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BACKING BOARDS AND GLAZING ON PAINTINGS: THEIR DAMPING CAPACITY IN RELATION TO SHOCK IMPACT AND VIBRATION

Keywords: preventive conservation, transit, shock, vibration, backing board, glazing, damping capacity, transport simulation

ABSTRACT

The use of backing boards and glazing as a protective measure is well established in preventive conservation of delicate canvas paintings. A wide range of materials is currently being applied. However, there has been little knowledge on the effectiveness of these modern materials in relation to transport protection of canvas paintings, i.e., vibration and resonance reduction. A range of such damping systems was mounted on sample paintings and compared in their damping capacity with respect to shock impact and vibration in a newly developed transport simulator. Some of the systems produce very effective damping, whereas other systems recommended as standard showed little protective effect. Some even induced negative resonance effects and must be classified as unsuitable. Current findings thus highlight the importance of the evaluation regarding the effects of the protective system as a whole. This should help to avoid unwanted destructive effects induced by unsuitable combinations of "protective" materials.

RÉSUMÉ

L'utilisation de dos protecteurs et de vitrage est une mesure de sécurité bien établie en conservation préventive des peintures sur toile fragiles. Un large éventail de matériaux sont aujourd'hui employés. Pourtant, nous disposons de peu de connaissances sur l'efficacité de ces matériaux modernes au regard de la protection des peintures sur toile lors des transports, notamment pour limiter les vibrations et la résonnance. Une variété de systèmes d'amortissement ont été fixés sur des tableaux tests et leur capacité d'amortissement des chocs et des vibrations a été com-

INTRODUCTION

It is well known that transportation of artwork causes unwanted and harmful exposure to shock and vibration of these often delicate and fragile objects. In particular the handling of freight at airports, as well as transfer on bumpy roads on the way to delivery, are associated with considerable risks to the art objects. Several approaches to this topic have been published in the 1980s and early 1990s (Caldicott 1991, Green 1991, Marcon 1991, Michalski 1991, Saunders 1991). An interdisciplinary research project currently aims at reconsidering the classification of shock and vibration events caused during transportation from one exhibition to the next, providing more reliable risk analysis, defining limits of tolerance, and developing new preventive strategies. The focus of this paper is the analysis of currently accepted and widely applied vibration damping materials and techniques. The development of successful damping systems implies a good knowledge and characterisation of shock and vibration input along a full transport path as well of the response of canvas paintings. Published research delivers mainly acceleration data. Truck transport experiments documented 5-10 m/s2 (continuous vibrations) (Marcon 1991, 129) and 30-80 m/s2 (shock events) (Saunders 1998, 71). Shock levels of up to 120 m/s2 due to handling at airports and within the cargo compartment have been documented (Saunders 2005, 704). While Saunders (1991, 319) states the relevant frequency range of continuous vibration as 50-500 Hz, Marcon (1991, 128) arrived at 2.5-100 Hz. More recent logging of truck transportation documented much lower frequencies as being predominant, namely 2-74 Hz on trucks,[1] and even lower on trolleys 7-33 Hz (Palmbach 2007, 65). The core development of the current research project is a new transport simulator (Figure 1) that allows reproducible simulation of any transport logs on sample paintings in the laboratory (Fankhauser 2009). This tool has delivered a great deal of new information on the vibration behaviour of canvas paintings in combination with the effectiveness of widely used backing board types. Analysis of the data has resulted in highly relevant new findings and a reassessment of a wide range of backing board materials. The complexity of the research questions has set the demand for an interdisciplinary approach, combining conservation scientists (Bern University of the Arts), engineers (Institute for Mechatronic Systems at Bern University of Applied Sciences – BUAS), an insurance and several removalist companies, as well as fine art museums (http://www.hkb.bfh.

parée à l'aide d'un simulateur de transport récemment mis au point. Plusieurs systèmes assurent un amortissement véritablement efficace, tandis que d'autres préconisés à titre de standards ont montré un effet protecteur limité. Certains ont même induit des effets de résonnance négatifs et doivent être considérés comme impropres. Les découvertes actuelles soulignent ainsi l'importance de l'évaluation pour mesurer les effets du système de protection dans son ensemble. Ceci devrait permettre d'éviter des effets destructeurs indésirables induits par des combinaisons de matériaux « protecteurs » inadaptées.

