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PREVENTIVE CONSERVATION

Optimising the protection of the Kröller-Müller Museum's wax-resin-lined van Gogh paintings from shocks and vibrations in transit

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Abstract
The Kröller-Müller Museum holds the world's second largest collection of works by Vincent van Gogh (1853–1890): 182 works on paper and 88 paintings. Most of the canvas paintings have been wax-resin lined and often travel internationally. However, the vibrational behaviour of wax-resin-lined (oil) paintings on canvas has been investigated in only a few studies. In this paper, the authors discuss the experimental results establishing risk parameters for shocks and vibrations when moving paintings during internal transport and international shipping. The mitigation of these risks by improving framing mechanisms and methods and by customising the construction of backing-boards is examined. The considered approaches include changes in the construction of transit crates and carts to reduce the transference of potential shocks and vibrations. Modifications to the framing and backing-boards of three test paintings as well as to one van Gogh painting are described. Tests of different shock absorbers and mounting systems used for transit showed that modifying the crates and carts used to ship and move paintings so as to improve vibration isolation and simultaneous shock absorption can reduce the mechanical loads

INTRODUCTION

The application of backing-board constructions to paintings on canvas is common practise. This reversible, structural modification reduces the response of the canvas both to vibrations during transport and to impact shocks (Hartin 2017). Padded backing-boards may further decrease vibrations. However, Bäschlin et al. (2011) reported that, if an inappropriate backing-board material is used or if the backing-boards are not mounted correctly, vibrations will increase. The mitigation of vibrational behaviour by using fibrefill (polyester batting) inserts was tested by Kracht on an unlined painting (Kunsthalle Mannheim 2018). The results showed that the padding needs to be in direct contact with the canvas to effectively reduce both shocks and vibrations (Radermacher et al. 2018). Placing fibrefill padding between the stretcher crossbars and canvas has an additional positive effect. These findings were incorporated into the Kunstmuseum's (The Hague) project 'A revolution in art transport – Safe packaging and transport of Mondrian's artwork *Evolution*' (Kunstmuseum Den Haag 2021). The results of a 2017 research project showed that customising rigid-wooden transport crates and using T+ holder blocks (TURTLE) further reduces transferred vibrations during transit. Lipp and Kracht (2021) used finite element modelling (FEM) to study the vibration reduction ability of paintings equipped with fibrefill padded backing-board constructions on glass steles. Their observations refined the search for appropriate materials. Those studies provided the context for the current research carried out by the Kröller-Müller Museum (KMM) with the aim of better safeguarding their van Gogh's paintings, which are highly requested for exhibition loans.

RESEARCH QUESTION

The majority of the KMM's 88 van Gogh canvas paintings have been wax-resin lined. However, with aging, the wax-resin layer becomes increasingly brittle. Compared to ductile substances, brittle materials are extremely reactive to alternating stresses such as occur during transport (Freiman and Mecholsky 2019). Modelling of the response of unlined paintings to dynamic-mechanical forces has been conducted (Lipp and Kracht 2021, Kracht et al. 2023). Data on the static-mechanical behaviour of wax-resin-lined paintings showed that those paintings may be particularly responsive to shocks and vibrations (Young and Ackroyd 2001, Andersen 2013). Transportation, among other movements, can produce characteristic

of the painting by up to 90%. The combination of these transport modifications with better framing and newly developed backing-boards reduced the reaction of the painted canvas by up to 96%.

vibration modes. The smaller the transfer factor of the vibration mode, the less the painting is stressed during transport. However, the vibrational behaviour of wax-resin-lined paintings has yet to be investigated. The aim of the KMM study (December 2021–September 2022) was to fill this knowledge gap. Its results will allow a review and adaptation of the framing systems and crates used for the frequently traveling van Gogh paintings.

Currently, all frames of the KMM van Gogh paintings are fitted with safety glass and backing-boards. These are screwed onto a wooden build-up, mounted on the reverse of the frame. The backing-boards consist of a 4 mm, multiwall polycarbonate plate (PCP), some with inserts of polyethylene (PE) foam (not touching the reverse of the canvas) attached to the inside of the PCP with book screws. TURTLE crates with T+ holder blocks are often used for external shipment of the KMM's paintings. Internal transportation uses wheeled transport carts. A further aim of this study was to optimise the backing-board construction and the T+ holder blocks configuration and to improve the KMM transport carts to provide better isolation and simultaneous shock absorption. To this end, the following questions were addressed:

- What is the influence of a wax-resin lining on the vibrational behaviour of a canvas painting?
- Do the current backing-boards and framing method offer sufficient protection against shocks and vibrations during transport, or might different types of backing-boards and framing methods be more suitable?
- Do the current transit carts and crates provide sufficient buffering of vibrations and shocks during transit, or is improvement possible?

