SPEECH INTELLIGIBILITY AND RESPIRATOR USE

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1 INTRODUCTION

The issues discussed here were first raised when investigating the sound attenuation provided by the standard issue riot helmet used by UK police forces[1]. On that occasion the aim was the need to carry out a realistic assessment of the noise exposure of those officers undergoing frequent training sessions, and of those instructing them. Available information for these helmets specified a maximum, but not a minimum, attenuation as a function of frequency. This reflects a concern that good verbal communication is important to the users of these helmets in operational, if not in training, situations. The attenuation was measured using two techniques, the results agreeing very well indeed except at 6 kHz, and tending to confirm that speech intelligibility is an issue for the users of these helmets. Figure 1 shows the measured attenuation values.

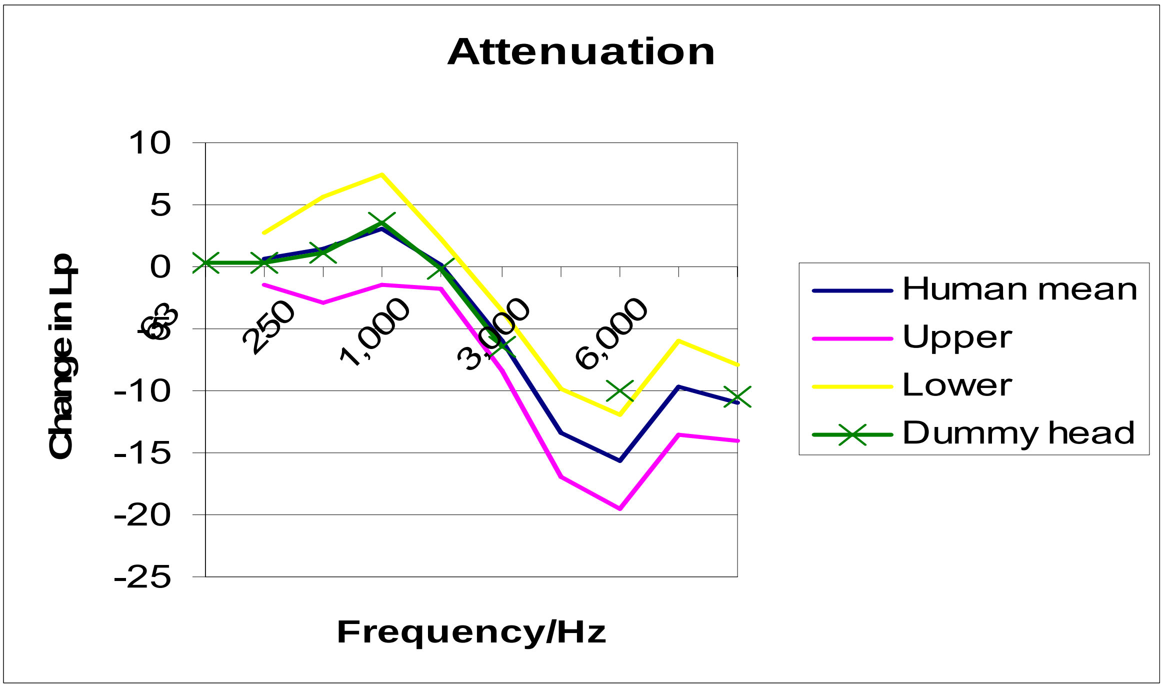

Figure 1; measured attenuation values for a police public order helmet

Any personal protective equipment (PPE) which covers the mouth and/or the ears can be expected to reduce speech intelligibility. This includes equipment for protection of the face and head as well as various types of respirator. More obviously it includes hearing protection equipment, and a certain amount of attenuation has been focused on this issue with the introduction of legislation to implement the Physical Agents (Noise) Directive[2].

Often devices like these are used in rescue work but they are also important in maintenance work and in some production environments. In extreme conditions it may be sufficient for wearers to be able to alert each other to unspecified dangers via a simple phrase, but very often more detailed information needs to be communicated accurately. Table 1 lists the intelligibility ratings recommended for different situations by ISO 9921[3]. These criteria are intended to be used with a number of different intelligibility assessment techniques, including STI.

