VIBRATION AND CONSERVATION

International Symposium, 7 and 8 November 2024, Paris, France

Organized by the Vibration & Conservation Consortium, coordinated and held by the French National Institute for Heritage

Vibratory impacts of music and transport on museum collections

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[3] *Bickerdike Allen Partners, London, UK*

[4] *Formerly Cultural Heritage Agency of the Netherland, Amsterdam, The Netherlands*

[5] *Mildred Lane Kemper Art Museum, St Louis, Missouri, USA*

[6] *The Field Museum, Chicago, Illinois*

** This short-format presentation will be given by Arne Johnson on behalf of the full research group.*

As museums and other heritage organizations seek to use their collections and buildings in ways never previously considered to engage audiences and raise income, this often has the unintended consequence of increasing vibration exposure, e.g. increased loan transportation, proximity to construction works or accommodating musical or loud noise events near collections. There is thus a very real and urgent need within the heritage sector to improve understanding of the impact on collections of repeated exposure to vibration and how to minimise the associated risk. While approaches to safeguard museum collections from construction vibration has been relatively well studied in recent times, the potential impact of sound-induced vibration is less understood. In addition, new questions are being raised about the potential impact of vibrations experienced during transportation.

To help shape and inform future research in relation to the impact of vibration from music and transportation on museum collections, a research questionnaire was developed by an international research group of museum professionals and engineers [1,2]. This short-format presentation will reference the key findings from this questionnaire and provide an update on progress and outcomes. One of those outcomes, a "Good practice guide for musical events" is targeted for publication by a subset of the research group in late-2024; it is intended that the guide will be regularly updated as new research findings become available.

Research and development for the guide has included: a pilot study in an anechoic chamber to measure the degree to which direct sound pressure from music can cause vibration of paintings [3]; sound and vibration measurements at various museums during musical and loud noise events [4]; and development and pilot implementation of real-time monitoring methods using laser vibrometers, sound meters and wireless accelerometers with customized software. The good practice guide will address the following topics:

- Principles and testing of the interaction of sound with objects, differentiating three source-to-

object paths (air-borne, structure-borne, and structure-borne via supports) and how these vary when the sound source is in the same space as objects and when it is outside or in adjacent spaces [Figure 1]

- Limits and criteria to consider, referencing previously published technical works and drawing on the authors' experiences and research, recognizing that effects from vibration and sound exposure are highly likely to be cumulative
- Monitoring and measurement methods, with recommendations for when monitoring during musical events is prudent; and when it is needed, what specific monitoring methodologies can be followed to more effectively limit and manage the effects on collections
- Practical guidance and approaches that cultural heritage institutions can take, starting at the event planning stage, mitigation options at the source or at the objects, and specific guidance relative to cases where the sound source is in the same space as objects and when it is outside or in adjacent spaces

By sharing information about this initiative, it is hoped that other museum professionals, engineers and researchers will receive useful guidance and that others will provide input to develop further guidelines defining best practice for the heritage sector in relation to the vibratory impacts of music and transport on museum collections.

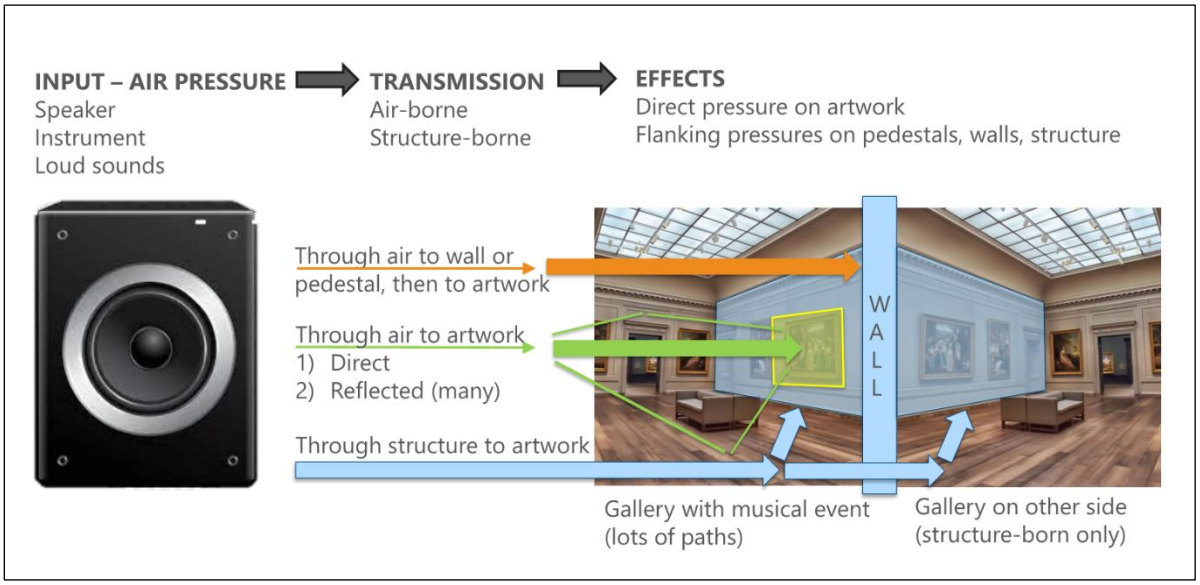

Figure 1. Simplified illustration of three potential vibration paths to art objects during a musical event. Figure taken from [4]; see [3] for a similar illustration.