RESUMEN

El uso de tablas de soporte y de cristales son medidas de conservación preventiva bien establecidas para pinturas en lienzo delicadas. Actualmente se están empleando numerosos tipos de materiales. Sin embargo, se ha sabido poco sobre la efectividad de estos materiales modernos en relación con la protección en el transporte de las pinturas sobre lienzo, es decir, para reducir vibraciones o resonancias. Utilizando pinturas de prueba, se montaron varios de estos sistemas de amortiguación y se comparó su capacidad de amortiguación frente a impactos de choque y vibraciones en un simulador de transporte recientemente desarrollado. Algunos de estos sistemas proporcionan una amortiguación muy eficaz, mientras que otros sistemas, recomendados como estándares, mostraron una protección mínima. Algunos incluso inducían efectos de resonancia negativa, por lo que deben clasificarse como inadecuados. Las averiguaciones más recientes destacan así la importancia de analizar los efectos del sistema protector en su conjunto. Esto debería ayudar a evitar efectos destructores no deseados provocados por combinaciones inapropiadas de materiales de "protección".

ch/de/forschung/forschungsschwerpunkte/fspmaterialitaet/; http://www.gemaeldetransport.ch/)

MATERIALS AND METHODS

Sample painting

A sample painting was designed to examine the damping capacity of different backing board systems. A medium weight canvas (16 × 16 threads in each direction) was mounted on a wooden stretcher (70 × 90 cm) and sized with Rabbit skin glue and a chalk ground was applied. Band clamps were mounted to adjust the tension in all corners. The test specimen was fixed to a wooden frame that was screwed to the vibration rig.

Backing board systems

The selection of backing board and damping materials to be tested was based on published data and surveys (Buckley 2008, Läuchli 2004). It represents the range of currently applied systems and is summarised in Table 1. Distinction criteria were stiffness, porosity, density, surface texture and physical distance from the canvas (verso).

Transport simulator

The transport simulator (shaking machine) is built to simulate linear movement along a single axis with a maximum displacement of 70 mm. It is driven by four parallel voice-coil motors mounted perpendicular to the axis of movement. A maximum of 20 kg can be accelerated up to 50 m/s2. Sample paintings can be mounted along the x-y-z on the slider (Figure 1). This allows performing the simulation sequentially along each axis to achieve every translational degree of freedom (Figure 2). The control element is capable of reproducing any harmonic vibration or logged vibration profiles captured during real transport monitoring. The movements on the sample painting are logged by a triaxial accelerometer attached to the stretcher and two uniaxial accelerometers mounted on the canvas. The placement of the uniaxial sensors (Figure 1) was based on the ideal behaviour of membranes. The highest amplitudes are expected in the centre of the canvas (denoted as P1), whereas higher oscillation modes were recorded in the centre of the upper left quadrant (P4). An alternative recording system could be based on laser distance measurements (Lasyk 2008). While there are three translational degrees of freedom in practice, it is mathematically feasible to simulate each axis separately and superimpose the three data sets or else analyse each direction individually, as was of interest initially. Logged profiles from true transportation paths required pre-treatment of the data prior to simulation, since the maximum movement is limited to 70 mm. Frequencies below 1 Hz were considered as non-relevant and were removed applying data filtering. The precision of the simulator is within ±3 dB (approx. ±30%) for the effective range from 1 to 70 Hz. Strong resonance behaviour of heavy payloads may lead to larger errors.

Table 1

Discussed backing boards, vibration protections and glazings

no.	backing board	vibration protection			dist.	glazing	
(1)	corrugated cardboard, 3 mm	CARDBOARD 3	-		40 mm	-	
(2)	corrugated cardboard, 4.5 mm	CARDBOARD 4.5	-		40 mm	-	
(3)	corrugated cardboard, 8 mm	CARDBOARD 8	-		40 mm	-	
(4)	honeycomb cardboard, 13 mm	CARDBOARD 13	-		40 mm	-	
(5)	polyurethane hard foam core board (kapaline®), 5 mm	HARD FOAM CORE	-		40 mm	-	
(6)	polycarbonate multiwall boards (lexan®), 5 mm	MULTIWALL BOARD	-		40 mm	-	
(7)	corrugated cardboard, 8 mm	CARDBOARD 8	polyethylen hard foam (ethafoam 220®), 20 mm	PE HARD FOAM 20	20 mm	-	
(8)	corrugated cardboard, 8 mm	CARDBOARD 8	polyethylen hard foam (ethafoam 220®), 35 mm	PE HARD FOAM 35	5 mm	-	
(9)	corrugated cardboard, 8 mm	CARDBOARD 8	polyethylen hard foam (ethafoam 220®), 25 mm/ polyester fleece ,10 mm	PE HARD FOAM 25/ PET FLEECE 10	5 mm	-	
(10)	corrugated cardboard, 8 mm	CARDBOARD 8	polyester fleece, 35 cm	PET FLEECE 35	5 mm	-	
(11)	corrugated cardboard, 8 mm	CARDBOARD 8	polyester fleece, 40 cm	PET FLEECE 40	contact	-	
(12)	corrugated cardboard, 8 mm	CARDBOARD 8	cushioning foam (regelin 55/65®), 35 mm	CUSHIONING FOAM 35	5 mm	-	
(13)	corrugated cardboard, 8 mm	CARDBOARD 8	loose lining with sunk-in frame	LOOSE LINING	contact	-	
(14)	-		-			laminated safety glass (mirogard protect®)	SAFETY GLASS
(15)	corrugated cardboard, 8 mm	CARDBOARD 8	polyethylen hard foam (ethafoam 220®), 35 mm	PE HARD FOAM 35	5 mm	laminated safety glass (mirogard protect®)	SAFETY GLASS
(16)	corrugated cardboard, 8 mm	CARDBOARD 8	polyethylen hard foam (ethafoam 220®), 35 mm	PE HARD FOAM 35	5 mm	Polycarbonate glass (macrolon®)	POLYCARBONATE