Table 1; Communication conditions in ISO 9921

Application	Vocal effort	Minimum intelligibility
Alert & warning (sentences)	Loud	Poor
Alert & warning (critical words)	Loud	Fair
Person-person (critical)	Loud	Fair
Person-person (normal prolonged)	Normal	Good
Public address	Normal	Fair
Communication systems	Normal	Fair

PPE manufacturers routinely check the *effectiveness* of their products by means of standardised measurements of – for example – leakage. It would be beneficial to extend the assessments of *suitability* to parameters such as speech intelligibility. It is by no means obvious that a series of physical measurements followed by the calculation of STI or some similar parameter is the best approach to assessing the effect of PPE on speech communication. To demonstrate that this is the case, it would be necessary to show that these measurements could be carried out practically and economically, and that the results generated provided sufficient information to assess the effect of each device on intelligibility, and to evaluate any development work to improve communication. It would also be necessary to compare STI measurements with simpler objective tests (such as, for example, a simple measurement of insertion loss at 2 kHz) and show that the extra effort involved pays off in terms of the results obtained.

2 PUBLISHED RESEARCH

It is probable that a great deal of research has been carried out by the military in the UK and elsewhere into speech communication between those wearing chemical and biological protection suits. Apart from the fact that most of this work is not published, it represents a rather extreme form of PPE and may not be directly applicable to common civil applications.

Much of the published work can also be traced back to military establishments, especially in the United States[4,5,6]. These measurements have been made using volunteers to implement a range of different subjective speech intelligibility assessments. Unless a plentiful supply of volunteers is available, this approach does not lend itself to large scale testing, and indeed results tend to relate just to one model of mask. No direct measurements of speech intelligibility using objective techniques such as STI have been found.

Some research has looked at some of the factors affecting speech intelligibility, including the altered vocal output of a mask wearer[7,8] and the insertion loss from over-the-head devices such as hoods[9] and hearing protection[10].

3 A SPEECH INTELLIGIBILITY MODEL

Communication between two individuals who are wearing respirators without hoods, helmets or any form of hearing protection will be affected by a number of factors;

1. The vocal output of the speaker will be modified because of any physical constraint imposed by the mask on the movement of the jaw, but also because of the change from free-field to enclosed conditions.
2. The material of the mask will attenuate the sound emitted

3. The background noise at the ear may be enhanced by the action of any airlines or pumps forming part of the listener's own breathing apparatus

Figure 2 shows this, and figure 3 extends the argument to the situation where the users are wearing respirators including some kind of hood or helmet which also encloses the ears. Figure 4 shows the insertion loss reported in (8) for a respirator mask.

