Acoustic and Aesthetics: The Effect of Paint on Fabric Backed by a Sound Absorber

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1. INTRODUCTION

In recent years, new acoustical aesthetic materials have been developed due to the need to blend acoustics materials into a space without sacrificing the aesthetics due to their capability of passing unnoticed [1]. Although there is a variety of aesthetic absorption solutions, there is the misconception that the options are limited [1 -2]. Hence, porous materials are commonly covered in woven fabric, considered as an acoustically transparent facing [3-4], which sometimes does not contribute to overall aesthetic of the room.

Although it is known that woven fabrics are good to cover acoustic materials, paint on the fabric facing could be an aesthetic option to make absorptive material blend with the room. The outcome of this combination could still serve its original purpose, of absorbing sound as well as being an art piece. Considering that paintings are a typical way to decorate a space, using a painting as an absorber becomes of interest because of its dual-purpose application.

Previous studies consider the direct effect of paint and paint coats on sound absorbing materials and the use of paintings to absorb sound, reduce reverberation time, and increase speech intelligibility. Chrisler [5] and Burby, et al. [6] have studied paint on acoustic materials and concluded that one coat of paint could be used on an absorber, and that spray paint could be used and would be more likely to preserve the acoustic properties of the material. Martellotta & Castiglione [7] and Cudina, et al. [8] have studied the use of paintings as sound absorbing materials and concluded that the absorption of paintings backed by an absorber would depend on if the textile is made permeable or impermeable by the paint, the thickness of the paint, painting dimensions, and among other factors that could be used to shift the absorption coefficient in the frequency range. Additionally, several authors [1, 3], 6, 9] state that most paints will close the material's pores and will reduce sound absorption except for non-bridging paints (acoustic paints) which can be applied without considerably decreasing the absorption.

As previously mentioned, woven fabrics are used as a common facing for absorbers, and although woven fabrics are not commonly used on their own as an absorber, studies have been carried out to determine the acoustical properties of woven fabrics [10]. This research concluded that there is a

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possible effect of pore shape and size in relation to sound absorption performance of the fabric. The pores' shape and size be influenced by thread count or the yarn. In addition, patterns can be designed into a fabric using fabric dye which chemically bonds to the fibres of the fabric [11].

Despite few previous studies related to the absorption of paint on acoustic materials and the use of ready-made paintings as absorbers, the effects of different type of paints on fabrics and absorptive materials still need extensive research. The main aim of this study is to investigate the effects on the absorption of painted fabric backed by an absorber to determine the type of paint, area percentage and area distribution that make the fabric the most acoustically transparent so that the sound absorption of the polyurethane backing is not affected. Also, to establish the effect of the type of fabric on the overall absorption. The Noise Reduction Coefficient (NRC) was used as noise criteria to compare the overall absorption of the samples.

2. METHODOLOGY

2.1. Materials

One hundred and four of the one hundred and nine samples were hand-painted. The samples were made from cotton and canvas fabric that are painted with acrylic, watercolour, fabric paint, oil, spray paint, gesso (primer) and fabric dye. The final sample to be measured was polyurethane foam with the painted fabric in front held by an O-ring.

2.1. Preparation of fabrics

The fabrics were painted to the percentages shown in Figure 1. Maintaining the painted area consistent was an essential factor to consider in this investigation. The paints were applied by using the stencil method which proved to be quick and precise while maintaining the same painted area on the fabric by avoiding some excess paint in the borders. This method was chosen because it standardized the paint application. Moreover, this method could also be implemented in a further investigation to characterize the effect of other types of paints on fabric backed by an absorber.

Table 1: Data combinations – type of fabric, type of paint, area, and area distribution

			% of Painted Area							
Fabric Type	**Paint Type**	**Distribution**	**0%**	**9%**	**16%**	**32%**	**49%**	**64%**	**81%**	**100%**
Cotton and Canvas	Acrylic	Homogeneous	x	x	x	x	x	x	x	x
		Scattered		x	x	x	x	x		
	Oil	Homogeneous		x	x	x	x	x	x	x
		Scattered		x	x	x	x	x		
	Watercolour	Homogeneous		x	x	x	x	x	x	x
		Scattered		x	x	x	x	x		
	Fabric	Homogeneous		x	x	x	x	x	x	x
		Scattered		x	x	x	x	x		
	Spray	-		-	-	-	-	-	-	x
	Fabric Dye	-		-	-	-	-	-	-	x
	Guesso Primer	-		-	-	-	-	-	-	x

One coat of paint was chosen for this study since, according to Chrisler [5], the material can be coated with one thin layer of paint without closing the pores and considerably affecting absorption. One brush stroke per non-covered area was applied where possible. One sample per area for each type of paint was painted, and spare fabrics were considered in case the area was not painted correctly and had to be repainted.