METHODOLOGY

Investigation and optimisation

The concept of a digital twin was initially used to predict the vibrational responses of the paintings during their transportation. FEM was used to model the paintings, with the model parameters adapted by incorporating the results of measurements such as thickness, contour and vibration. Contour and the vibration measurements were carried out as defined in an earlier study by Kracht (2011). The paintings, elastically mounted to the test rig, were excited (force < 1 N) to achieve very small vibrations (amplitude < 0.5 mm), using a shaker with a built-in force sensor. The averages and tolerances of the temperature and humidity during testing were: T=21°C ± 0.1°C and RH=56.8% ± 1.2%. The contour and vibrational responses were measured at sixteen measurement points per cm² using a laser (later in the project, three lasers) mounted on an automatic linear positioning unit as shown in Figure 1. The duration of the measurement at one point was 4 s. The method used to model the digital twin paintings is described in Kracht et al. (2023).

Vibrational behaviour analyses

Measurements were first carried out on test paintings to obtain a comparative dataset. The results provided a baseline to establish the influence of the wax-resin layer on the behaviour of the canvas in response to vibrations.

Figure 1. Left and lower middle images show vibration measurements of unframed and framed painting no. 8. The upper middle image shows vibration measurements of framed painting no. 7 in the gallery of the KMM. The image on the right shows drop testing of framed painting no. 2 in a Turtle crate (without lid)

A method and recipe similar to that used to line the KMM van Gogh paintings[1] (Table 1, 1–3) was applied to three test paintings. All three were subsequently artificially aged.[2] The test paintings' responses to vibrations were measured (unframed and without backing boards) before and after lining (Table 2) as well as before and after artificial ageing. All test paintings were then framed. The vibration experiments were repeated with the current KMM backing-board system. The results led to modifications of the backing-boards, including replacement of the multiwall PCP (4 mm) with corrugated cardboard (CCB, 4.5 mm), a thicker multiwall X-structure PCP (XPCP, 16 mm) or honeycomb cardboard (HCCB, 8.3 mm). Additionally, two types of acoustic fleece of different stiffnesses (WLG35 (stiffer) and WLG40) were tested for use in two attachment systems (Table 2), replacing the polyester fibrefill padding used in previous studies: (1) sewing and (2) solvent-free self-adhesive Velcro. The data derived from each test scenario were compared and used to design testing parameters for the six van Gogh paintings selected for further study.

In the second part of the project, six van Gogh paintings were selected as case studies (Table 1, 4–9). Data on their vibrational behaviour were acquired (Figure 3). Paintings no. 6[3] and no. 7 were evaluated while on the wall in the galleries, framed with the current KMM backing-board (Figure 1). The vibrational behaviour of the other four van Gogh paintings was measured with the paintings on the test rig in an unframed state, without a backing-board, as well as framed and with the current KMM backing-board system (Table 2, Figure 3). The painting in case study no. 8 was subsequently equipped with a backing-board system of CCB/WLG40 and subjected again to the same vibrational analysis.

In the final part of the project, software experiments were carried out in which the digital twin paintings were virtually equipped with the investigated backing-board constructions. The goal was to find the best solution, customised for each painting.

Endurance testing

The two methods of attachment (sewing and self-adhesive Velcro) of the acoustic fleece to the backing-board were subjected to endurance testing

Table 1. Information on the measured test paintings and van Gogh paintings

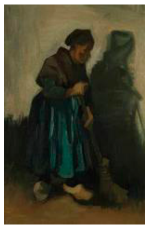
No.	Picture	Details
1		*Small Landscape* 2008 oil on canvas 30 × 40 cm (K. Kracht)
2		*Blue-white* 2020 oil on canvas 40 × 60 cm (K. Kracht)
3		*Big Landscape* 1925 oil on canvas 100 × 70 cm (K. Kracht)
4		*Woman with a broom* 1885 oil on canvas (wax-resin lined) 42 × 27.2 cm (KM 108.559/F152)
5		*Digger* 1885 oil on canvas (wax-resin lined) 45.4 × 31.4 cm (KM 102.175/F166)
6		*Bridge at Arles (Pont de Langlois)* 1888 oil on canvas (glue-paste lined) 54 × 64 cm (KM 111.056/F397)
7		*Terrace of a café at night (Place du Forum)* 1888 oil on canvas (wax-resin lined) 80.7 × 65.3 cm (KM 108.565/F467)
8		*The lover (portrait of Lieutenant Milliet)* 1888 oil on canvas (wax resin lined) 60.3 × 49.5 cm (KM 102.392/F473)
9		*Wheat fields in a mountainous landscape* 1889 oil on canvas (wax-resin lined) 73.5 × 92 cm (KM 100.443/F721)

