs when the simulator is facing away from the microphone for the 2 m source-receiver position in the lecture theatre (Figure 7).

5. DISCUSSION

The directivity measurements show that mouth size can have an effect on source directivity. Differences are particularly prominent at 1 kHz, for which the head diameter is approximately half a wavelength. Discrepancies between our directivity measurements and those of Chu and Warnock highlight the difficulty in accurately measuring source directivity. Discrepancies between the 4128C and our replication of it are partly due to a small rubber insert that is present in the orifice of the 4128C, but not in our model (making the effective mouth area smaller in the 4128C).

The findings on the effect of simulator on STI are consistent with those Bozzoli et al. [8] – i.e. there is very little effect in normal rooms. Our method of rotating the sound source provides an efficient way of exploring this question. In the small reverberant room, the reverberant field had a strong effect on STI, and so the rotation had little effect. An effect of rotation was only seen in the situation where the direct sound was relatively strong (within a reverberant field). Further measurements will be made to confirm this.

One of the limitations of the 4128C is its low maximum acoustic power. A larger mouth area provides the potential for greater sound power, which could be helpful for measurements (for example, of singers or situations where stage voices are used). Combined with a higher power long excursion loudspeaker driver, our modified HATS has the potential to be useful in such situations.

6. CONCLUSIONS

This study has shown that mouth directivity of a head and torso simulator is related to the mouth shape and size, but that this does not have a significant effect on STI measurements in general room acoustical conditions.

7. ACKNOWLEDGMENTS

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