2.2. Measurements

The measurements of the normal incidence sound absorption were carried out according to the BS EN ISO 10534-2 in the BSWA impedance tube in the software VA-Lab IMP with the two-microphone transfer function method. To comply with this standard, two identical microphones were used for the measurements, the samples were cut to fit securely in the tube, and the sample holder was chosen accordingly. Two microphone configurations were used to measure low and mid frequencies from 80 Hz to 1600 Hz. The impedance tube method was chosen over other methods since it has more controlled conditions and required a small sample size which allowed for a broader comparison between the variables. The sample thickness was set to 0.076 mm and the parameters were set as shown in Table 2. The weather conditions were stable throughout the days on which the measurements were undertaken.

All measurements were carried out with no airgap between the sample and the backplate. The polyurethane porous absorber was measured with and without the O-ring to determine if it affected the measurements. Then, the absorber with the unpainted fabric was measured to have this absorption value as a reference to compare with the different paints and painted areas.

Table 2: Parameters and set value for VA LAB software

Parameter	Set value
Atmospheric pressure (Pa)	101325
Temperature (°C)	19
Relative humidity (%)	50
Velocity of sound (ms^{-1})	342.651
Density of air (kgm^{-3})	1.2081
Characteristic impedance of the air (Pa s m^{-1})	413.273

2.2. Data processing

As the measurements were carried out with two microphone configurations the crossover point was chosen from 400 Hz to 500 Hz to have a full range of data. The NRC was calculated from 200 Hz to 1600 Hz to have a single number rating for the absorption per sample to carry out statistical analysis. Due to limitations in the frequency range measured by the impedance tube, the 2000 Hz octave band was represented by 1600 Hz. The single value of the NRC allowed for easier comparison between the data sets and further statistical processing and analysis.

The statistical data analysis was done over one hundred and four of the results in the software R studio (2021). The NRC was evaluated versus the type of paint, fabric, area, and area distribution, as the NRC depends on the mentioned variables. Firstly, an exploratory data analysis using box and whiskers (boxplot) was used to determine how the NRC behaved in terms of the mentioned variables. Secondly, The Mann-Whitney U test and The Kruskal-Wallis one-way ANOVA tests were used to determine significant differences between the variables in relation to the NRC. Finally, the post-hoc of multiple comparisons test was carried out to identify the variables with higher NRC, allowing for more precise conclusions. All the statistical tests were evaluated with a 5 per cent level of significance, meaning that there was a 5 per cent probability of concluding that there was a significant difference in the data when there was no actual difference.

3. RESULTS AND DISCUSSIONS

This project aims to investigate the effects of paint on fabric backed by an absorber to determine the best category of the variables: type of paint, type of fabric, area percentage and area distribution that will cause the fabric to be the most acoustically transparent. The results were compared with the absorption coefficient of unpainted fabrics cotton and canvas placed in front of an absorber as shown in Figure 1.

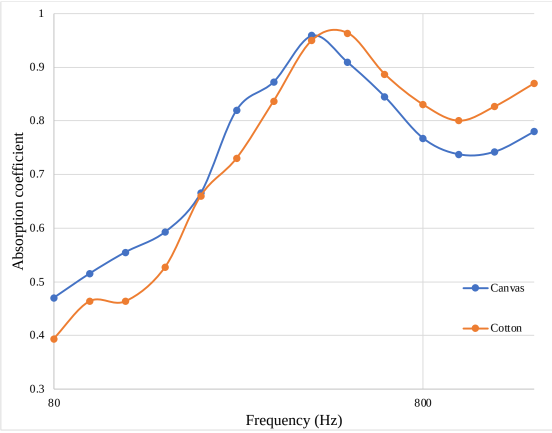

Figure 1: Absorption coefficient versus frequency of cotton and canvas backed by polyurethane foam

Statistical non-parametric tests results can be seen in Tables 3, 4, and 5 where significant differences are those that present a p-value < 0.05. Table 3 presents significant differences in the type of fabric, type of paint and area percentage, meaning that they have a significant effect on the NRC. The area distribution does not present a significant difference, meaning that the area distribution does not affect the NRC. As the type of paint and area percentage presented significant differences, a post-hoc test of multiple comparisons was carried out to find the individual factors in which the NRC was highest to establish more precise conclusions, as seen in Tables 4 and 5.