Table 2. Investigated vibration behaviour (X) and endurance test configuration (e)

No.	Configuration \ Painting	1	2	3	4	5	6	7	8	9
1	Unlined + unframed	X	X	X						
2	Freshly lined + unframed	X	X	X						
3	Lined + aged + unframed	X	X	X	X	X			X	X
4	Lined + framed + PCP backing-board	X (e)	X (e)	(e)	X	X	X	X	X	
5	Lined + framed + PCP/PE-foam backing-board	X (e)	X (e)	X (e)						X
6	Lined + framed + PCP/PE-foam backing-board + Turtle T+ *feather*		X							
7	Lined + framed + CCB/WLG45/Velcro backing-board			(e)						
8	Lined + framed + CCB/WLG40/Velcro backing-board	X (e)	X (e)	X (e)					X	
9	Lined + framed + CCB/WLG40/Velcro backing-board + Turtle T+ or T+ feather		X (T+ feather)	X (T+)						
10	Lined + framed + CCB/WLG35/Velcro backing-board		X (e)							
11	Lined + framed + HCCB/WLG40/Velcro backing-board		X	X						
12	Lined + framed + HCCB+PCP/WLG40/ Velcro backing-board			X						
13	Lined + framed + XPCP/WLG40/Velcro backing-board		X	X						
14	Statics standing, unframed	X	X						X	
15	Statics lying, unframed		X							

in order to determine whether the fleece would retain its shape during transport and not detach. Transport simulations were carried out on a shaker (Figure 6, Table 2) with input signals according to the literature (Kracht and Kletschkowski 2017). Initially, fibrefill padding material was sewn onto the corrugated cardboard, but since acoustic fleece is too stiff to sew, attachment with self-adhesive Velcro was tested as an alternative.

Framing

For many years, the KMM has used rigid, bent copper strips to frame paintings. These strips are screwed to both the wooden build-up on the reverse of the frame and the stretcher. The number and location of the copper strips is determined intuitively, albeit influenced by the possibility of re-using existing screw holes in the stretcher. The effect of the placement and attachment of the copper strips on the vibrational behaviour of the canvas was examined.

Transport carts and crates

Paintings are typically transported internally on transport carts and externally, for exhibition loans, in standard-sized TURTLE crates equipped with T+ holder blocks to place and secure the painting within the crate. The effectiveness of these systems was investigated.

The KMM transport carts (Figure 8) consist of a lower wheeled framework and an upper framework, with cushioned vertical racks to hold the paintings. Both frameworks are steel constructions mounted without shock absorbers. The only dampening element is the connection between the frames, which consists of hard rubber buffers. To improve the vibration isolation and shock absorption, the rubber buffers were replaced with wire-rope isolators (WRI). Their type and position were calculated using finite element analysis (FEA). Measurements were taken to determine the operational shocks and vibrations caused by several common internal scenarios at KMM using existing and modified carts.

The TURTLE crates consist of extra strong, temperature- and humidity-isolated walls. In combination with the T+ holder blocks, equipped with WRI, the system can provide optimal vibration and shock reduction. With this modular system, it is possible, by changing the configuration and type of T+ holder blocks, to customise the vibration isolation according to the weight and size of the framed painting, the inherent dynamics of the paintings with their backing-board constructions and the orientation of the crate (vertical or horizontal). The best possible combination, in terms of minimising the stress on the canvas, was calculated for the mounting of paintings nos. 6 and 7 in packing crates. The TURTLE crate (without lid), but with one of the test paintings (no. 2, framed and with a backing-board of CCB/WLG40) held in position as for transport, was placed on the test rig and measured to provide insights into the interaction between the painting, backing board construction, frame, T+ holder blocks and crate. The response of the canvas during extreme situations, such as drop testing, was also measured (Figure 1).

