Vibration Injury Network

Research Network on Detection and Prevention of Injuries due to Occupational Vibration Exposures

Protection effectiveness of anti-vibration gloves: field evaluation and laboratory performance assessment

Appendix H4C to Final Report
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1. Introduction

In the last few years, anti-vibration gloves have been manufactured and marketed as personal protective equipment (PPE) with the aim of minimising the health risks from hand-transmitted vibration. Test procedures to measure the vibration attenuation characteristics of gloves have been defined in International Standard ISO 10819 (1996).

This standard provides a means for checking whether gloves comply with the Personal Protective Equipment EC Directive 89/686. To be marketed as an anti-vibration glove in Europe, with the "CE" mark, a glove must achieve the vibration attenuation criteria set out in the standard.

International Standard ISO 10819 specifies the vibration reduction criteria for an anti-vibration glove as follows: $TR_M < 1.0$ and $TR_H < 0.6$, where TR_M is the overall transmissibility of vibration using a spectrum called 'M' [31.5 Hz -200 Hz] and TR_H is the overall transmissibility when using a spectrum called 'H' [200 Hz - 1 kHz], as defined in the standard. These requirements mean that in the medium frequency range an anti-vibration glove must not amplify the vibration. In the high frequency range, the overall effect of the glove must be to reduce the frequency-weighted vibration by at least 40%.

These criteria, by themselves, do not indicate the extent to which a glove decreases the magnitude of the frequency-weighted vibration transmitted to the hand by vibratory tools. The information provided for an anti-vibration glove is of little use to prospective purchasers and users: they cannot determine the degree of protection, if any, that a glove will provide for exposures to vibration produced by specific tools.

An investigation of five commercially available anti-vibration gloves has been carried out in the framework of the collaborative glove tests between Partner 6 (Ispesl) and Partner 1 (ISVR). The purpose of the study was to:

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a) assess the isolation effectiveness of the gloves when the users were exposed to the vibration from eleven tools;

b) develop laboratory glove test methods useful for estimating the protection that the glove might provide with exposures to vibration produced by specific tools, where vibration spectra are known.

2. International Standard 10819 test procedure

The ISO standard 10819 specifies the test procedures that must be used to measure the vibration transmissibility of gloves (1). This is done by simultaneously measuring the vibration inside and outside the glove using a handle mounted on a horizontal shaker, instrumented to measure grip and feed force. The test involves using a palm adapter to measure vibration at the glove-palm interface. Both the push force (50 N) and the grip force (30 N) to be applied on the handle are specified in the standard, and the duration of vibration exposure is defined as 30 seconds. The vibration signals that are measured at the handle and in the palm are the overall acceleration signals that are passed through the frequency weighting filter specified in International Standard 5349 (2). The transmissibility is calculated as follows:

$$Transmissibility = \frac{\text{Frequency weighted acceleration at hand}}{\text{Frequency weighted acceleration on handle}} \qquad (1)$$

All transmissibility measurements must be corrected by the bare hand transmissibility using:

$$Corrected\ Transmissibility = \frac{\text{Glove hand transmissibility}}{\text{Bare hand transmissibility}} \qquad \mathbf{(2)}$$

The transmissibilities are measured for three different operators with hand sizes 7 to 9 according to EN 420 (1994) with two input spectra: the medium frequency spectrum, M, and the high frequency spectrum, H. Figure 1 and Table 1 show the one-third octave band magnitudes of the vibration spectra for the medium and high frequency test spectra, respectively. Sets of two measurements on each of three test subjects for a total of six measurements are made for both spectra. The six individual transmissibility values for the medium and high frequency spectra are averaged to obtain the average ISO 10819 vibration transmissibility values. The average medium frequency transmissibility is designated $\underline{TR}_M$ and the average high frequency transmissibility is designated $\underline{TR}_H$.

The vibration reduction criteria for an anti-vibration glove according ISO 10819 are:

$$\underline{TR}_M < 1.0$$

$$\underline{TR}_H < 0.6$$

These requirements mean that in the medium frequency range an anti-vibration glove must not amplify the vibration. In the high frequency range, the overall effect of the glove must be to reduce the frequency-weighted vibration by at least 40%.