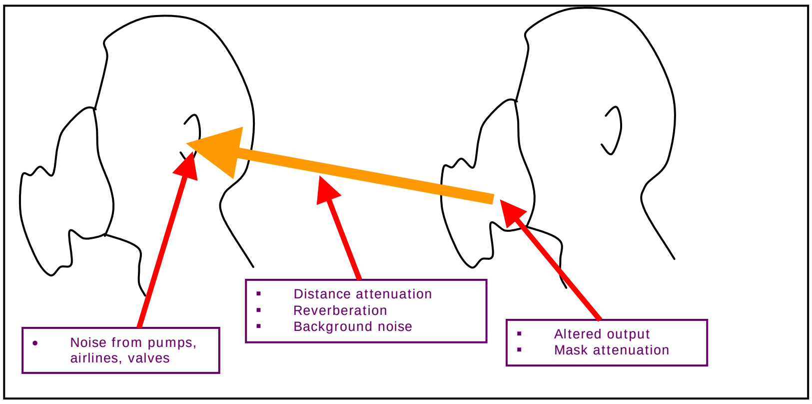

Figure 2; a speech intelligibility model for respirator users

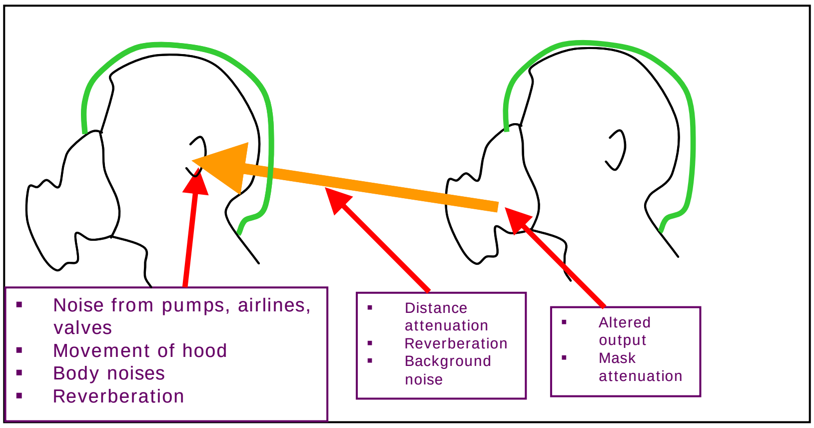

Figure 3; an extended model for over-the-head devices

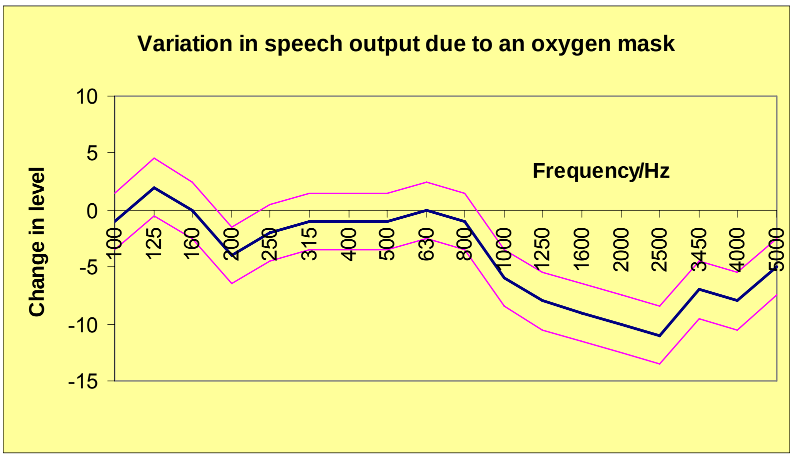

Figure 4; altered vocal effort when wearing a mask (based on Vojnovic, 1996)

4 MEASUREMENT PROCEDURES

Measurements were restricted to a comparison of two respirator masks so as to avoid the greater complications involved when the ears are covered as well as the mouth. Two models from different manufacturers chosen for comparison, and both were fitted with simple dust filters. Both used filters to clean ambient air and the valves were operated by the wearer's breathing rather than the more complicated devices which take their air supply from a tank or air line or use a pump to pull air through the filter. One device has a single filter in front of the wearer's mouth while the other has a filter on each side of the mask.

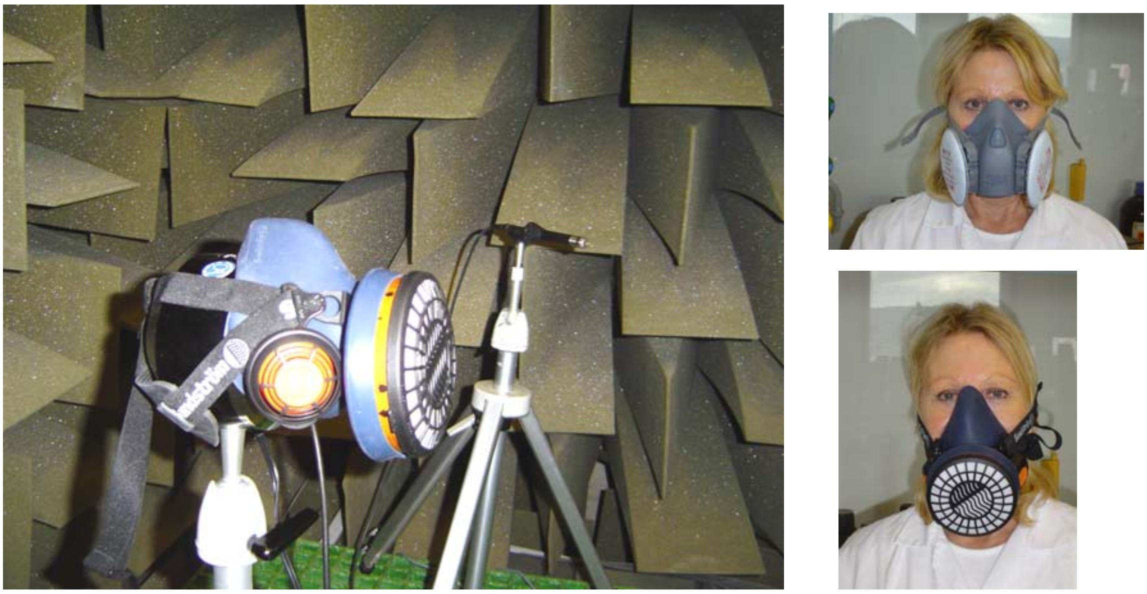

Figure 5; the two masks and the measurement set up

A head and torso simulator incorporating an artificial mouth was not available. Apart from the cost of acquiring these, another issue is the fact that at least one other artificial head with a different specification is in use for testing this type of respirator for leakage[11]. It would not be possible to use a single head for both types of test and this might affect the practicality of routine measurements of the effect of respirators on intelligibility. On the other hand it was found relatively easy to fit the respirators to a simple mouth simulator. This was used for all measurements although it may be desirable to experiment with simpler, cheaper sources.