MEASUREMENTS

Frequency response measurements

A first experiment was run to determine the characteristics of the frequency response of each individual component and specified system combinations thereof. The model painting was thus exposed to sinusoidal oscillations and their frequency response was logged at P1 and P4 on the canvas. Frequency response is defined by the ratio of the excitation amplitude to the response amplitude and their phase difference, measured over a frequency range. The ratio is commonly expressed in dB (decibels). Resonant frequencies of canvas, glazing, backing boards or combinations thereof lead to maxima in the frequency response plot.

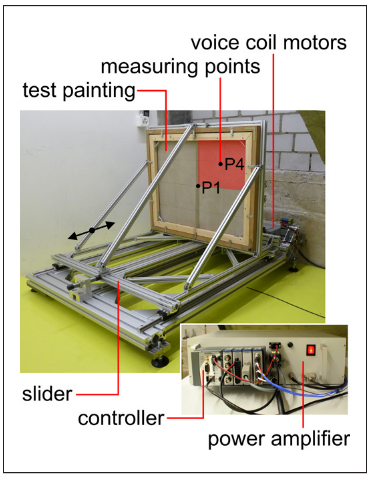
Simulated transport measurements

The next step was exposing the sample painting to a simulated transport sequence previously logged with identical sensors on a real artwork transport. The focus here was set on the following two sequences (Figure 3):

A: transportation on an air-sprung two-axle vehicle (Figure 2) on sealed roads during normal traffic hours: the duration is 5 s and the sequence is characterised by a sudden movement after 3 s, initially along x with lateral z coming in with a delay, caused by a bump in the road.

B: transfer of the case on a trolley equipped with solid rubber wheels, representing a moderate shock event: total duration is 1.5 s and at 0.25 s the case suddenly collides with a door-frame.

Reference measurements were performed without protection. Several series of backing board and glazing protection combinations involving the various damping materials and protective systems were run (Table 1). The focus was set on x and z-directed movements, since acceleration along y has been shown to have a minimal influence on canvas oscillation. The acceleration at the frame is denoted as *immission* (Figure 3, P4), whereas the canvas acceleration (either at P1 or P4) is denoted as *emission* (Figure 4, P4). Each experiment was run in triplicates under constant climatic conditions (23°C and 50% RH).



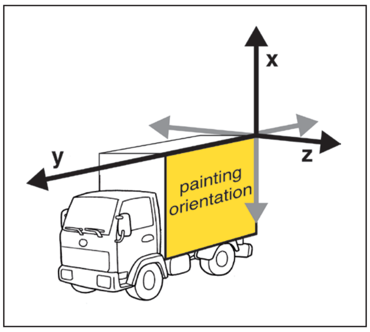


Figure 1
Newly developed transport simulator

Figure 2
Painting orientation during transport

Data processing

In order to characterise and compare immission and emission levels, acceleration minima and maxima and the rms-level (root mean square) were determined. The kurtosis was calculated to describe the roughness of a vibration signal (Caldicott 1991). The dominant frequencies were derived from a Fourier transformation (FFT) of the dataset. Often it is of interest to derive the actual displacement from the acceleration logs. This can be achieved by appropriately filtering and integrating the acceleration signal.

EXPERIMENTAL RESULTS

The study delivers data in two fields of interest: first, the general description of shock and vibration events logged on several real artwork transfers throughout Europe, determining their frequency range, magnitude and intensity; and second, the reproducible characterisation of the response of the canvas to simulated transport sequences testing a series of damping materials and systems, and as a result thereof, develop a classification with respect to their effectiveness.