The standard also requires that the resilient, or vibration-damping, material must be placed in the palm and the full finger and thumb stalls of the glove.

3. Review of main criticisms of ISO 10819 (1996)

***Repeatability and reproducibility of the test*.**

Some of the factors that affect the results of transmissibility measurements have been summarised by Hewitt (3). Table 2 indicates the observed contribution of each of the factors to the uncertainty of the measurement. The variation due to different operators seems to be the most influential factor affecting the results of the test. Similar results have been obtained from other investigations (4). Both studies conclude that proper training of the test subjects is necessary to obtain reliable and repeatable test results.

According to these investigations (3,4) care is needed to ensure that the palm adapter containing the accelerometer is properly placed between the palm of the hand and the glove during the test.

Table 2 Variation in measured transmissibility due different influencing factors (Hewitt (3)).

Variable	Approximate variation in measured transmissibility
Misalignment of the adaptor	±20%
Within subjects variability	±5%
Between subjects variability	±10%
Monitoring feed force only	±4%
Vibration magnitude	±3%
Temperature	±4%

Transmission of shear vibration through gloves

The direction of vibration considered within the standard is perpendicular to the palm of the glove and the hand. International Standard 10819 does not consider transmission of shear axis vibration through the gloves, even though many vibrating tools expose the hands of workers to high levels of shear vibration. An example of such tools includes a percussive chipping hammer when holding the chisel. A study carried out by Paddan and Griffin (5) on 10 gloves showed that only two gloves offered attenuation of shear vibration at frequencies above 400 Hz. The other gloves offered no beneficial attenuation of shear axis vibration at any frequency below 1000 Hz, indeed they generally amplified vibration in the shear axis.

Frequency weighting

The ISO weighting of the acceleration signals used for the vibration transmissibility test, according to ISO 10819 may understate the effectiveness of a glove in attenuating vibration to the hand. The frequency weighting has a large effect on the perceived effectiveness of gloves in attenuating vibration. Consideration of the consequences of changes to the frequency weighting should be included in the evolution of glove standards (6).

4. Experimental investigation

4.1 Methods

4.1.1 Field measurements

Field measurements were carried out on five different chain saws and six different grinders. Measurements took place in Italy at two different companies. Grinders were tested at a ship construction company in Viareggio (Italy). Chain saws were tested at the forestry works centre of Amiata Mountains (Tuscany-Italy).

Vibration measurements were carried out during simulated work procedures designed to avoid interruptions between operations, which usually occur during normal working. Five samples of anti-vibration gloves were tested. Each of the gloves was commercially available and labelled as an "anti-vibration glove" according to the EU Directive on Personal Protective Equipment (EU Directive 89/686).

In the case of grinders, three skilled operators performed a 30-s series of five grinding or cutting operations of steel plates artificially created to represent vibration exposure conditions during normal tool operation.

For chain saws, three skilled operators performed a 30-s series of five cutting operations. Test log shape, guide bar length and measuring condition specifications were set up according to ISO 7505 (8).

Tri-axial acceleration measurements were performed according to the recommendations of International Standard ISO 5349. Three piezoelectric miniature accelerometers (Bruel and Kjaer type 4374) were fixed into a small adaptor held in the palm of the hand inside the glove, according to the ISO 10819 palm adaptor requirements. The same set of measurements was repeated by the same subjects without wearing the glove. Vibration signals were amplified by three charge amplifiers (B&K type 4325) and then recorded using a 4-channel digital recorder (Teac RD-101 T). Frequency analysis was performed using the spectrum analyser Larson-Davis model 2800. The measurement chain was calibrated using the calibration exciter B&K type 4294.

The 'field glove isolation effectiveness' has been calculated as follows:

$$\text{Field glove isolation effectiveness} = \frac{\text{acceleration at the palm when wearing glove}}{\text{acceleration at the palm without glove}}$$

The calculation has been performed for both weighted and unweighted acceleration spectra.

