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Editorial

Nancy Workshop 2023 on Hand-Transmitted Shock and High-Frequency Vibration

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Abstract: Since its initial publication in 1986, ISO 5439 has been unclear on the evaluation of isolated and repeated shock vibration. In 2015, an expert's workshop was held in conjunction with the 13th International Conference that identified features of a vibration signal that may be important for predicting health outcomes, including high-frequency vibration and shock. Since then, ISO standards have been drafted on the measurement of shock and measurement of high-frequency vibrations, and in the European Union, a proposed revision of machinery supply legislation will require manufacturers to provide information on the average peak amplitude of acceleration. The Nancy Workshop introduced the issue of hand-transmitted (mechanical) shock (HTS) and work currently active within International Standards groups, and discussed options for defining HTS measurement. The workshop concluded that HTS is likely to present different risks to those of continuous hand–arm vibration, and that, therefore, there is a need for different metrics, and that high-frequency vibration is an important component of many HTS sources, e.g., impact wrenches, nail guns, riveting hammers, etc.; therefore, HTS evaluation should include higher frequencies of vibration, possibly up to 10 kHz.

Keywords: hand-transmitted; vibration; shock; isolated-shock; continuous-shock

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1. Introduction

Since its initial publication in 1986, ISO 5439 [1] has been unclear on the evaluation of isolated and repeated shock vibration. In the current version of ISO 5349-1:2001 [2] the scope notes: "*The time dependency for human response to repeated shocks is not fully known. Application of this part of ISO 5349 for such vibration is to be made with caution*".

To be useful, any measurement or study methodology must be capable of the reliable quantification of a parameter related to risk. The effective quantification of risk relies on a measurement metric targeted at a well-understood damage mechanism or injury type. Standard ISO/TS 15694:2004 [3] provides potential metrics for single shocks, but there is currently neither a preferred metric, nor any accepted relationship between a specific metric and a health outcome.

1.1. Expert's Workshop, 2015—Beijing

In 2015, an expert's workshop was held in conjunction with the 13th International Conference on Hand–Arm Vibration in Beijing [4]. That workshop reviewed some of the issues that created the current uncertainty about the approach to the evaluation of shock hand–arm vibration and discussed some of the implications for control of vibration risks and development of low-vibration-risk machinery.

The expert workshop identified features of a vibration signal that may be important for predicting health outcomes. Very high frequency vibration was believed to have the potential to cause damage, although the practicalities of reliable measurement of such signals were not discussed at that time. Other parameters, such as impact force and energy entering the hand–arm system may also be influential. The use of high-speed video and measurement at the wrist were suggested as ways of assessing shock vibration.

1.2. Activities within International Standards

Since 2015, ISO TC 108 SC 4 "Human exposure to mechanical vibration and shock" has considered issues around hand-transmitted shock and high-frequency vibrations. Two Technical Specifications are currently being developed related to hand-transmitted shock and high-frequency hand–arm vibration. The work on these standards will be introduced in the workshop.

1.3. EU Machinery Directive

Recently, the EU Regulation 2023/1230 [5], a revision of the European Union (EU) Directive 2006/42/EC, has introduced a new requirement for the declaration of hand–arm vibration emission: "*the mean value of the* ***peak amplitude of the acceleration from repeated shock vibrations****, to which the hand-arm system is subjected*".

This requirement for declaration of peak amplitude of hand–arm vibration means that in the EU, a definition is required for a suitable metric of peak amplitude measurement.

2. Nancy Workshop Structure and Objectives

In the Nancy Workshop, the issue of hand-transmitted shock (HTS) and the work currently active within International Standards groups was introduced, with presentations from the workshop's organisers on the:

- health effects of high-frequency vibrations, Appendix B;
- physics of shock vibration and physiological effects on the biological system [6];
- relationships between exposures and health effects; [7] and
- current activity in ISO on HTS [8].

Following the last presentation, there were presentations on the experience of three groups who had recently been assessing the measurement of HTS to high frequencies. Summaries of these presentation are given in Appendix A.

The programme was structured in two parts, the first introduced questions relating to health effects and epidemiology, the second looked at what is needed from International Standards. Following each of these parts there were breakout sessions, where delegates were asked to consider specific questions on the topics and report back to the workshop.

In the first breakout session, on health effects and epidemiology, the questions were:

Q1.1 Do we accept that the health effects due to exposure to shocks are the same as those from continuous vibration?
Q1.2 Is ISO 5349-1 and the A(8) metric suitable for predicting the risks of health effects from HTS?
Q1.3 Do we need a new metric specifically for HTS?

The second breakout session asked:

Q2.1 Should we be looking at frequencies greater that 1250 Hz?
Q2.2 What is the upper frequency limit (5 k, 10 k, 50 k . . .)?
Q2.3 What are the measurement challenges for that upper frequency?
Q2.4 Do we need a time-domain metric? If so what metric?

The principal objective of the workshop was to achieve a consensus view amongst experts on the metric most suited HTS evaluation. In doing that, it was important to consider the measurement domain (frequency or time), frequency range, measurement parameter(s), and any required supplementary information.