Shock and vibration events (immission)

In the acceleration patterns of the air-sprung truck sequence A the highest values are reached along the z-axis, probably reflecting events on potholes or bumps (Figure 3). The frequency range along the x-axis covers the full spectrum between 0-45 Hz, with a large number of amplitude maxima of similar intensity (Figure 3A, x-axis); movements along the z-axis are dominated by an isolated event of high intensity at 20 Hz (Figure 3A,

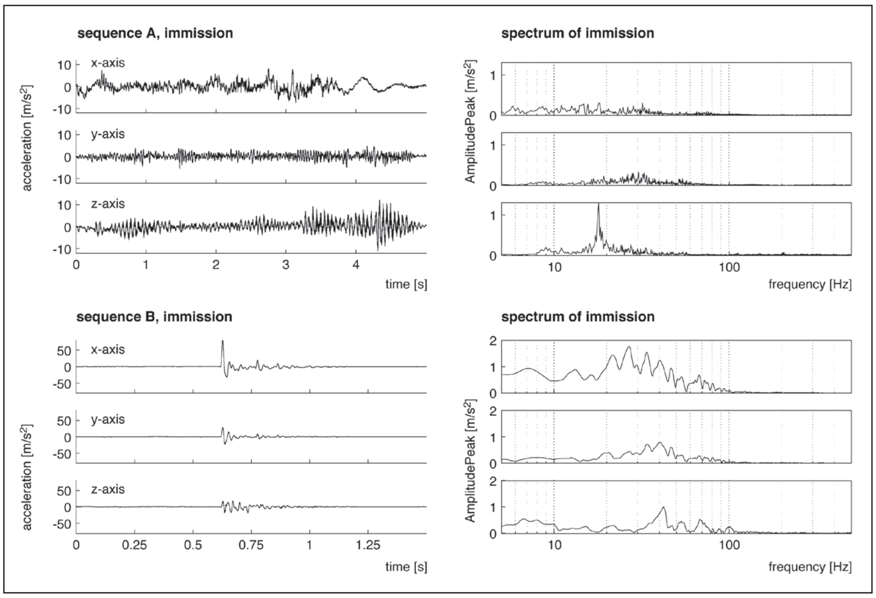


Figure 3
Immission measured on the frame: acceleration and frequency spectrum

z-axis). This characteristic frequency range of the sequence is regarded as representative and is based on an evaluation of several truck transport loggings on a common road mix (motor- and highways) and reflects realistic truck transport patterns on European roads. On evaluation of the full transfer paths from museum to museum, the highest rms-levels were always reached during transportation on trucks.

The trolley sequence represents mainly a shock event along x, reaching a short maximum upon collision with the door-frame, with only weak z displacement (Figure 3B).

Sample painting without backing board and glazing (emission)

The following observations on the unprotected reference painting (Figure 4) are relevant for later interpretation of vibration reducing systems: acceleration maxima along the x-axis are 2-3x lower on the canvas (emission; Figure 4A, x-axis) than the acceleration on the wooden stretcher (immission; Figure 3A,

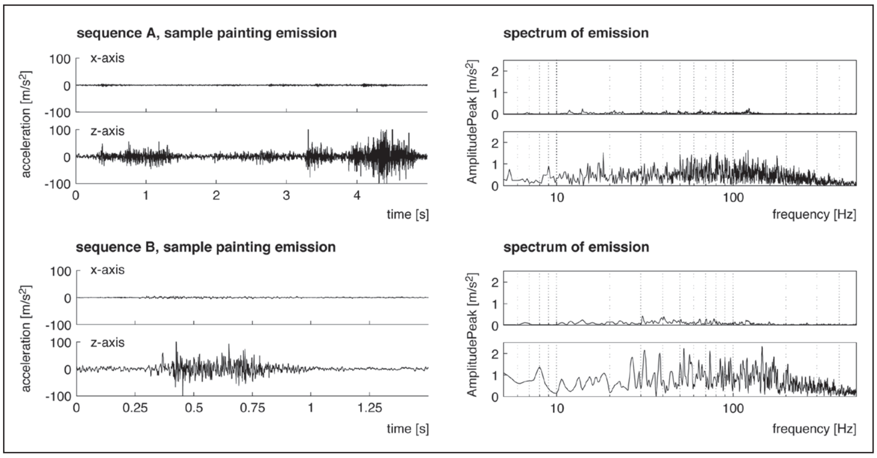


Figure 4
Emission measured on the canvas: acceleration and frequency spectrum

x-axis). The rms-level is reduced by a factor of 1.5-2 (Table 2). In the z-direction, however, immission on the stretcher is fully transferred to the canvas and thus results in high vibration of the textile along z despite the lower input (Figure 3A vs 4a, z-axis). Acceleration maxima are enhanced by a factor of 20-40, whereas the rms is 10 times higher.[2] The z-immission induced vibrations of the canvas exhibit particularly high amplitudes (Figure 4, z-axis). Based on those observations it appears necessary to focus on the z-axis and analyse both z-immission and emission isolated from the x-axis in both sequences.