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[1] *Vibratory Impacts of Music and Transport on Museum Collections: Research Questionnaire Report*. WJE, 2022. https://online.flippingbook.com/view/1044278564/

[2] Webinar: *Findings of Research Questionnaire on Vibratory Impacts of Music and Transport on Museum Collections*, 2023. https://www.wje.com/knowledge/webinars/detail/findings-of-research-questionnaire-on-vibratory-impacts-of-music-and-transport-on-museum-collections

[3] *The Art of Noise: Investigating the Impact of the Hidden Threat of Sound on Artworks.* Catherine Higgitt, Tomasz Galikowski, David Trew. IIC News in Conservation, Issue 102, June-July 2024. https://www.iiconservation.org/publications/nic/news-conservation-issue-102-june-july-2024

[4] *Vibrations and Museum Collections - Part 2: The Effects of Vibrations from Musical Events and Transportation.* Arne Johnson and Mohamed ElBatanouny. Papyrus, November 2023. https://www.wje.com/knowledge/articles/detail/vibrations-and-museum-collections-part-2

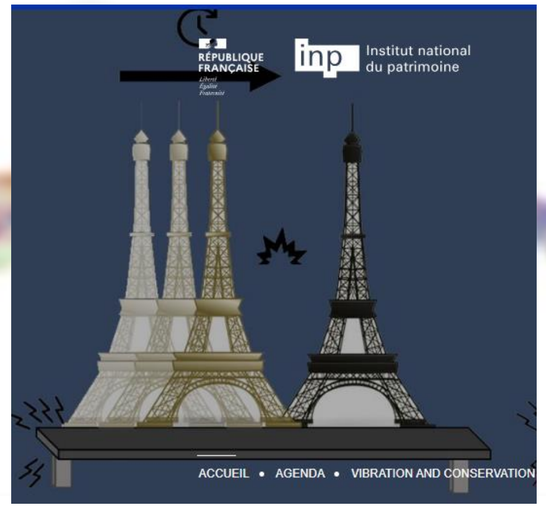
Mr. Arne Johnson is a Principal Structural Engineer with Wiss, Janney, Elstner Associates, Inc. (WJE) in Chicago, Illinois, USA. He holds a BS in Civil Engineering from the University of Illinois Urbana-Champaign and a MS in Structural Engineering from the University of California, Berkeley. In his 35-year career at WJE, Mr. Johnson has specialized in the forensic evaluation, testing, monitoring, and repair of structures of all types, especially museums and cultural heritage institutions. Mr. Johnson has practiced and published widely on the management of vibrations during museum construction projects. He has served as vibration expert for over two dozen museums and historic sites in the U.S. over the past two decades. His recent clients include the Art Institute of Chicago, the Field Museum in Chicago, the Portland Art Museum in Portland, Oregon, the Neue Galerie New York, the Saint Louis Art Museum, and the Baltimore Museum of Art. In the past few years, he has researched the vibratory effects of musical events and transportation on museum collections along with an international team of experts, several of whom are here at this colloquium. Among his other publications, Mr. Johnson is principal author of “Vibration Control During Museum Construction Projects” (JAIC 2013), “Vibration Limits for Historic Buildings and Art Collections” (APT 2015), “The Effects of Vibrations from Human Traffic and Construction on Museum Collections (IAMFA Papyrus 2019), “Vibration Mitigation and Sound Testing in SUE Hall at the Field Museum in Chicago” (APT 2020), and “The Effects of Vibrations from Musical Events and Transportation on Museum Collections” (IAMFA Papyrus 2023).