4.1.2 Laboratory tests.

Laboratory tests took place at the Institute of Sound and Vibration Research in the University of Southampton (UK).

Transmissibility curves for each glove were measured in the laboratory in accord with the ISO 10819 test, except that the input vibration was a computer-generated Gaussian random waveform having a nominally flat acceleration spectrum with a frequency-weighted acceleration of 3.1 ms^{-2} r.m.s. at the handle. The experiment was conducted using an electrodynamic vibrator, Derritron VP85, powered by Derritron 1.0 kW amplifier. Acceleration was measured at two locations: on the vibrating handle and between the palm of the hand and the glove using piezoelectric accelerometers B&K type 4374 each with mass of 0.65 gram. Acceleration between the palm of the hand and the glove was measured using a palm adapter of mass 9.21 grams (ISO 10819 states a maximum mass of 15 grams). The acceleration signals from the two locations were passed through charge amplifiers (B&K type 2635) and then acquired into a computer-based data acquisition and analysis system *HVLab*, developed at the Institute of Sound and Vibration Research of Southampton. The frequency range of the input vibration was 5 Hz to 1260 Hz. The waveform was sampled at 7877 samples per second and low-pass filtered at 1260 Hz before being fed to the vibrator. Acceleration signals from the handle and the palm adapter were passed through signal conditioning amplifiers and then low-pass filtered at 1260 Hz via anti-aliasing filters with an elliptic characteristic; the attenuation rate was 70 db/octave in the first octave. The signals were digitised into a computer at a sample rate of 5000 samples per second. The duration of each vibration exposure was 31 seconds. The experiment was approved by the Human Experimentation Safety and Ethics Committee of the Institute of Sound and Vibration Research. Five right-handed male subjects participated in the study.

Transfer function were calculated between acceleration on the handle (i.e. input) and acceleration measured at the palm-glove interface adaptor (i.e. output). The cross-spectral density function method was used. The transfer function $H_{io}(f)$ was determined as the ratio of the cross-spectral density of input and output accelerations, $G_{io}(f)$, to the power spectral density of the input acceleration, $G_{ii}(f)$:

$$H_{io}(f) = G_{io}(f)/G_{ii}(f)$$

Frequency analysis was carried out with resolution of 4.88 Hz and 608 degrees of freedom (Bendat and Piersol, 7).

4.2 Results

Figure 2 shows individual transmissibilities curves $Tr(f)$ for the five subjects.

The estimated glove isolation values have been calculated as follows:

$$\text{Estimated glove isolation effectiveness} = \frac{[\sum (a_i \times Tr_i)^2]^{0.5}}{[\sum (a_i)^2]^{0.5}}$$

where a_i are the frequency components of the acceleration spectrum measured at the frequency f_i , and T_{ri} are the mean values of the glove transmissibility measured at the same frequency. The calculation has been performed on frequency-weighted and unweighted (band-limited) one-third of octave band spectra over the frequency range 6.3 Hz to 1250 Hz.

Table 2 shows the comparison between predicted values of glove isolation effectiveness and the glove isolation values obtained in field conditions

5. Conclusion

Table 3 shows a summary of the glove isolation effectiveness results reported in the previous paragraph. The first column reports also the subjective opinion on suitability given by the workers who carried out the field tests. Gloves were judged 'poor' by workers with regard two main considerations:

– they impaired manual dexterity required for the working procedures investigated: this was the case of gloves #4 and #5 both for chain saws and grinders.

- they caused the hands to become to hot and sweaty; this was the case of glove #4 for chain saws and grinders when used during spring or summer seasons.