While immission input in sequence A reaches higher acceleration maxima and rms-values in comparison to the trolley sequence B (Figure 3), observed emissions on the canvas are lower in A (Figure 4). The propagation of the shock waves in sequence B seem to affect the canvas vibration more effectively despite the lower immission input. This could possibly be due to the high ratio of low acceleration frequencies and the sudden acceleration increase on the impact. The detrimental effect is enhanced by a clearly larger displacement (amplitude of relative positions), which puts greater tensile stress on paint and canvas than observed throughout truck transportation. Nevertheless, this short and sudden event amidst generally lower frequency input on trolley transport contrasts with the continuous and higher frequency immission with frequent directional and intensity changes on a truck in motion.

Damping capacity of backing board systems and glazing

A further step comprises the classification of canvas oscillations induced by the transport simulator and counteracted by the various protective systems.

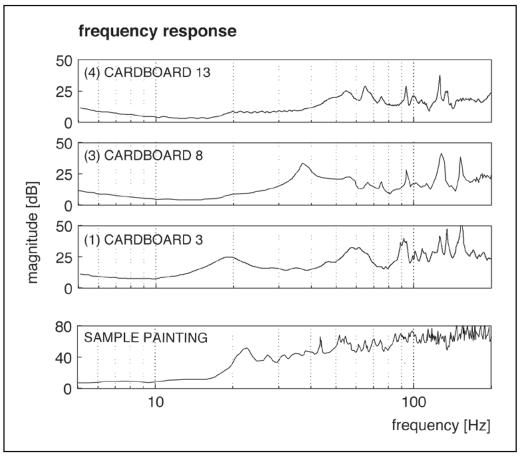


Figure 6
Eigenfrequencies of some discussed systems

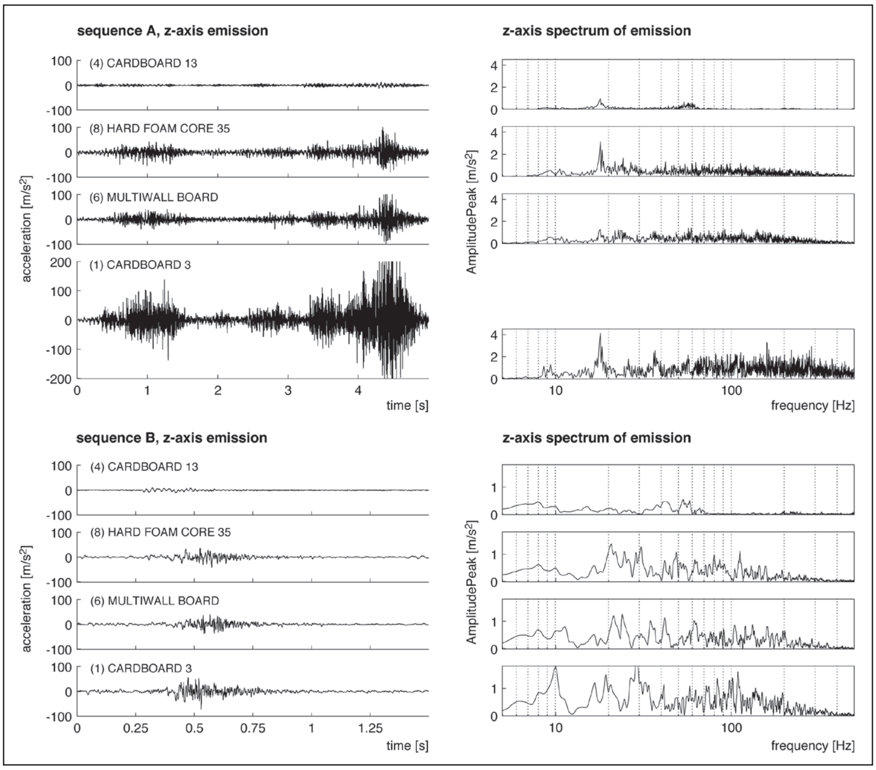


Figure 5
Emission measured on the canvas protected with different backing boards

Table 2

Acceleration values and displacements (amplitudes) of the canvas

no.		sequence A (truck/vibration)											
		min. (m/s²)		max. (m/s²)		rms		kurtosis		min. ampl. (mm)		max. ampl. (mm)	
	SAMPLE PAINTING immission	-8.1	± 0.07	6.6	± 0.14	1.3	± 0.00	4.3	± 0.02	-		-	
	SAMPLE PAINTING emission	-108.2	± 34.50	169.4	± 76.32	10.8	± 0.52	31.6	± 29.60	-2.1	± 0.54	1.7	± 0.12
	backing board												
(1)	CARDBOARD 3	-264.0	± 87.95	377.7	± 100.72	28.6	± 1.20	16.1	± 5.29	-3.4	± 0.43	3.0	± 0.36
(2)	CARDBOARD 4.5	-112.0	± 4.31	85.0	± 2.75	10.4	± 0.13	9.8	± 0.58	-1.7	± 0.24	1.2	± 0.06
(3)	CARDBOARD 8	-14.8	± 0.12	19.5	± 0.42	3.3	± 0.00	2.1	± 0.02	-1.3	± 0.21	1.0	± 0.05
(4)	CARDBOARD 13	-10.8	± 0.03	12.8	± 0.54	2.1	± 0.01	2.7	± 0.01	-0.9	± 0.37	1.0	± 0.25
(5)	HARD FOAM CORE	-120.1	± 9.45	155.4	± 27.55	12.6	± 0.50	15.3	± 3.68	-2.0	± 0.59	2.0	± 0.45
(6)	MULTIWALL BOARD	-94.8	± 11.28	213.1	± 9.86	14.2	± 0.07	24.6	± 4.02	-1.9	± 0.40	2.1	± 0.31
	vibration protection												
(7)	PE HARD FOAM 20	-11.4	± 0.48	13.0	± 0.15	2.4	± 0.02	2.3	± 0.00	-0.5	± 0.03	0.6	± 0.21
(8)	PE HARD FOAM 35	-10.4	± 0.44	9.2	± 0.24	1.7	± 0.00	4.3	± 0.10	-0.6	± 0.09	0.8	± 0.04
(9)	PE HARD FOAM 25/ PET FLEECE 10	-13.2	± 0.05	10.2	± 0.26	2.0	± 0.01	4.6	± 0.01	-0.6	± 0.19	0.7	± 0.06
(10)	PET FLEECE 35	-14.2	± 0.32	12.6	± 0.74	2.1	± 0.01	4.7	± 0.03	-1.2	± 0.42	1.1	± 0.36
(11)	PET FLEECE 40	-13.0	± 0.15	11.7	± 1.45	1.9	± 0.04	4.8	± 1.61	-0.8	± 0.17	0.8	± 0.02
(12)	CUSHIONING FOAM 35	-14.6	± 0.19	13.3	± 0.58	2.2	± 0.01	5.5	± 0.09	-0.9	± 0.44	0.9	± 0.06
(13)	LOOSE LINING	-18.8	± 0.87	15.4	± 0.80	2.8	± 0.11	5.6	± 0.12	-0.7	± 0.33	2.6	± 3.73
	glazing												