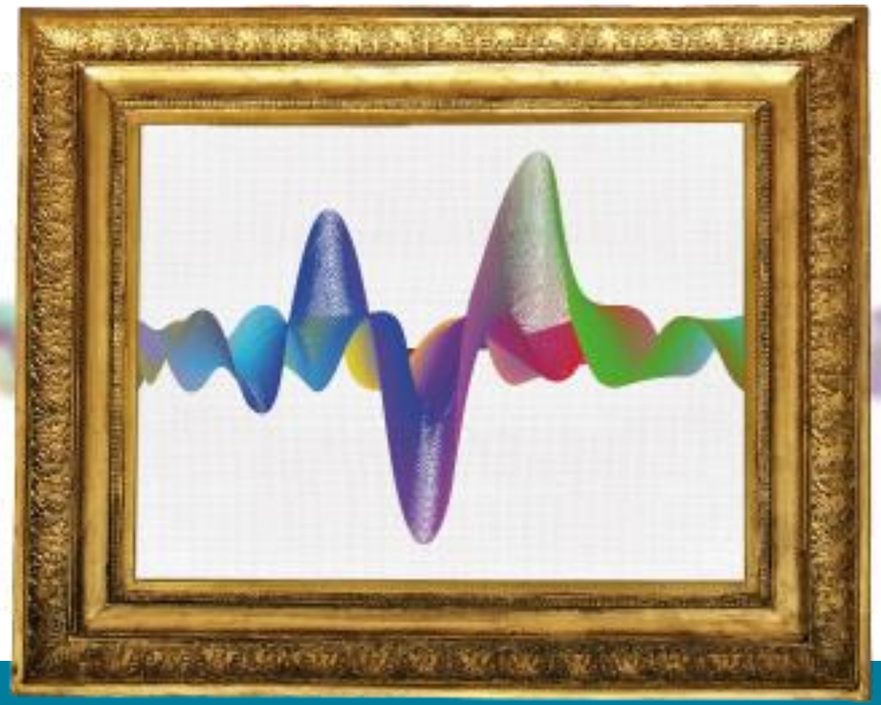
VIBRATION AND CONSERVATION

Vibratory Impacts of Musical Events (and Transport) on Museum Collections

Arne Johnson, WJE (Chicago, USA)

November 7, 2024





Research Questionnaire (2020-2023)

Vibratory Impacts of Music and Transport on Museum Collections: Current Practices and Experiences

International Research Group Questionnaire

A RESEARCH QUESTIONNAIRE SUPPORTED BY

- Association of Registrars and Collections Specialists (ARCS)
- American Institute for Conservation (AIC)
- International Institute for Conservation (IIC)
- International Council of Museums Conservation Committee (ICOM-CC) Working Groups

INTERNATIONAL RESEARCH GROUP MEMBERS

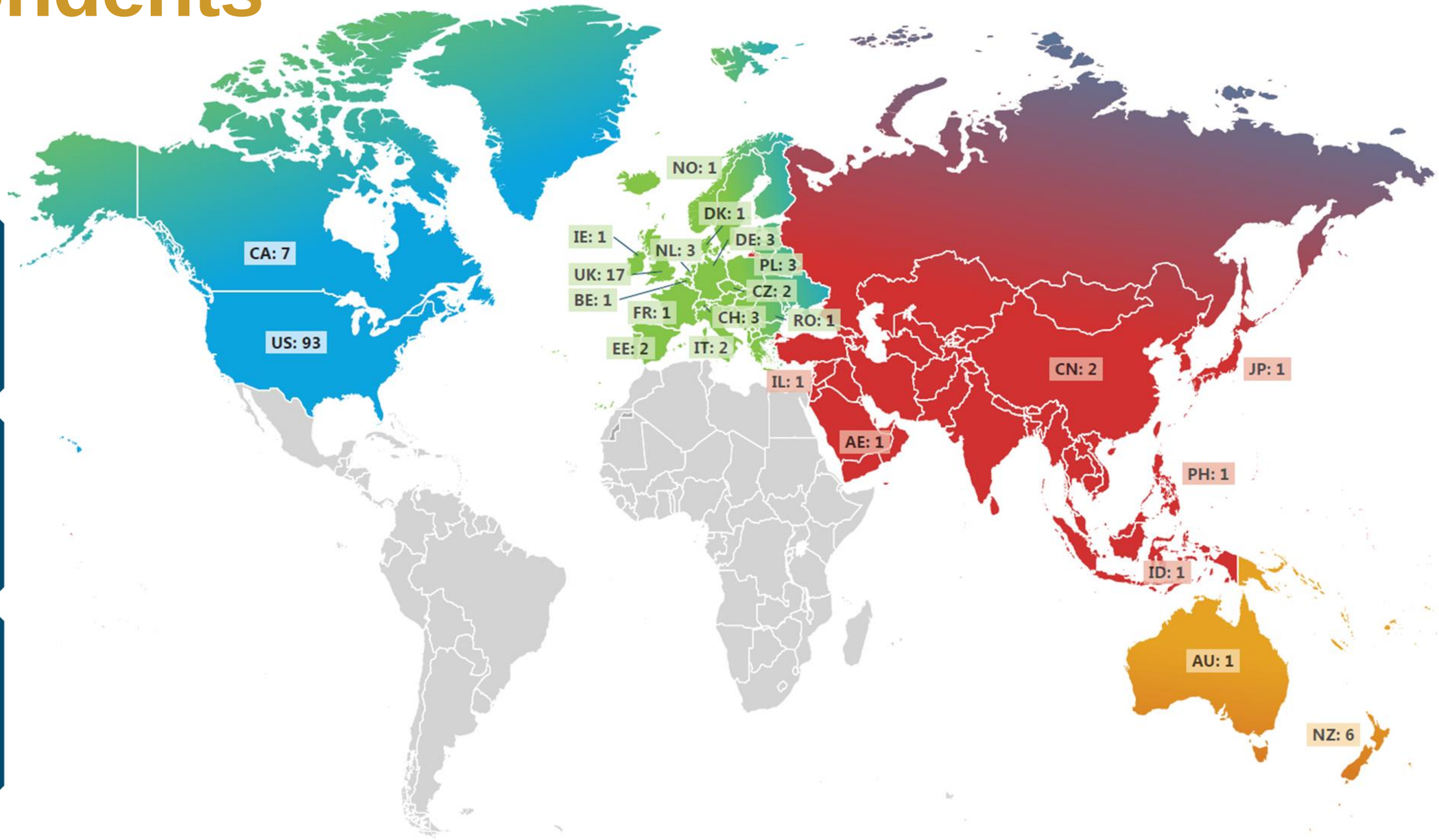
- Dr. Catherine Higgitt, Principal Scientist, Scientific Department, National Gallery London
- Arne Johnson, Principal Structural Engineer, and Dr. Mohamed ElBatanouny, Senior Structural Engineer, Wiss, Janney, Elstner Associates, Northbrook, Illinois
- Dr. W. (Bill) Wei, Senior Conservation Scientist, Cultural Heritage Agency of the Netherlands (RCE)
- Mark Ryan, Assistant Director for Collections & Exhibitions, Mildred Lane Kemper Art Museum, St. Louis, Missouri
- J.P. Brown, Regenstein Conservator, The Field Museum, Chicago, Illinois
- Tomasz Galikowski, Associate Acoustic Engineer, and Peter Henson, Practice Consultant, Bickerdike Allen Partners, London