Table 3: Nonparametric tests, NRC vs variables

Comparison	**p-value**	**Test**
NRC vs Type of Fabric	0.000082	Mann-Whitney U
NRC vs Type of Paint	0.01675	Kruskal-Wallis
NRC vs Area Percentage	0.0000019	Kruskal-Wallis
NRC vs Area Distribution	0.1826	Mann-Whitney U

Table 3 demonstrates a significant difference in the NRC between both types of fabrics. Based on the box and whiskers graph seen in Figure 2, it can be affirmed that cotton gives a higher NRC, as almost 50 per cent of the obtained results for cotton are higher than canvas. It can be seen in Figure 2 that canvas has a higher variability within the obtained data than cotton. Additionally, it can be argued that cotton and canvas fabrics have different absorption performances due to the pore shape and size [10]. The pore shape and size can also be influenced by thread count, which are considerably different between the two fabric types.

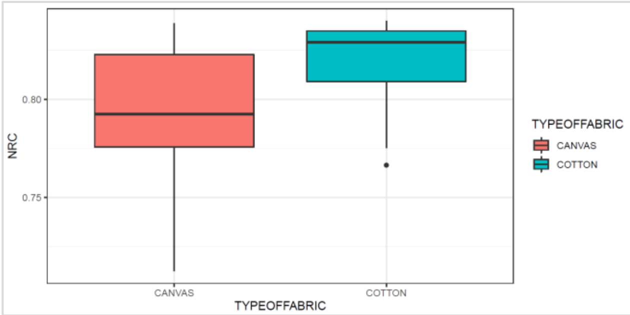

Figure 2: Box and whiskers, noise reduction coefficient vs type of fabric

Figure 3 and Figure 4 show that the higher NRC in relation to the unpainted fabric (NONE) as a reference is given by fabric paint, spray paint, and fabric dye. The paints which result in the lowest NRC are oil paint and watercolour, while gesso has a considerably lower performance. It is demonstrated by the post-hoc test results seen in Table 4 that fabric paint has the best overall effect on the absorption. Significant differences can be seen in the mentioned table for fabric paint, acrylic, and gesso, being fabric paint is the paint that has the higher NRC. When comparing fabric paint to gesso, oil and watercolour, fabric paint also has a higher NRC. In addition, the dyed fabric does not present a significant difference from most of the paints.

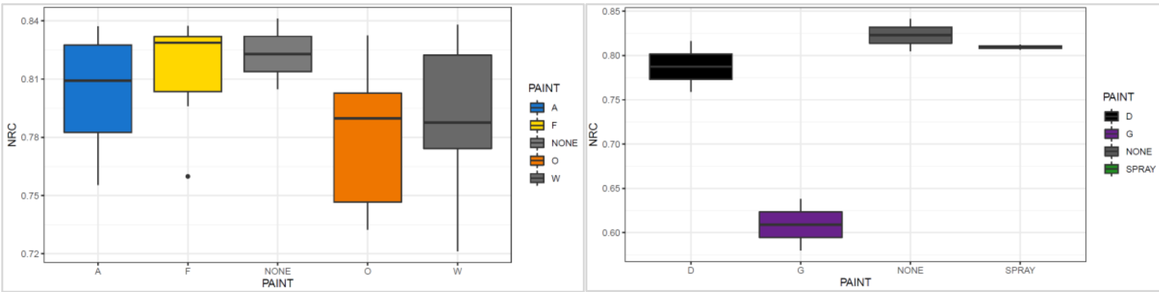

Figure 3(a) and (b): Box and whiskers - noise reduction coefficient vs paint

Table 4: P-values of post-hot tests in NRC vs type of paint

Type of Paint	A	D	F	G	NONE	O	SPRAY
Dyed (D)	0.8099	-	-	-	-	-	-
Fabric Paint (F)	**0.0067**	0.1538	-	-	-	-	-
Guesso (G)	**0.0304**	0.3333	**0.0062**	-	-	-	-
NONE	0.229	0.6667	0.6154	0.3333	-	-	-
Oil (O)	0.9671	0.8123	**0.0048**	**0.0062**	0.1846	-	-
SPRAY	0.7362	1	0.3938	0.3333	1	0.5538	-
Watercolour (W)	0.7966	0.8862	**0.0373**	**0.0062**	0.2215	0.9268	0.6769

As it can be seen from Figure 5 even at a high-painted area percentage with fabric paint, the absorption coefficient is not substantially affected, as the absorption of painted fabric paint is very similar to the reference absorption. Hence, it can be claimed that this paint has non-bridging properties when applied on fabric. This assumption cannot be made with spray paint, as according to Burby, et al. [6], spray paint has less effect on the absorption due to its droplet size, which minimises the probability of closing the pores. Additionally, fabric dye does not have a considerable effect on absorption as the dye bonds to the fibres of the fabric [11].