(14)	SAFETY GLASS	-46.3	± 8.11	63.6	± 4.98	6.4	± 0.01	10.4	± 1.39	-1.0	± 0.30	3.1	± 2.84
(15)	PE HARD FOAM 35/ SAFETY GLASS	-12.4	± 0.12	11.1	± 0.02	2.2	± 0.00	3.3	± 0.05	-0.7	± 0.10	1.0	± 0.29
(16)	PE HARD FOAM 35/ POLYCARBONATE	-16.2	± 0.46	23.3	± 0.44	3.3	± 0.00	3.9	± 0.05	-1.1	± 0.54	1.4	± 0.51

Current data delivers very distinctive results: the system “glazing – canvas – backing board” delivers eigenfrequency values different from its single components. The system exhibits multiple eigenfrequencies of variable intensity throughout the package volume that may lead to substantial resonance effects. These may cancel out to a positive vibration reduction or, the opposite, add up to catastrophic oscillations on the canvas.

Backing boards

Backing board materials do have a strong influence on the vibration behaviour of the canvas, induced by transportation immissions. Their effectiveness, however, varies significantly (Figures 5, 6). The damping capacities of corrugated cardboards, honeycomb cardboards (Cardboard 13), polyurethane hard foam core (Hard foam core) and polycarbonate multiwall boards (Multiwall board) have been thoroughly characterised and are summarised in Table 2. Of particular note is the thin corrugated cardboard (Cardboard 3), which enhanced rather than reduced emissions. Overall enhancement of accelerations of the canvas was by a factor of 50 at P1 and 65 at P4. This was observed with sequence A, also manifested by larger displacements (amplitudes) of the canvas. With sequence B reproducing the trolley transfer, a minimal reduction of the vibrations was achieved. This could be explained by the dominant frequency (20 Hz) of the sequence A corresponding to the eigenfrequency of the 3 mm corrugated cardboard (20 Hz). The initial eigenfrequency of the combined system measured on the canvas surface is 20-28 Hz. Resonance effects are seen as distinct amplitude maxima at the dominant frequency of 20 Hz (Figure 6). These are clearly being reduced with the stiffer 4.5 mm corrugated cardboard (Cardboard 4, 5), but even more effective is the 8 mm corrugated cardboard (Cardboard 8). Here, vibrations in comparison with the non-protected painting are being effectively reduced by a factor of 2-4. The eigenfrequency of the 8 mm cardboard is at 40 Hz. Honeycomb cardboard (13) achieves even better damping with its high eigenfrequency value of 50 Hz. The eigenfrequency of the combined system measured on the canvas surface is at 45-50 Hz. Acceleration values were only half of the 8 mm corrugated cardboard (Cardboard 8). The eigenfrequency of the polyurethane hard foam core (Hard foam core) and polycarbonate multiwall boards (Multiwall board) is even lower: just over 20 Hz for the Hard foam core, around 25 Hz for the whole system and 23 Hz for the Multiwall board system. While they both successfully can eliminate the shock event of sequence B, pronounced resonance development similar to the 3 mm cardboard (3) was observed.