Respondents

155
Respondents

138
Museums

24
Countries



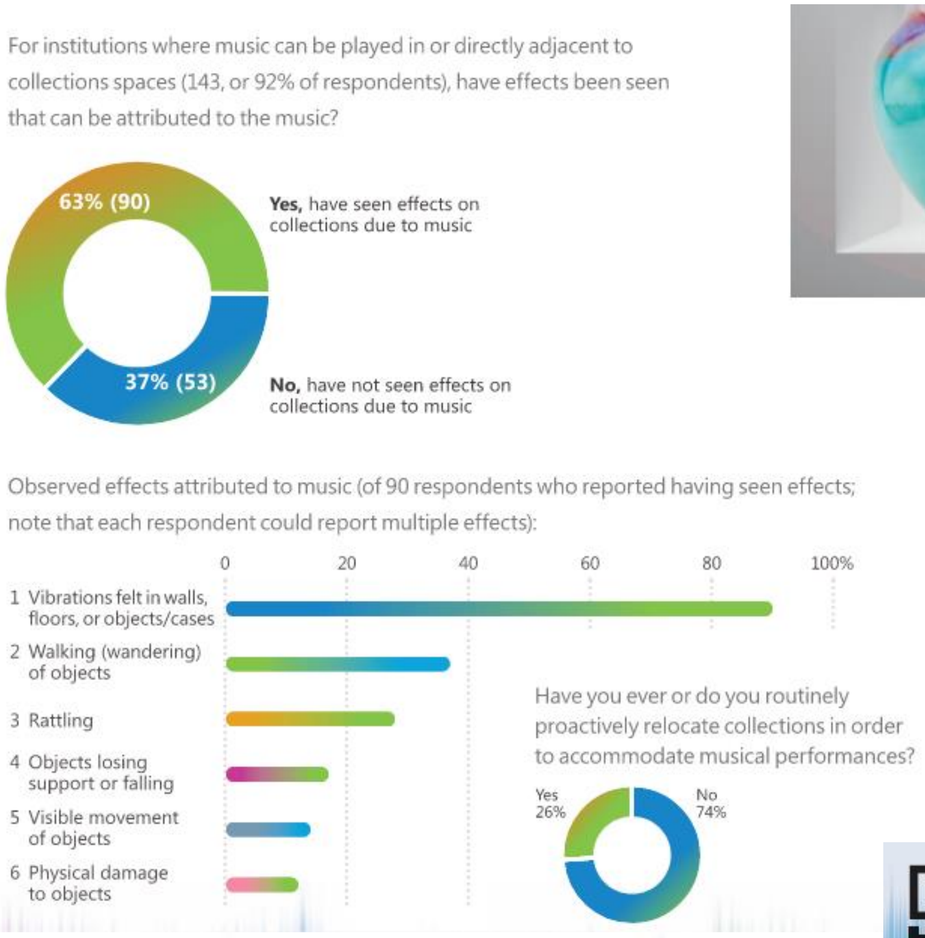
RESEARCH QUESTIONNAIRE FINDINGS

Vibratory Impacts of Music and Transport on Museum Collections

October 2022

Report of findings Oct 2022
Webinar explaining report April 2023

Reported Effects from Music on Collections



- 63% who permit music have seen effects on collections
- Of effects reported:
  - Vibrations felt 89%
  - Walking (wandering) 37%
  - Rattling 29%
  - Physical effects 12-18%

Report of findings
Webinar explaining report

p. 21 of report

Review of Vibratory Effects of Music

Severity of effects reported during musical events:

- None or mild – 67%
- Moderate – 19%
- Substantial – 14%

National Gallery London

Report of findings
Webinar explaining report

Review of Vibratory Effects of Music

Severity of effects reported during musical events:

- None or mild – 67%
- Moderate – 19%
- Substantial – 14%

} 33%

Art Institute of Chicago

Report of findings
Webinar explaining report

Review of Vibratory Effects of Music

Factors that did not appear to be correlated with effects from music:

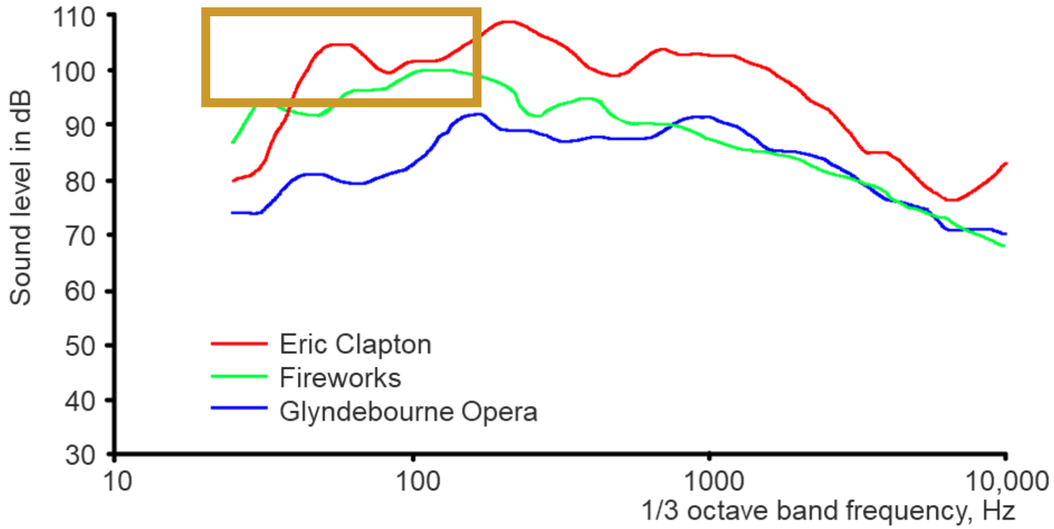
- Whether a decibel limit is used or not
- Magnitude of any decibel limit
- Restrictions, distance
- Current practices largely ineffective to avoid effects

Report of findings
Webinar explaining report

Review of Vibratory Effects of Music

Factors correlated with effects from music:

- Type of music allowed – worst effects from music with more bass and percussion
- Regularity of musical events
- EQ parameters or filters on speakers



Report of findings
Webinar explaining report

Taken from Gibb et al., 'Shake, Rattle and Roll: Vibration Effects at the Hampton Court Music Festival', in *Conservation Science*, pp. 36 – 39, Milan, 2007