RESULTS

Vibrational behaviour of the test paintings

The vibration study showed that the natural frequencies of the lined test paintings increased upon ageing (Figure 2). Unexpectedly, the first natural frequency of painting no. 2 did not increase. The higher the first natural frequency, the easier it is to build a working system for vibration isolation. Wax-resin adhesives maintaining some residual elasticity will be able to partially resist the impact of shock and vibrations. However, when the residual elasticity is below a specific limit, the brittleness of the wax-resin effects a greater sensitivity of the paintings to dynamic loads. This was previously demonstrated during the chemical drying of oil test paintings, described in Kracht (2011).

Vibrational behaviour of the original paintings

The natural frequencies of the original paintings were relatively unaffected by the KMM framing or backing-board systems (Figure 3). However, the geometry of the painting influenced the vibrational modality. The results emphasise that a twisted, warped stretcher must be stabilised with a cushioning material in order to prevent a tilted movement within the frame. In the absence of fixation, shocks to the stretcher can occur within the frame.

Vibrational behaviour of the paintings with different backing-board constructions and in crates

The measurements derived from the three test paintings showed that the backing-boards with CCB/WLG40 reduced the vibration by 31%–76%

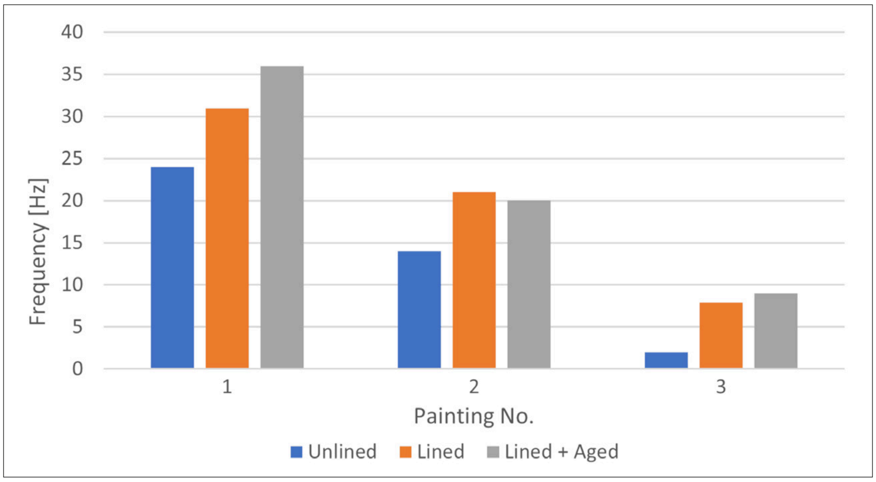


Figure 2. First natural frequencies of the unframed test paintings under unlined, wax-resin lined, wax-resin lined and artificially aged conditions

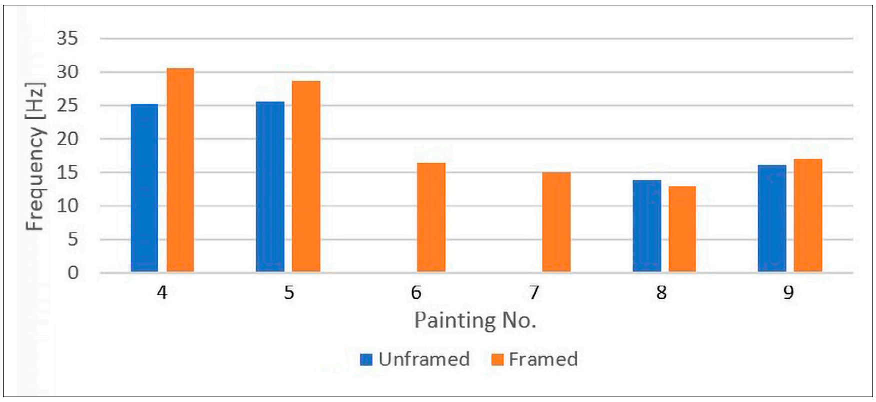


Figure 3. First natural frequencies of the unframed and framed van Gogh paintings with PCP backing-boards, and PCP/PE backing-board for painting no. 9