Combined backing board systems with oscillation protection effect

Current preventive conservation practice suggests the use of backing board systems to achieve oscillation reduction, whereby the rigid boards are combined with filling materials like lightweight hard foam and cushioning foams, fleece and pile textiles with variable surface textures and distance to the canvas. Other methods in use are loose lining techniques with canvas, some in combination with rigid boards. This study has explored the effectiveness of the different filling materials in combination with the 8 mm corrugated cardboard (Cardboard 8) (Figure 7). The cushioning

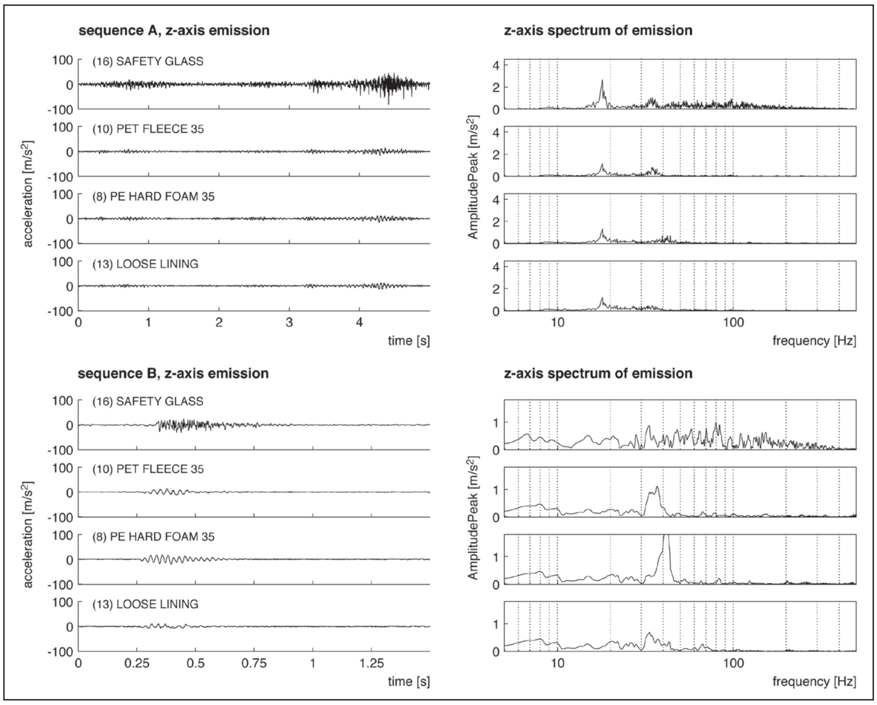


Figure 7
Emission measured on the canvas with different backing boards, vibration protections and glazing

foam (Cushioning foam 35) mounted 5 mm from the canvas achieves good damping capacities in both simulation sequences A and B. The polyethylene lightweight hard foam was tested at 5 mm and at 20 mm distance from the canvas (PE hard foam 35 and 20). The shorter distance results in lower acceleration emissions, particularly at P4. PE hard foam 35 mounted at 5 mm from the canvas achieves twice the damping effect of the cushioning foam 35 along the z-axis. Overall, the cushioning foam is better at reducing shocks, whereas the polyethylene lightweight hard foam is more efficient at reducing continuous vibrations. The second peak of the emission frequency around 40-45 Hz again is evident only with PE hard foam 35, which exhibits an eigenfrequency at a similar level (38 Hz). Better results regarding damping efficiency are achieved when the polyethylene lightweight hard foam is combined with 10 mm of polyester fleece[3] (PE hard foam 20/Pet fleece 10) towards the canvas. The observed dominant emission frequencies of this system are effectively reduced amplitudes at 45 Hz. By applying polyester fleece (Pet fleece 35) mounted on 8 mm corrugated cardboard a similar damping capacity is achieved to reduce continuous vibrations. However, this material is less effective in reducing shocks. By mounting the polyester fleece at 5 mm from the backside, damping is even more efficient then in direct contact. Loose lining techniques with canvas are clearly less efficient in both simulation sequences and essentially fail with shock events.