Future Research and Initiatives

Table 1. Future research topics and initiatives based on input from participants of April 2023 webinar "Vibratory Impacts of Musical Events and Transport on Museum Collections"

Topic/initiative	Involved individual(s)	Actions underway or planned
Vibration: technical issues and future research		
1. Perform further research on cumulative effects of vibrations on museum and cultural heritage objects; perhaps create vibration limits for different objects and exposure conditions	Bill Wei Input from others is welcome	Bill led a workshop in Amersfoort, NE on 11/30/2023 where he presented his most recent findings. A recording of the workshop will be available online. Bill's research is ongoing; he will present further results at the 2024 AIC annual meeting in Salt Lake City.
2. Perform further studies on mitigation/isolation strategies at the object level	Various	Reference study for mitigation/isolation of paintings by Catherine Higgitt and Tom Galikowski published in IIC 2020. Other studies are available in the literature or are forthcoming.
3. Explain and explore standardization of which measurement units, types of equipment and associated limits are appropriate for different conditions (acceleration, velocity, peak, rms, etc.)	Various	See "good practice guide" below to include bibliography of existing literature on this topic
4. Form working group(s) to look at various vibration-related topics and/or create reposit… of related technical literature		See actions under other items for progress to date
Transportation		
5. Organize the next "Art in Transit… address current topics in packing m… design, etc. (perhaps create reposi… technical literature, e.g., recent or … publications from various institutio… mentioned in the responses to this…		