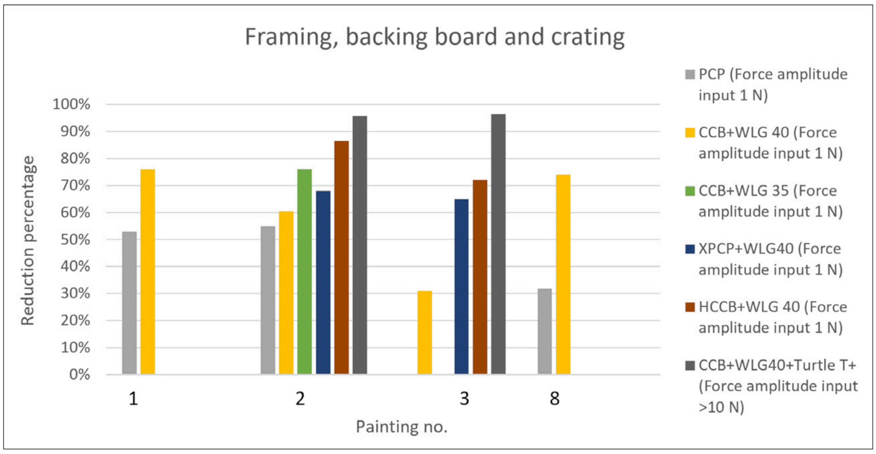


Figure 4. Reduction of the transfer factor in relation to the unframed painting (selection). Note: The reduction percentage of the backing-board constructions was valid within the range 0.1 N < Input < 2 N. For input forces > 2 N, the loss of contact between canvas and padding material followed. The reduction percentage of backing-board constructions with TURTLE T+ was valid within the range Input > 10 N. In the case of Input < 10 N, the reduction percentage is 100%

of the averaged transfer factor[4] of the unlined painted canvas. The stiffer XPCP plate (16 mm) reduced the vibration by a further 8%–42%, and the 8 mm-thinner HCCB plate by as much as 86% of the starting value. These results recommend the use of this honeycomb board.

Measurements on the van Gogh painting (no. 8) mounted with CCB/WLG40 showed a significant reduction in the vibrations (Figure 4). Among the