At the end of the workshop, the organisers tried to summarise the reports back from the table rapporteurs as a series of workshop outcomes.

The response by the German National Committee on ISO TC 108 SC 4 WG 3 to a request for comments on a draft of this document is appended as Appendix C.

3. Workshop Delegates

There were 40 workshop delegates from eleven countries. All delegates had attended the 15th International Conference on Hand–Arm Vibration, and so had significant professional interest in hand–arm vibration. The delegates were divided into five groups for the breakout discussions. Table 1 shows, for each breakout table, the countries from which their delegates came.

Table 1. Breakout tables—distribution of delegate countries.

Country	Table 1	Table 2	Table 3	Table 4	Table 5	Total
Canada		3				3
China			1			1
France	1	1	2		3	7
Germany	1	1	2	2	3	9
Italy	2	1				3
Japan	1				1	2
Netherlands				1		1
Sweden	2	3	2	1	1	9
Switzerland		1				1
UK	1			2		3
USA				1		1
Totals	8	10	7	7	8	40

Each table included two facilitators who were asked to try to keep discussions focused on the questions and ensure there was a record of the outcomes of those discussions for reporting back to the full workshop. The facilitators were all themselves technical specialists who were free to contribute to the discussions. One facilitator on each table was a member of the ISO hand–arm vibration working group, so had knowledge of the discussions and developments in that group.

The four workshop organisers (one from the UK, two from Sweden, and one from Canada) did not join the breakout sessions, but were available to answer questions.

4. Workshop Outcomes—Summary at the Workshop by the Organisers

Based on the summaries delivered by the rapporteurs from the five groups, the workshop organisers summarised the overall responses to the seven questions as a series of outcomes.

Question 1.1 Do we accept that the health effects due to exposure to shocks are the same as those from continuous vibration?

The consensus of the workshop groups did not support the statement that the health effects are the same as from continuous vibration. The strength of the outcome was not completely clear as 56% either disagreed or partly disagreed while 44% partly agreed (no one agreed with the statement).

The submitted comments from the tables showed that the main feeling was that there is a lack of knowledge in this area, with many commenting that more research is needed.

Outcome #1: The health effects from exposure hand-transmitted shocks (HTS) are not the same as exposure to continuous vibration.

Question 1.2 Is ISO 5349-1 and the A(8) metric suitable for predicting the risks of health effects from HTS?

There was a substantial majority disagreeing with the statement that ISO 5349-1 and the A(8) metric are suitable for predicting health risks from HTS.

Outcome #2: A(8) is not appropriate for predicting the risk of health effects from exposure to shock vibration.

Question 1.3 Do we need a new metrics specifically for HTS?

There was a substantial majority supporting the statement that there is a need for a new metric specifically for HTS. There were no votes disagreeing with the statement.

Outcome #3: There is a need for a new metric for hand-transmitted shocks.

Question 2.1 Should we be looking at frequencies greater that 1250 Hz?

There was a substantial majority supporting the statement that we should be looking at frequencies greater than 1250 Hz. There were two votes against the statement, and the comment attached to one of those suggested that the investigation of higher frequencies should be limited to research.

Outcome #4: It was agreed there is a value in looking at frequencies greater than 1250 Hz.

Question 2.2 What is the upper frequency limit (5 k, 10 k, 50 k . . .)?

The workshop groups all appeared to accept that measurement up to 10 kHz was reasonable. Some expressed concern that higher frequencies increase the challenges of measurement, and some preferred to limit measurement to lower frequency ranges, while others were happy to go to frequencies greater than 10 kHz. Some commented that the upper frequency may depend on the application or machine.

Outcome #5: There was no consensus, though 10 kHz was considered to be a reasonable frequency limit and may depend on the application.

Question 2.3 What are the measurement challenges for that upper frequency?

The groups expressed concerns regarding transducers, mounting, calibration, reproducibility, and other data handling issues.

Outcome #6: There are challenges including sensor mounting (resonances), calibration, repeatability, and quantity of data.

Question 2.4 Do we need a time-domain metric? If so, what metric?

While there was general support for a new metric for HTS shock, the objective of the first part of this question was unclear to the workshop groups, so discussions tended to be focussed on the second part, "*if so which metric?*".

The VPM and peak count were highlighted by some groups.

Outcome #7: Some groups struggled with the interpretation of the question. VPM was considered a reasonable metric by some groups, as well as determining the number of shocks.

5. Detailed Outcomes—Based on Post Workshop Analysis

Following the workshop, the notes or spreadsheets from the table rapporteurs have been collated and summarised in Tables 2–7. In these tables, the rough comments recorded by rapporteurs in the workshop have been corrected for spelling and other clear grammatic errors and to anonymise the contributions, but the adjustments are minimal to ensure that the intended meaning is not changed.

Question 1.1 Do we accept that the health effects due to exposure to shocks are the same as those from continuous vibration?