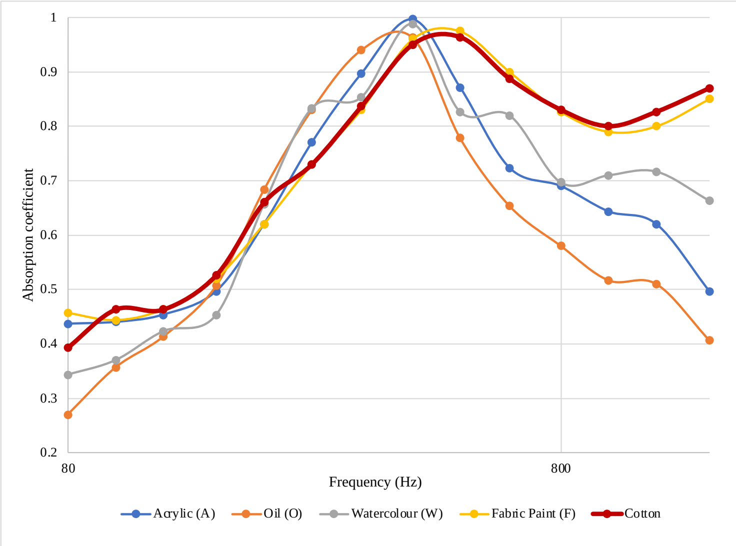

Figure 5: Absorption coefficient vs frequency of cotton fabric painted 100% with different paints backed by a polyurethane foam

The results obtained from this study prove that the area that can be painted on fabric without affecting the efficiency of the absorber is around 9-16%, according to the results of the post-hoc statistical tests reported in Table 5. The aforementioned areas have the highest NRC and absorption coefficient compared to the reference absorption, as seen in Figure 6.

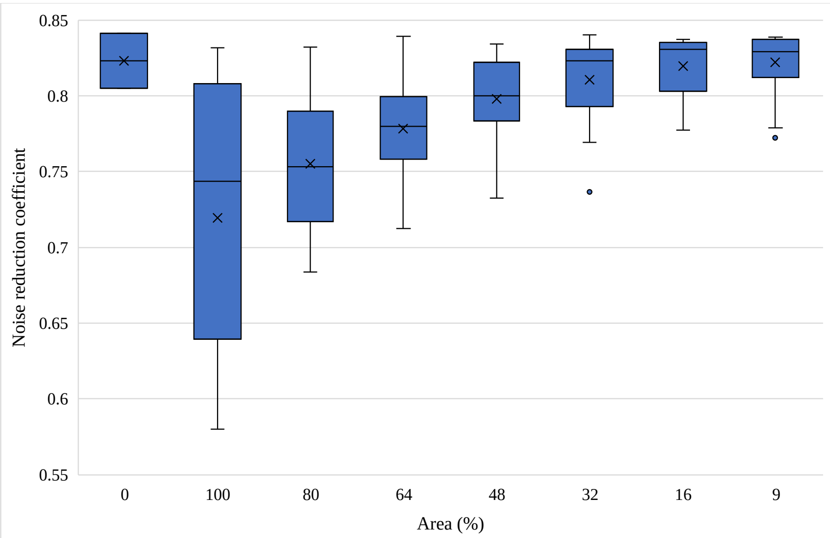

Figure 6: Box and whiskers - noise reduction coefficient vs area in canvas and cotton

Although the 32% painted fabric presents positive results, seen in Table 5, it does not have significant differences with 48% painted fabric, meaning that the absorptions of these two painted areas are equivalent. In contrast, 48% painted fabric presents significant differences versus 80% and 100% painted fabric. According to the data seen in Figure 6, it can be stated that 32% of the area can be painted without considerably affecting the absorber's efficiency, although 32% painted fabric is statistically the same as 48% painted fabric. Therefore, if the purpose of the acoustic treatment requires less absorption at high frequencies, a painted area of 32% or 48% can be used.

Table 5: P-values of post-hot tests in NRC vs area percentage

AREA %	0	9	16	32	48	64	80
9	0.8366	-	-	-	-	-	-

16	0.549	0.5147	-	-	-	-	-
32	0.549	0.1016	0.1963	-	-	-	-
48	0.2614	**0.0039**	**0.0194**	0.1808	-	-	-
64	0.07843	**0.0009**	**0.0007**	**0.0074**	0.067	-	-
80	0.0888	**0.0009**	**0.0219**	0.0844	**0.03205**	0.2635	-
100	0.15	**0.00003**	**0.00025**	**0.00061**	**0.0117**	0.0701	0.4411

4. CONCLUSIONS

This study determined that the combination of area, fabric, and paint for an acoustically transparent cover is 9% to 16% painted on cotton fabric with fabric paint. If it is possible to slightly compromise the overall absorption, 32% of cotton fabric can be painted. In addition, if the total area of the fabric needs to be painted, fabric paint, spray paint and fabric dye are the first options since they do not affect the absorption considerably. Further investigation could be carried out to determine acoustical properties of samples at higher frequencies between 1600 Hz and 6300 Hz.

5. ACKNOWLEDGEMENTS

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