12/28/2023

Topic/initiative	Involved individual(s)	Actions underway or planned
6. Develop a list of transport monitoring devices that have sufficient battery life, memory capacity, and functionality to meaningfully measure vibrations as well as shock; encourage development of new, better devices for this use		This is one potential outcome of Item 5
7. Perform further studies on transport of collection objects inside the building, such as on carts and dollies		This is one potential outcome of Item 5
Musical and other "loud" events		
8. Develop a "good practice guide" for musical events, including effects of music both inside and outside the building, fireworks, car races, etc. Make usable by both large and small institutions.	Arne Johnson Catherine Higgitt Tom Galikowski Mohamed ElBatanouny Input from others is welcome	This group will publish a "good practice guide" in the form of a white paper by Spring-Summer 2024 (with future updates being released as needed) giving input for museums in these general categories: 1 – Practical guides/mitigations for musical sources, objects, event spaces 2 – Sound interaction with canvas/object 3 – Approaches to monitoring/measurement during musical events and evaluation of limits/criteria

Musical and other "loud" events

8. Develop a "good practice guide" for musical events, including effects of music both inside and outside the building, fireworks, car races, etc. Make usable by both large and small institutions.

Arne Johnson
Catherine Higgitt
Tom Galikowski
Mohamed ElBatanouny
Input from others is welcome

GOOD PRACTICE GUIDE

Musical and Loud Noise Events at Museums

Coming Soon!

ARNE JOHNSON AND MOHAMED ELBATANOUNY, WJE
CATHERINE HIGGITT, NATIONAL GALLERY LONDON
TOMASZ GALIKOWSKI, BICKERDYKE ALLEN PARTNERS, LONDON

February 2025

SECTION 4

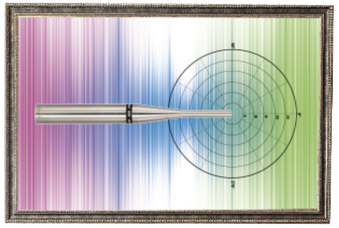
Monitoring and Measurements During Events

4.1 Introduction – What Causes Damage to Objects and Can One Monitor to Avoid It?

Stress, typically measured in force per cross-sectional area of a material, is the mechanical factor that can cause damage to a material. The stress magnitude at which damage may occur depends on the material type, material condition, and the number of stress cycles. Put simply, stress is caused by displacement (movement) of a material when the material is restrained in some manner (e.g., movement of a painting canvas restrained around its perimeter or movement of a three-dimensional object restrained by its mounts).

In structural applications, stress in a material is often measured by affixing strain gauges or other similar devices to a material. However, such direct measurement of stress is typically not practical for museum collection objects. As a result, some indirect measurements are necessary. In some special cases, non-contact measurement of the displacement or vibration of the object surface can be made using special equipment like laser vibrometers. However, such techniques require expensive equipment and use of lasers in the gallery space. (Advances in high resolution digital imagery may at some point allow accurate non-contact imaging for this purpose.)

More commonly in a museum environment, vibration or displacement measurements are taken on surfaces immediately adjacent to the objects, such as on frames, adjacent wall surfaces, platforms, pedestals or showcases. Such vibration measurements may be interpreted to infer vibration, displacement, and stress levels in the object itself, although such inferences are approximate. Recent research and practice have used advanced analysis and testing to more accurately predict object response and correlate object response with measurements on adjacent surfaces.[1]



Indirect damage of objects may also occur due to resonant-like effects in the objects, which can occur due to continuous (sustained) vibration input but rarely from transient (impact-type) vibrations. Resonance or dynamic amplification can occur when the

[1] Jorge paper on Oxford research and Kirsten Krecht paper on finite element modeling.

frequency of a steady-state or pseudo-steady-state input matches or nearly matches the natural frequency of the object or a portion of the object. Continuous vibrations can be caused by sustained music or noise as well as by sustained mechanical inputs like vibratory pile driving, vibratory soil compaction, or reciprocating machinery. Resonant-like effects include walking (horizontal traveling) of objects, especially light objects on smooth shelves; indirect damage can occur if walking results in objects losing support (such as falling off shelves). Resonant-like effects may also include excessive movement (shaking) of objects or objects projections; indirect damage can occur if the excessive movement leads to object instability (e.g., toppling) or high stress levels (e.g., at the base of slender projections of three-dimensional objects).