Table 3. Gloves isolation effectiveness: comparison of field measurements and predicted values (Mean value (±SD))

User judgement of suitability	Glove no.	Isolation effectiveness Predicted values		Isolation effectiveness Field values	
		unweighted	weighted	unweighted	weighted
Chain saws					
good	1	0.95 (0.05)	0.94 (0.06)	0.74 (0.35)	0,77 (0.34)
medium	2	0.91 (0.12)	0.96 (0.08)	0.86 (0.13)	0.89 (0.16)
good	3	Not available	Not available	Not available	Not available
poor	4	0.89 (0.08)	0.91 (0.08)	0.77 (0.29)	0.79 (0.27)
poor	5	0.94 (0.05)	0.94 (0.05)	0.96 (0.23)	0.97 (0.20)
Grinders					
good	1	0.92 (0.06)	0.94 (0.04)	0.38 (0.17)	0.70 (0.47)
medium	2	0.64 (0.23)	0.85 (0.13)	0.32 (0.18)	0.62 (0.48)
good	3	0.78 (0.1)	0.84 (0.07)	0.36 (0.16)	0.54 (0.33)
poor	4	0.83 (0.1)	0.87 (0.08)	0.52 (0.24)	0.68 (0.35)
poor	5	0.94 (0.04)	0.92 (0.05)	0.54 (0.31)	0.70 (0.29)

On the basis of the study carried out it is possible to draw several conclusions:

- With the grinders, the protection values estimated by the laboratory transmissibility curves seem to underestimate the effective protection offered by the gloves in the field. Better agreement between field results and the predicted isolation values were obtained for chain saws.
- From the results, it could be said that laboratory tests on glove performance did not yiled the correct rank order of gloves isolation properties in working conditions. Explaining this finding requires further study. The result may suggests that predictions are valid only in work situations where the feed force and/or the shape of the spectrum is similar to that used in the laboratory tests.
- The frequency weighting had a large effect on glove isolation effectiveness for grinders.
- An anti-vibration glove should also meet ergonomic design requirements. In particular it should be comfortable to wear and it should allow the worker to maintain control of his tool or workpiece. From this point of view some gloves which presented good isolation properties were not considered suitable by workers (see results obtained for gloves 4 and 5).
- A further aspect which should be investigated is the performance profile of anti-vibration

gloves with age. As with other types of PPE, there is a possibility that as the equipment gets older and becomes worn it will no longer provide the same level of protection

– The current glove test standard should be improved to provide data useful for estimating the protection values for different classes of tool. Results obtained from the present study may be helpful in the development of new standards.

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Table 2a: Comparison of glove vibration transmissibility test results: Unweighted values

TR_cal = Estimated value of transmissibility using transmissibility curves and measured spectra of each tool; TR_ms: Measured transmissibility from field tests. s.d.: standard deviation.