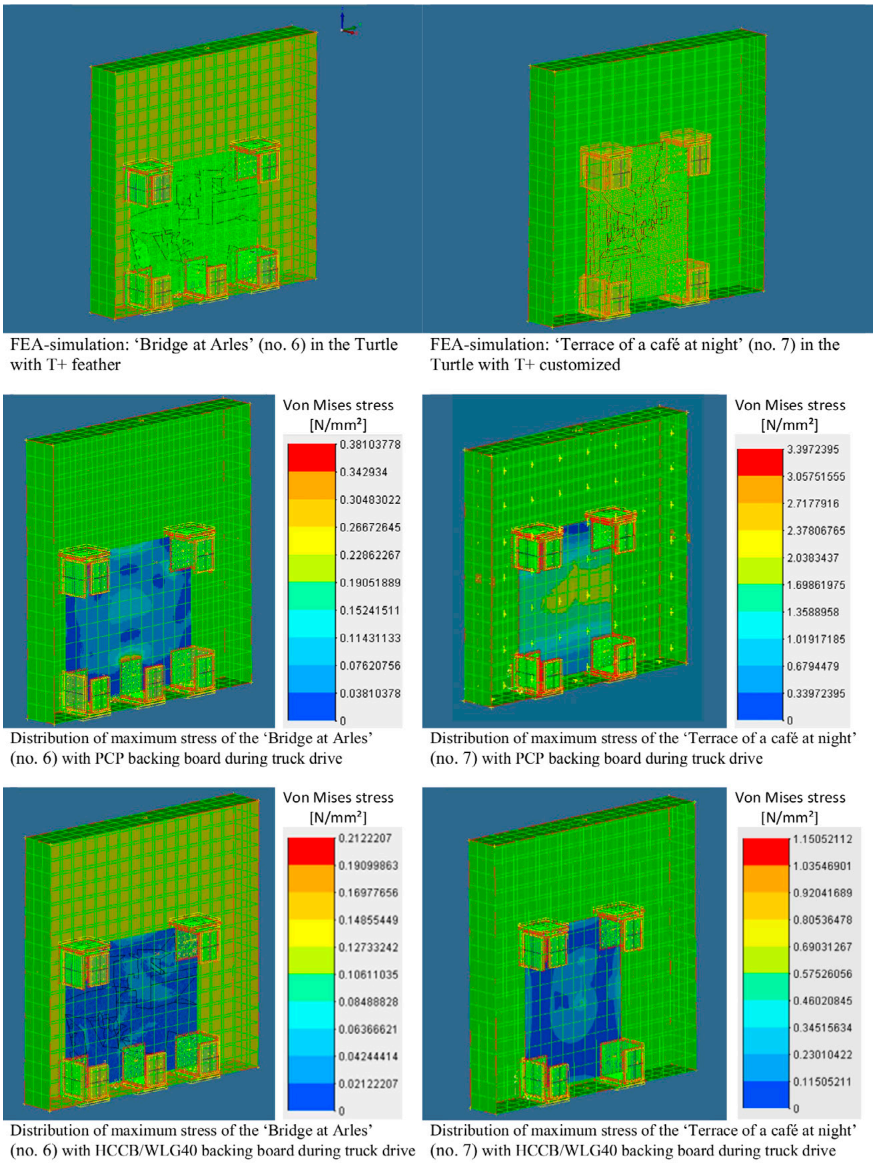


Figure 5. FEA study of maximum stress distribution during a truck drive with paintings nos. 6 and 7 in the TURTLE uNLtd with T+ holder blocks (no. 6: T+ feather; no. 7: T+ customised)

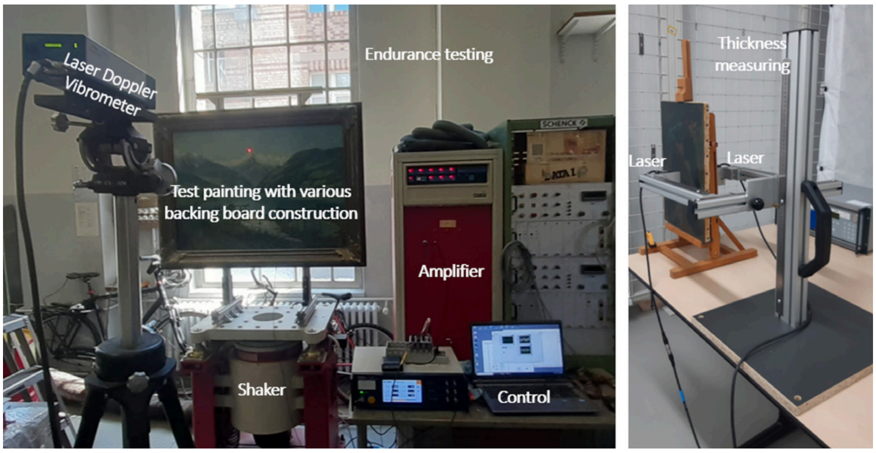


Figure 6. Left: endurance testing set up (TU Berlin); right: thickness measurement of the test and original paintings (KMM)

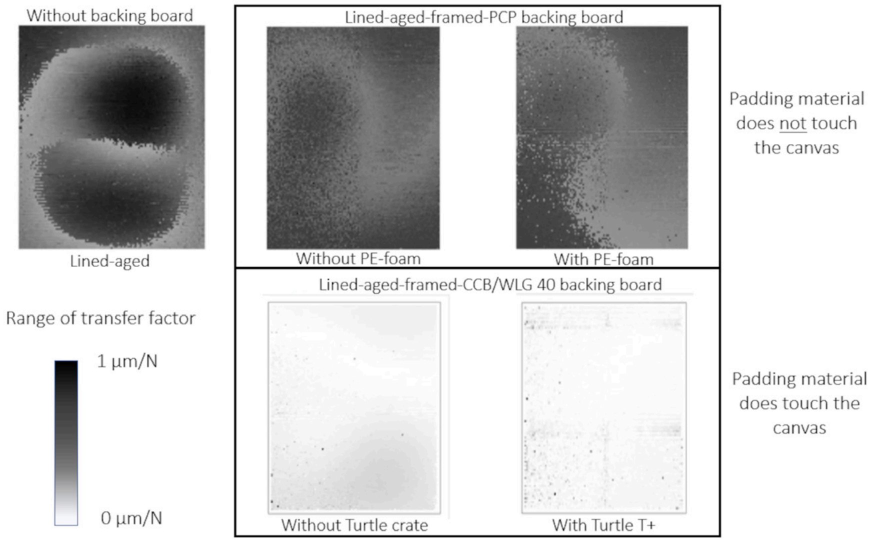


Figure 7. First characteristic vibration mode of painting no. 2 in different configurations: (above) with PCP backing-board without direct contact with the reverse of the canvas, and (below) with CCB/WLG40 backing-board with WLG40 touching the reverse of the canvas (without and with Turtle crate and T+ corner holders)