Screen capture from NASCAR Cup Series race, showing lead cars approaching The Art Institute of Chicago (arrow). Source: https://www.youtube.com/watch?v=pjJGWREWSTA.

Rigorous research into these effects is challenging since vibration inputs will affect different objects in different ways and to different degrees due to a wide range of variables. These include many different object types, countless object geometries, a wide range of pre-existing conditions, different types of vibration inputs, different building and object display types, and so on. Considering these complexities, simplifications and conservative assumptions are needed in the development and implementation of monitoring approaches that are both practical and effective to limit adverse effects in collections.

4.2 Monitoring for Structure-Borne Vibrations (Such as from Construction)

For ground- and structure-borne vibrations, such as those caused by construction, practical monitoring solutions to protect museum collections have been published and implemented.[2,3] In these cases, monitoring normally involves installing vibration monitors between the vibration source and the objects, and then enforcing a vibration limit at the monitors. Vibrations in the objects, which are farther away from the source than the monitors, are typically similar to or less than the levels at the monitors. In this manner, the monitors "intercept" the structure-borne vibrations along their path and serve as a "fuse" in the system. Monitors are normally placed on floors near walls or at other "hard spots" in the building, and allowable vibration limits have been adopted based on testing and practice.[4]

Unlike construction vibrations that are solely structure-borne, musical and loud noise events produce both structure-borne vibrations and air-borne vibrations in the form of sound pressures (see previous discussion in this guide about the three paths for vibrations to travel from a sound source). Sound pressures may travel directly from the sound source to the objects or flanking surfaces and cause vibration of the objects. Typically the vibrations caused by direct sound pressures are very small and insignificant, but in some circumstances they may be significant and need to be considered. As such, an effective monitoring method for musical and loud noise events needs to consider the air-borne vibration (direct sound pressure) component.

[2] Galikowski and Higgitt from the UK have used...[footnote]
[3] Johnson et al. from the US have typically used a limit of 0.08 to 0.12 in/sec PPV depending on project circumstances for primarily transient vibrations, and a lower limit based on site-specific testing if vibrations are continuous and thus have the potential to cause resonant-like effects such as walking or resonant shaking of objects. [footnote]
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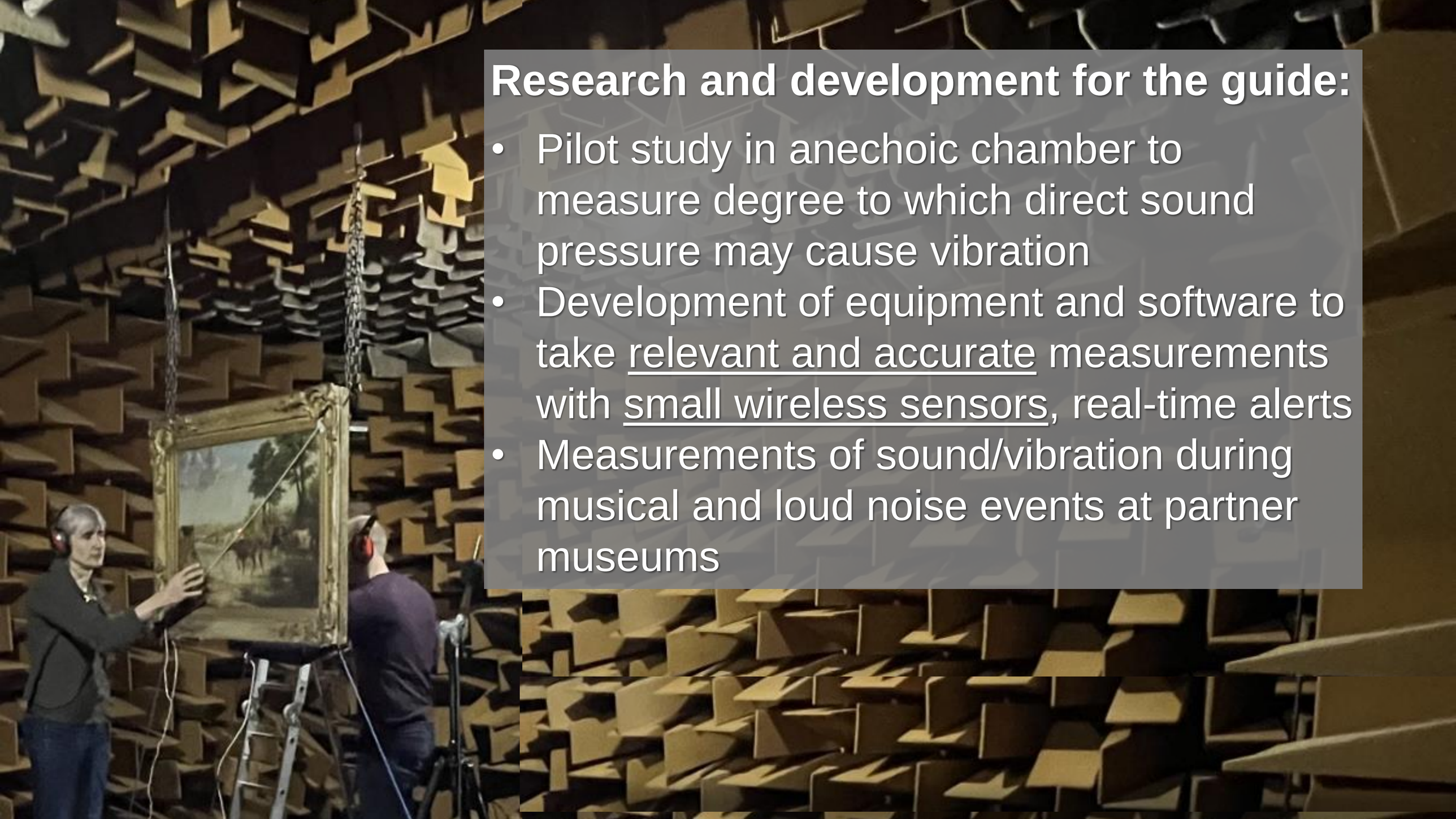