Band limited values																						
	Glove #1				Glove #2				Glove #3				Glove #4				Glove #5				A rms (ungloved)	
n.	TR_calc	s.d	TR_ms	s.d	TR_calc	s.d	TR_ms	s.d	TR_calc	s.d	TR_ms	s.d	TR_calc	s.d	TR_ms	s.d	TR_calc	s.d	TR_ms	s.d	Alin m/s^2	s.d m/s^2
	Chain saws																					
1	0,94	0,05	0,98	0,62	0,92	0,18	1,26	0,11					0,90	0,09	0,94	0,54	0,93	0,05	1,07	0,55	21,08	13,55
2	0,94	0,05	0,89	0,24	0,92	0,07	0,75	0,10					0,90	0,08	0,83	0,34	0,94	0,05	0,85	0,19	35,08	5,36
3	0,95	0,05	0,53	0,45	0,95	0,11	0,82	0,16					0,91	0,08	0,74	0,21	0,94	0,06	1,02	0,15	34,17	4,58
4	0,95	0,05	0,56	0,24	0,74	0,16	0,77	0,16					0,83	0,09	0,63	0,21	0,95	0,05	0,85	0,16	23,13	0,57
5	0,95	0,05	0,76	0,21	1,01	0,07	0,73	0,11					0,90	0,08	0,70	0,15	0,94	0,05	1,01	0,09	40,53	7,74
avg	**0,95**	**0,05**	**0,74**	**0,35**	**0,91**	**0,12**	**0,86**	**0,13**					**0,89**	**0,08**	**0,77**	**0,29**	**0,94**	**0,05**	**0,96**	**0,23**	**30,80**	**6,36**
	Grinders																					
1	0,95	0,05	0,27	0,07	0,91	0,20	0,19	0,08	0,84	0,06	0,18	0,02	0,91	0,08	0,28	0,11	0,94	0,06	0,30	0,10	38,96	3,50
2	0,89	0,09	0,44	0,10	0,71	0,30	0,36	0,11	0,78	0,14	0,43	0,09	0,83	0,12	0,54	0,21	0,92	0,06	0,56	0,23	34,11	8,57
3	0,93	0,05	0,58	0,41	0,83	0,13	0,59	0,58	0,82	0,06	0,37	0,27	0,88	0,08	0,74	0,73	0,93	0,05	0,90	0,88	39,23	29,82
4	0,89	0,08	0,55	0,17	0,56	0,34	0,32	0,13	0,71	0,12	0,47	0,05	0,78	0,10	0,78	0,01	0,93	0,01	0,67	0,22	21,64	4,14
5	0,98	0,01	0,15	0,09	0,49	0,06	0,15	0,06	0,83	0,04	0,32	0,29	0,85	0,03	0,30	0,15	0,98	0,03	0,37	0,14	24,10	12,52
6	0,92	0,06	0,20	0,11	0,63	0,34	0,19	0,05	0,75	0,12	0,22	0,09	0,82	0,13	0,23	0,12	0,94	0,05	0,19	0,07	22,16	14,59
avg	**0,92**	**0,06**	**0,38**	**0,17**	**0,64**	**0,23**	**0,32**	**0,18**	**0,78**	**0,10**	**0,36**	**0,16**	**0,83**	**0,09**	**0,52**	**0,24**	**0,94**	**0,04**	**0,54**	**0,31**	**28,25**	**13,93**

Table 2b: Comparison of glove vibration transmissibility test results: Weighted values

TR_cal = Estimated value of transmissibility using transmissibility curves and measured spectra of each tool; TR_ms: Measured transmissibility from field tests. s.d.: standard deviation.

Weighted values																						
	Glove #1				Glove #2				Glove #3				Glove #4				Glove #5				A rms (ungloved)	
n.	TR_calc	s.d	TR_ms	s.d	TR_calc	s.d	TR_ms	s.d	TR_calc	s.d	TR_ms	s.d	TR_calc	s.d	TR_ms	s.d	TR_calc	s.d	TR_mis	s.d	Alin m/s^2	s.d m/s^2
	Chain saws																					
1	0,93	0,05	0,85	0,42	0,97	0,10	1,15	0,22					0,91	0,08	0,81	0,42	0,92	0,05	0,96	0,44	2,96	1,68
2	0,94	0,05	0,91	0,35	0,96	0,07	0,72	0,12					0,91	0,08	0,87	0,46	0,93	0,05	0,87	0,18	3,59	0,31
3	0,94	0,05	0,66	0,48	0,93	0,08	0,91	0,28					0,90	0,08	0,82	0,08	0,92	0,05	1,10	0,12	3,88	0,87
4	0,93	0,05	0,64	0,24	0,93	0,07	0,84	0,07					0,89	0,08	0,70	0,23	0,91	0,06	0,91	0,17	2,68	0,09
5	0,95	0,08	0,80	0,20	0,99	0,08	0,87	0,09					0,91	0,08	0,77	0,16	0,93	0,08	1,01	0,07	4,71	0,75
avg	**0,94**	**0,06**	**0,77**	**0,34**	**0,96**	**0,08**	**0,90**	**0,16**					**0,91**	**0,08**	**0,79**	**0,27**	**0,92**	**0,06**	**0,97**	**0,20**	**3,56**	**0,74**
	Grinders																					
1	0,93	0,05	0,33	0,15	0,96	0,11	0,27	0,18	0,84	0,07	0,21	0,04	0,91	0,08	0,31	0,18	0,92	0,06	0,32	0,20	5,12	0,32
2	0,94	0,05	0,71	0,48	0,88	0,12	0,75	0,58	0,86	0,07	0,67	0,45	0,89	0,08	0,61	0,35	0,92	0,05	0,67	0,40	2,93	1,44
3	0,93	0,05	0,81	0,55	0,96	0,13	0,60	0,52	0,84	0,06	0,50	0,34	0,91	0,08	0,30	0,05	0,92	0,05	0,40	0,05	4,21	2,97
4	0,94	0,01	1,00	0,56	0,85	0,22	0,94	0,84	0,82	0,07	0,50	0,10	0,88	0,06	1,10	0,50	0,94	0,03	1,30	0,54	1,20	0,52
5	0,95	0,06	0,50	0,32	0,70	0,08	0,42	0,11	0,86	0,07	0,54	0,28	0,87	0,08	0,77	0,25	0,93	0,06	0,70	0,03	1,34	0,39
6	0,92	0,05	0,48	0,46	0,88	0,09	0,41	0,36	0,84	0,06	0,50	0,50	0,88	0,09	0,61	0,60	0,91	0,05	0,44	0,42	2,58	2,86
avg	**0,94**	**0,04**	**0,70**	**0,47**	**0,85**	**0,13**	**0,62**	**0,48**	**0,84**	**0,07**	**0,54**	**0,33**	**0,89**	**0,08**	**0,68**	**0,35**	**0,92**	**0,05**	**0,70**	**0,29**	**2,45**	**1,63**