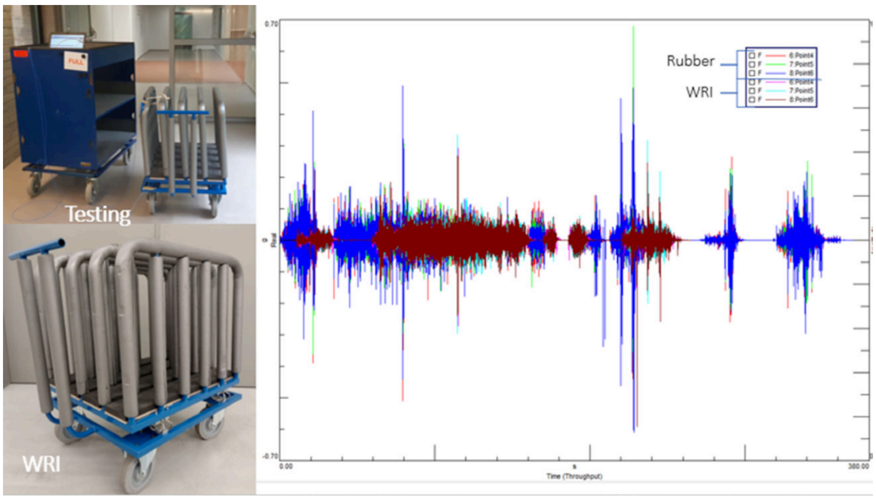


Figure 8. Upper and lower left images show the painting carts before and after replacement of the rubber connection with wire-rope isolators respectively. The graph on the right shows the excitation for both constructions

backing-board system tested, PCP reduced vibrations by 32% compared to the unframed painting without backing-board; the CCB/WLG40 system evidenced a 74% reduction.

The use of a TURTLE crate with the correct configuration of T+ holder blocks reduced the vibrations even further, by 96% compared to the unframed configuration, and with an input force greater than 1 N (Figure 4).

FEA modelling of the two most fragile van Gogh paintings (nos. 6 and 7) identified the most suitable combination of backing-board and crate. Figure 5 clearly shows that a 95% reduction in vibrations can be achieved by substituting the KMM backing-board system with that of HCCB/WLG40 backing-board in combination with the TURTLE crate and both types of T+ holder blocks. The example of painting no. 2 (Figure 7) shows the potential success of the interaction between the painting, backing-board construction, framing, crate and the mounting system in reducing vibrations.

Endurance testing

The transport simulation on the shaker showed that both sewing and self-adhesive Velcro enabled attachment of the acoustic fleece to the backing-boards, and that all tested types of acoustic fleece retained their shape and thickness. However, the smooth surface of WLG35 caused a loss of contact between the fleece and the canvas that in turn caused shocks during testing.

Improvements of the transport carts

Re-configuration of the transport carts using 6 WRI dampeners between the two frameworks reduced the vibrations to 10% of the initial value. The carts can support a cargo of up to 30 kg.

DISCUSSION

The results indicate that a broader range of padding material of different stiffnesses should be considered to reduce the vibrations imposed on paintings during their transport. Some paintings may require stiffer acoustic fleece. For example, painting no. 6 would benefit from a backing-board with a fleece that is slightly stiffer than WLG 035, but this type of fleece currently does not exist.

The honeycomb plates recommended as substitutes for the PCPs are far more hygroscopic. Investigation of an appropriate barrier foil or coating to protect the reverse of the cardboard plate is therefore recommended.

The self-adhesive used to mount the Velcro is still awaiting Oddy testing. Although the Velcro is not in direct contact with the painting, it is included in a closed environment for a long time.

(PRACTICAL) RECOMMENDATIONS

Although it would be desirable to assess each painting prior to the design of customised backing-boards, in practice this is not feasible for the 88 van Gogh paintings at the KMM. Additionally, few museums have continuous access to the required measuring equipment. It is therefore more realistic to provide guidelines based on the findings of this study:

1. The entire construction of the painting, the frame and its corresponding connections should be as rigid possible. Painting and frame need to act as a single stiff object. Flexible spring clips should not be used, but rather stiff metal strips, preferably screwed into the reverse of the stretcher or clamped tightly against it. Also, the configuration of the locations of the mounting strips needs to correspond to the 'node lines'[5] of the stretched canvas.
2. The use of a rigid backing-board consisting of honeycomb cardboard (HCCB, 8.3 mm) and suitable acoustic fleece (WLG40) must ensure that the fleece is placed against the reverse of the canvas and preferably between the reverse of the canvas and the stretcher bars, crossbars and keys.