Research and development for the guide:

- Pilot study in anechoic chamber to measure degree to which direct sound pressure may cause vibration
- Development of equipment and software to take relevant and accurate measurements with small wireless sensors, real-time alerts
- Measurements of sound/vibration during musical and loud noise events at partner museums

Outline:

1. Introduction
2. Sound interaction with canvas/object
3. Limits and criteria
4. Monitoring and measurements during events
5. Practical guidance and mitigation approaches
6. Literature and useful resources
7. Glossary of terms

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Indirect damage of objects may also occur due to resonant-like effects in the objects, which can occur due to continuous (sustained) vibration input but rarely from transient (impact-type) vibrations. Resonance or dynamic amplification can occur when the

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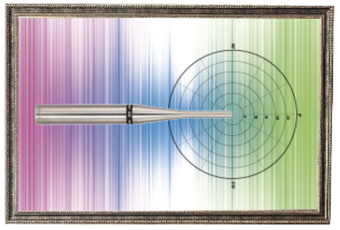

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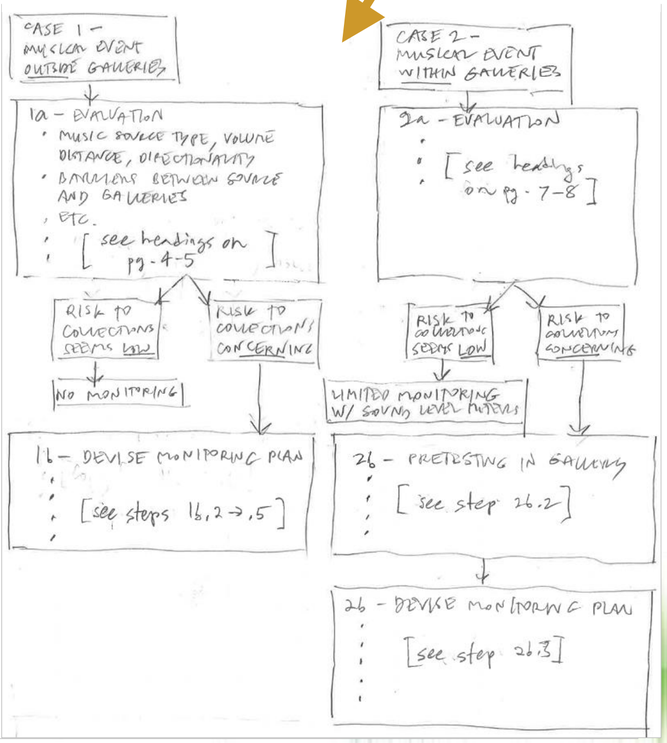
Decision-Making Flowchart



Vibration Control for Museums: During Musical and Loud Noise Events

Sound/Vibration Testing for SUE at the Field Museum

Thank you

Arne Johnson
ajohnson@wje.com

Scan for more info or go to wje.com/museums

WJE

Video demonstration of monitoring equipment

Thank you

Arne Johnson
ajohnson@wje.com

Scan for more info or go to wje.com/museums

We've learned so much about *T. rex* in the last hundred years,

Hemos aprendido mucho sobre los T. rex en los últimos cien años,

© Field Museum of Natural Hist
Photo by John Weinstein

Vibration Control for Museums: During Musical and Loud Noise Events

Sound/Vibration Testing for SUE at the Field Museum