Table 1a - ISO Standard 10819 medium frequency acceleration and tolerance values.

Frequency Hz	a_{rms} - m/s^2	a_{rms} - dB	Tolerance - dB
16	0,18	85,1	± 2
20	0,40	92,0	± 2
25	0,90	99,1	± 2
31,5	2,36	107,5	± 1
40	3,18	110,0	± 1
50	3,88	111,8	± 1
63	4,54	113,1	± 1
80	5,16	114,3	± 1
100	5,71	115,1	± 1
125	6,14	115,8	± 1
160	6,28	116,0	± 1
200	5,89	115,4	± 1
250	5,04	114,0	± 2
315	3,94	111,9	± 2
400	2,89	109,2	± 2

Table 1.b ISO Standard 10819 high frequency acceleration and tolerance values

Frequency Hz	a_{rms} - m/s^2	a_{rms} - dB	Tolerance - dB
100	3,77	111,5	± 2
125	6,29	116,0	± 2
160	10,47	120,4	± 2
200	15,24	123,7	± 1
250	20,20	126,1	± 1
315	24,86	127,9	± 1
400	29,07	129,3	± 1
500	32,48	130,2	± 1
630	35,15	130,9	± 1
800	35,95	131,1	± 1
1000	33,97	130,6	± 1
1250	28,91	129,2	2
1600	22,40	127,0	2

Fig. 1 - Medium frequency (M) and high frequency (H) spectra according to ISO Standard 10819

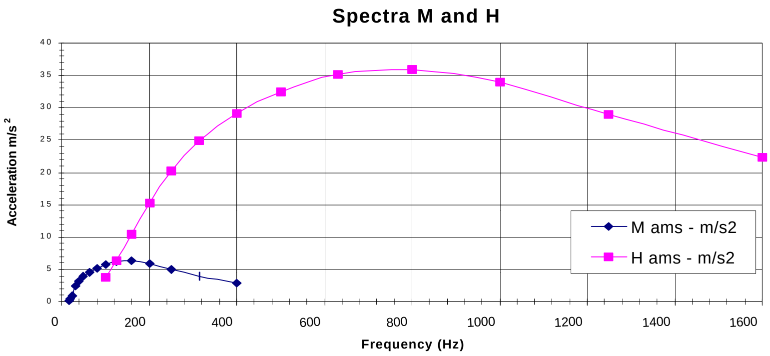
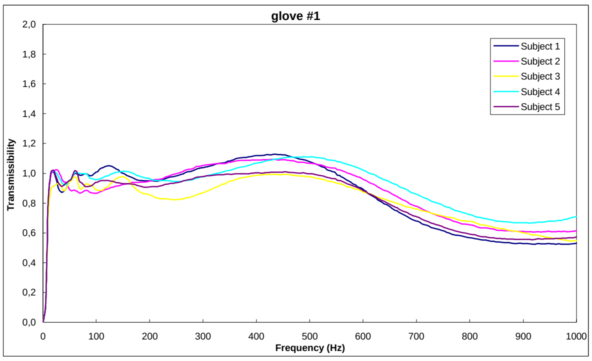
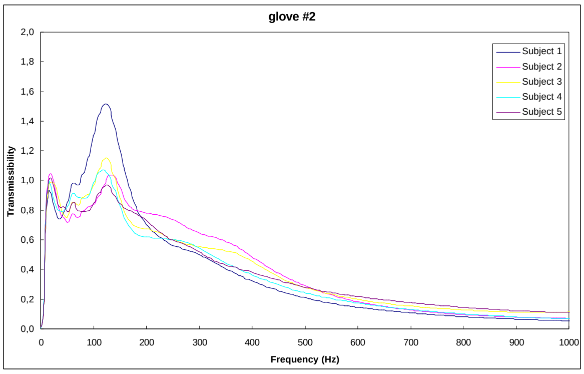