3. Carts used for internal transport should be fitted with a customised configuration of WRIs in order to dampen vibrations during internal transport.
4. The use of crates with a customised configuration of T+ holder blocks containing WRIs will significantly reduce the shocks and vibrations caused by external transport.

CONCLUSION

This study provided practical recommendations to better protect the fragile, increasingly brittle, wax-resin-lined van Gogh paintings housed in the KMM against vibrations and shocks. This was the first quantitative study of the vibrational behaviour of the lined paintings and the results showed that the first natural frequency of the canvas was increased by the wax-resin lining, causing the canvas to become stiffer and less resistant to vibrations. While the current KMM backing-boards reduce shocks and vibrations to the wax-resin-lined canvases of the paintings, alternative backing-boards, consisting of a combination of corrugated or honeycomb cardboard with acoustic fleece, will provide even greater reductions. This improvement, when combined with appropriate packaging and crating for transport, such as the TURTLE crate and T+ holder blocks, will reduce vibrations and shocks by 96% compared to the initial value. The results of this study and the ensuing recommendations for backing-boards and crates can be used by other museums whose collections include wax-resin-lined paintings. This study therefore recommends that museum practitioners review current practices for backing-board and transport crate selection used in the transport of paintings going on loan.

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NOTES

[1] As hardly any information is available on when, by whom and how the KMM van Gogh paintings were wax-resin lined, a method and recipe representative of Dutch wax-resin linings in the first half of the 20th century was chosen: the lining canvas consisted of a linen canvas, the wax-resin mixture consisted of seven parts beeswax, four parts colophony resin and Venetian turpentine (ca. 3%–5% of the total mixture) (see Materials list). The wax-resin linings were applied with a hot iron by Pauline Marchand and Jolijn Schilder.

[2] From 6 April until 6 May 2022, the three lined test paintings, as well as samples of acoustic fleece WLG35/40/45 were artificially aged at the BFSV Verpackungsinstitut Hamburg GmbH, Germany. The paintings and acoustic fleece were subjected to alternating individual climate change cycles: +20°C ± 2°C/30% ± 5% RH (6 h), +20°C ± 2°C/85% ± 5% RH (6 h).

[3] Although this painting is not wax-resin lined, interest in its vibrational and shock behaviour was sparked by loan requests, which were previously denied due to the very fragile state of the paint adhesion.

[4] The transfer factor is the ratio between the response of the paintings measured by the laser and the excitation force measured by the force cell.

[5] Node lines are sections of the mode shapes of objects (paintings, frames, crates, etc.) where no motion occurs. Mode shapes correspond to the natural frequencies. Every mode shape has its own node lines.

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MATERIALS LIST

Belgian linen raw (305 g/m², thread counts 13.2 cm × 14.65 cm)
Beeswax (100%, natural, yellow)
Deffner & Johann GmbH
https://deffner-johann.de/en/

Book screws (white, nylon-6, M6 with lengths 25 and 36 mm)
https://essentracomponents.com
Caruso-Iso-Bond® Basstrap Absorber fleece plate (WLG 035, WLG 040, WLG 045 in 300 and 500 mm)
https://www.don-audio.com/

CAVOFLEX® Wire Rope Isolators, type SX 6-64-76-74
Willbrandt Gummitechnik KG, Hamburg, Germany
https://www.willbrandt.de/willbrandt/de/index.php

Colophony resin, Interlabshop B.V.
https://www.labshop.nl/

Corrugated cardboard (EB 4.5 (4.5 mm) and honeycomb cardboard (071, natural white, 8.3 mm)
Klug Conservation
https://www.klug-conservation.com/

Polycarbonate sheet (Marlon ST Longlife by Brett Martin: twinwall, clear, 4 mm thickness)
Witteburg, Rotterdam, The Netherlands
https://www.witteburg.nl/

Polycarbonate sheet (multiwall X5-16, clear, 16 mm thickness)
https://www.xxldirect.nl/

Polyethylene foam (Museum Art Foam 241)
https://www.innosell.com/

TURTLE® uNLtd crate and T+ holder blocks
https://turtlebox.com/en/ (via https://hizkia.com/)

Velcro (self-adhesive Velcro with acrylic glue layer 50 mm)
https://klittenbandwinkel.nl/

Venetian turpentine
Stock supply by conservation studio Pauline Marchand
Rotterdam, The Netherlands
https://www.marchand-schilderijenrestauratie.nl/

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