Glazing

This technique applies a glazing on the front side of the canvas, which successfully reduces accelerations in z-direction (Figure 7). The dominant vibration in sequence A is at 20 Hz, the trolley sequence B has an additional maximum at 45 Hz. Higher frequencies are effectively reduced with the glazing, yet the damping effect is less compared to the 8 mm corrugated cardboard (Cardboard 8). Comparing glazing types, laminated safety glass (Safety glass) induces slightly lower accelerations on the canvas than the polycarbonate glass (Polycarbonate). The peak at 20 Hz causes noticeably higher amplitudes with the polycarbonate glass at P1. This is related to the lower eigenfrequency around 18-22 Hz as opposed to 33 Hz of laminated glass. Combining glazing at the front with padded backing boards at the rear, vibrations are effectively reduced, particularly at P4. The dominant frequencies are similar to the unprotected reference, yet intensities are being reduced significantly. Unsuitable backing board materials such as the 3 mm corrugated cardboard cannot be compensated through glazing in front. The damping capacity of such a system is still worse than the 8 mm corrugated cardboard without glazing.

Conclusion

The frequency range of acceleration forces (<45 Hz) applied within this study was lower than in previously published research and closer to the natural frequency of the “glazing – canvas – backing board” systems tested. The effect is strongly frequency, vector and amplitude dependent and thus delivers distinct results for trolley versus truck transport. For example: while the low dominant frequencies during trolley movement are the lateral ones along the z-axis in line with the main oscillation direction of the canvas fabric, the low dominant frequencies during truck transport are in the vertical direction along the x-axis of the image plane. Such results are currently being evaluated to develop selectively acting anti-shock and vibration damping systems.

The immission induced peak at 20 Hz along z was observed on all logged truck transports and thus is considered highly relevant. If backing board materials with an eigenfrequency around 20 Hz are being used, coupling effects may result in dramatic resonance vibration. This study documents the potentially negative effects of several backing board materials (3 mm corrugated cardboard; polyurethane hard foam core board; polycarbonate multiwall board) that are currently accepted and widely used in practice. Coupling effects, mainly on truck transportation, may lead to fatal resonance vibrations enhancing rather than reducing emissions. Nevertheless, most artwork transfers involve a high amount of truck driving and thus optimisation of effective reduction of z-accelerations should be tackled with high priority. There is a limitation of the current study since it refers only to non-contact protection systems, i.e. the canvas and the backing boards can vibrate without touching protective materials. Yet this is common practice even though there are differences in the selected geometry, air volume and positioning of the case relative to the cargo space.

Extending the current data with other packing situations and setups as well as optimised cushioning to minimise z-accelerations is the focus of further research. Recommendations based on the results presented here strongly suggest the use of backing board systems with higher eigenfrequencies, ideally above 45 Hz. These are rigid corrugated or honeycomb cardboards. Even better results can be achieved with multilayered systems combining the rigid cardboards with polyethylene lightweight hard foam and polyester fleece proximal to the canvas. The setup with the 5 mm air gap between fleece and canvas has achieved the best overall results. The combination of rigid corrugated cardboards with cushioning foam can be recommended as well, yet the limited lifetime due to ageing of the foam requires frequent replacement for safe use. Comparison of different glazing type materials favours the laminated safety glass over the polycarbonate glass. Backing board protection, however, achieves more effective damping than glazings. To date there is no known publication assessing the destructive potential of repeated deformation (i.e., due to transportation) on fragile painting structures. The critical level of tolerable strains induced by the vibration levels quoted in the literature are based on fatigue research dealing mainly with modern construction materials (Michalski 1991, Lasyk 2008). Considering the current trend towards global exhibitions and an increased cycle of thematic displays, effective shock and vibration damping systems become ever more important. A next step of this project will involve the study of fragile artwork behaviour applying this instrumentation and to develop a basis for predictive risk assessment.

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NOTES

[1] Special climate-controlled, air-suspension vehicles.

[2] The relative standard deviations of the mean acceleration maxima were up to 30%. Interpretation of acceleration maxima was thus based on signal trend and rms.

[3] Polyester fleece: density 200 g/m^2.

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MATERIALS LIST

Uniaxial accelerometers, PCB 352A73

Triaxial accelerometer, PCB 356A16

Control element, transport simulator: cRIO, National Instruments

Software for data processing: DiaDem, National Instruments

Tested backing board materials see Table 1