Fig. 2: individual transmissibilities curves *T*r(f) for the five gloves (five subjects in the laboratory)



Glove 1



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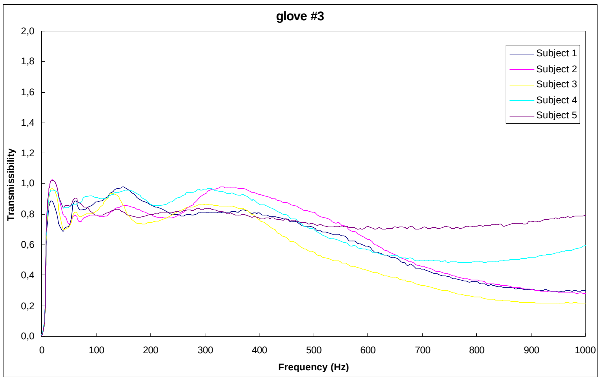

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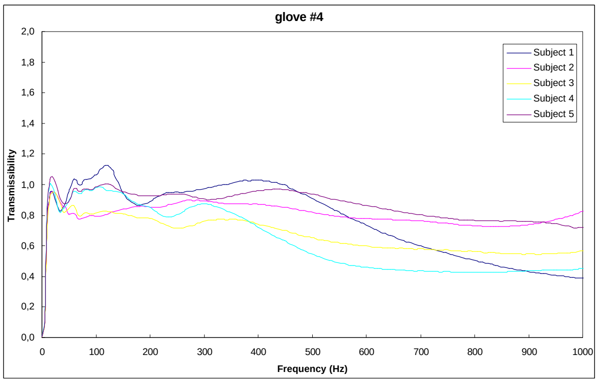

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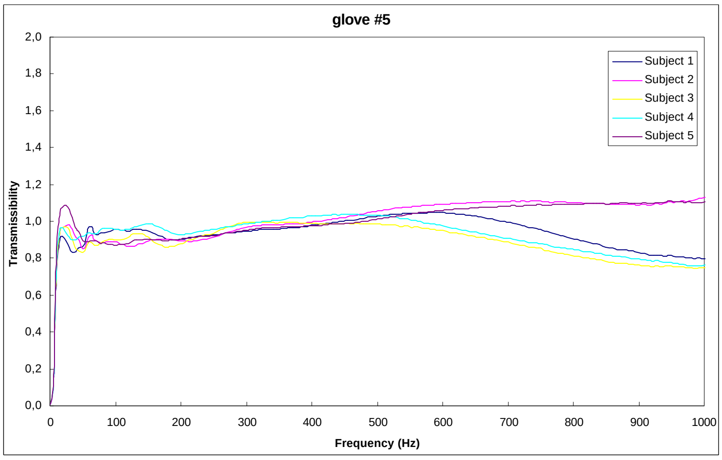

Glove 5