Measurements were made using a pink noise source of the insertion loss of the masks in three directions – straight ahead, 45° and 90°.

STI measurements were made using DIRAC software. Of the available systems, this has the advantage of providing easy access to the full range of parameters including all the variants of STI and the modulation transfer functions from which they are calculated. The noise source was the MLS output available from DIRAC, which can be filtered to approximate the male and female spectra of ISO 60628 part 16[12]. However a graphic equalizer was used to improve the accuracy of the output spectrum.

The DIRAC system allows background noise to be added to the recorded sound by the software so that a single measurement in quiet conditions can then be used to predict intelligibility under a variety of background noise conditions. Background noise conditions were simulated in this way.

5 RESULTS

5.1 Insertion losses

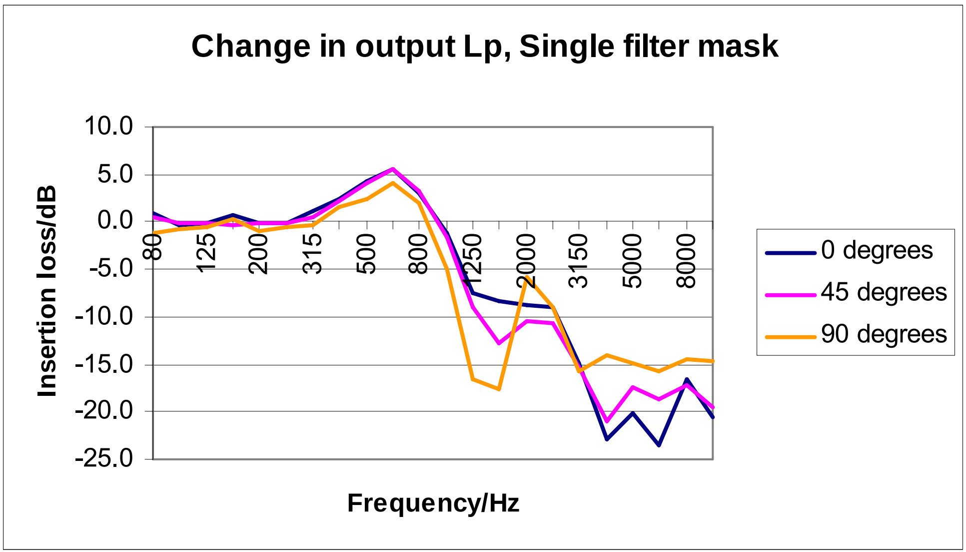

Figure 6; insertion loss of a mask

5.2 Intelligibility parameters

Table 2

STI values; male spectrum, normal voice, 2.0 m			
Mask type	**0°**	**45°**	**90°**
Single filter	0.58	0.45	0.42
Two filters	0.56	0.52	0.41

Table 3

STI values; female spectrum, normal voice, 2.0 m			
Mask type	**0°**	**45°**	**90°**
Single filter	0.34	0.52	0.41
Two filters	0.40	0.41	0.33

As expected, the double filter mask is slightly better for intelligibility off-axis. Values using a female voice spectrum are consistently lower than for male spectrum.

The measurements using a loud voice level were expected to show better STI values than those using the normal voice. It was discovered afterwards that at the loud level the valves on both masks tended to flap which generated noise levels which were noticeable externally (this does not happen with a normal vocal effort) and this is probably the reason for the lower values. In actual use this does not happen, presumably because there is always a positive pressure when the wearer is speaking.

Table 4

STI values; male spectrum, loud voice, 2.0 m			
Mask type	**0°**	**45°**	**90°**
Single filter	0.48	0.38	0.38
Two filters	0.66	0.67	0.54

Accurate measurements for loud vocal effort would need to be extrapolated from measurements using normal effort, or alternatively measured using a test rig which introduced a positive pressure.

5.3 Influence of background noise

Table 5

Male STI at 45° in different levels of background noise		
Background noise (pink spectrum, L_A in dB)	**Single filter**	**Double filter**
None	0.45	0.52
30	0.45	0.53
40	0.43	0.48
50	0.34	0.32
60	0.20	0.19
80	0.11	0.11
90	0.11	0.11

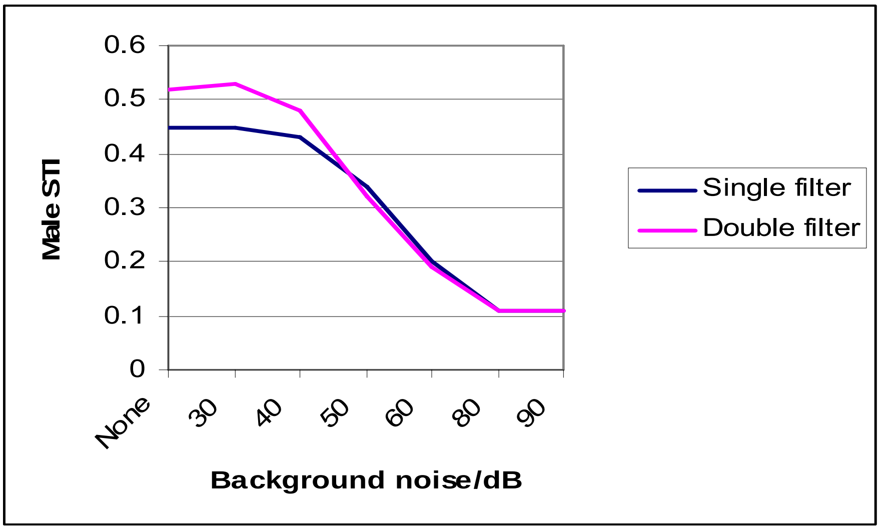

Figure 6; variation in STI with background noise level

Speech intelligibility parameters are uniformly low in the presence of background noise. But this is the normal practical condition

5.4 Comparison between different STI parameters

Table 6

Correlation between STI using the right spectrum and…	STI using the wrong spectrum	RASTI	STIPA
	0.989	0.874	0.996

By statistical standards correlation between all these parameters is good. As expected, RASTI shows some discrepancies compared with the other measures, and a scatterplot illustrates the uncertainties that may arise from the use of RASTI.

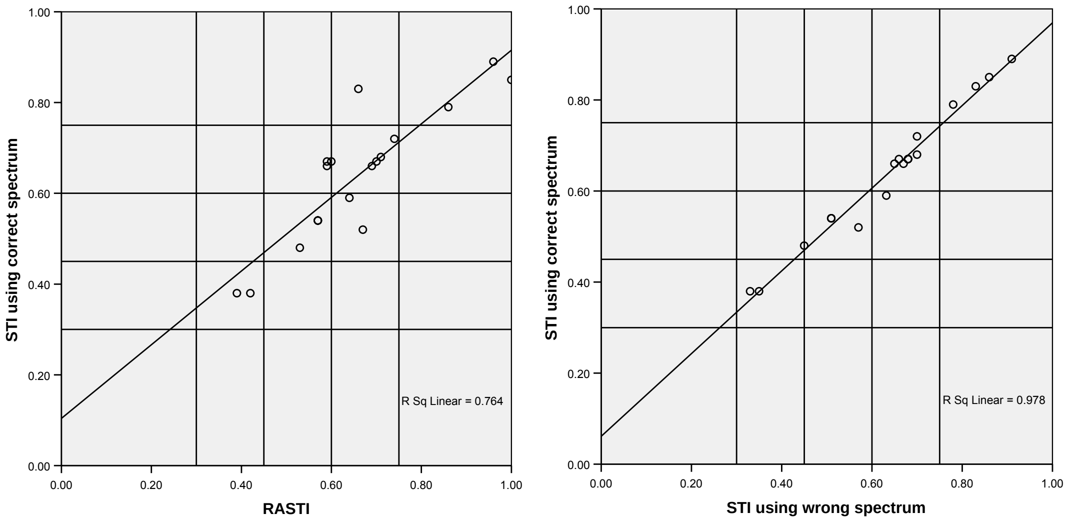

Figure 7; scatterplots illustrating possible errors when different STI parameters are selected

6 CONCLUSIONS

The measurements presented show that repeatable measurements are possible and can be used to identify trends and assess the influence of various environmental influences.

Decisions made about measurement procedure have a significant effect on the values measured and would need to be standardized before the technique could be used for product development.

There is a need for a standard test dummy – possibly based on the standard acoustic head simulator. There may be some problems with this for example it may be required to introduce a positive pressure into the mask during measurements. Acoustic heads are not always easy to fit with over-the head protective equipment.

7 REFERENCES

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12 ISO 60268-16:2003 Sound system equipment – part 16: Objective rating of speech intelligibility by speech transmission index