Four out of the five tables recorded individual voting on this question (based on the commentary, one table appeared to have answered the negative question, i.e., "is shock different", rather than "is shock the same". The voting results have been adjusted accordingly, but the actual effect on the results is minor):

Disagree	Partly Disagree	Partly Agree	Agree	Number Voting
28%	28%	44%	0%	32

The fifth table's written commentary stated that based on current information, the health effects are seen to be similar, but that there appear to be different responses with the time of exposure which suggests unknown damage mechanisms. This suggests that this group is broadly aligned with the general response of the other tables.

Written comments made against this question from all tables are shown in Table 2, where they are grouped according to the apparent agreement with the statement in the question.

Table 2. Recorded responses to Q1.1 Do we accept that the health effects due to exposure to shocks are the same as those from continuous vibration?

Category	Comment
Agree	Health effects seen to be similar—based on current information
Partly Agree	Agree that more research is needed, some effects are likely to be similar to continuous vibration, cavitation likely creates different effects, chisel hammer similar physical reaction to continuous vibration
	Same organs and body parts are affected, but by another mechanism of damage
	Same symptoms and effects, but different exposure and mechanism
Partly Disagree	Continuous vibrations provide faster recovery time, but both are problematic.
	Posture and how to hold the tools might be relevant. Tool handling is very different between tools emitting continuous and impact vibration and, therefore, has a big impact
	Shock has no continuation in the signal, therefore, it could not be compared directly with vibration signals and the health effects may be different
	There is most likely a great overlap, but there are still unknowns
	We can see different timely developments of effects indicating unknown mechanisms
	Accumulation of fatigue over day and years, until a point of dramatic change = failure
	We all agree that there is an overlap and similar resulting health conditions, but there might be unknown effects or a not complete overlap since we do not currently understand the difference in biological response fully
	Whole body vibration already has 2 metrics
	Compared to hearing: a gunshot is treated differently than continuous noise → same assumption might be made for vibration, but difference might be small enough to treat them as the same
	Most research in continuous vibration, but there are indications that shock might be different, but methods are not good enough to evaluate yet
	High frequencies should be considered, mechanisms of health effects may not be the same
Disagree	Effect big, quality different, resonance effects up to 2000 Hz
	The effects are different
	The effects for feet are different, so it should be for hands
	There must be different health effects
	We agree on the fact that there are health effects, and probably unknown diseases we have not identified yet
	Study from Bovenzi says that shock is different
	It is not the same effect
More research needed	More research on the development of health effects is needed
	Need more studies in higher frequency range
	Preventive measures, we do not know enough about shocks, existing studies to old
	We need more definitions of which conditions are related to repeated shock
	More research should be done
	It is a feeling, no proof available today. We should take a deeper look. It is hard to categorise exposure
	Not enough studies available about single shocks. We need more studies in higher frequency range
Wrong question	The question should be: Is there a negative health effect from shocks?
	"Same" is too specific

Question 1.2 Is ISO 5349-1 and the A(8) metric suitable for predicting the risks of health effects from HTS?

Four out of the five tables recorded individual voting on this question:

Disagree	Partly Disagree	Partly Agree	Agree	Number Voting
82%	9%	9%	0%	33

The fifth table's written commentary stated that ISO 5349-1 and the A(8) metric is suitable for predicting some risks for health but not all. This suggests that this group is broadly aligned with the general response of the other tables, disagreeing with the assertion in the question.

Written comments made against this question from all tables are shown in Table 3, where they are grouped according to the apparent agreement with the statement in the question.

Table 3. Recorded responses to Q1.2 Is ISO 5349-1 and the A(8) metric suitable for predicting the risks of health effects from HTS?

Category	Comment
Partly Agree	Reflects today's tool classes quiet well, high-impact tools are highest though frequency weighting remains issue also in measurement, judging by standardised measurements
	To support science and research there is need for a new metric. Regarding health effects, it could be possible that the current metric is suitable for addressing the health risk
Partly Disagree	In general, 5349-1 does a good job. Just be clear that effects have been reduced massively since the introduction. Exposure time is an open issue and what are the physiological effects? Good basis, but frequency weighting is an issue, time and amplitude of signal, exposure time evaluation needs work
	Local effects unknown, local absorbed in the fingertips
	Too limited
Disagree	Change the weighting
	Change the weighting. Not suitable as A(8) is based on long exposure time (t(shock) vs. t(cont.))
	Especially, effects related to higher-frequency vibrations show that it should be improved
	ISO 5349-1 and A(8) is suitable for predicting some risks for health, but not all
	It is not enough to include the higher frequencies
	It is not valid for shocks. Time is relevant. Not in its current form, so many unknowns, too many uncertain parameters, it needs to be modified for shock
	Not good for vascular, A(8) o.k. for non-shock
	Not sufficient
	Only good for non-shock, overload in the fingers
	Time is relevant. Not enough, the health effect is too complex
	We do not understand the biological response
	We filter away things without knowing their contribution on the body
	Weighting has to be re-invented, A(8) better with number of shocks and not time
	[ISO 5349-1:2001] Appendix D has too many elements which are not considered up to now
	Today the metric is blind to cumulative effects (exposure time, etc.)
More research needed	Further evidence and research is needed

Question 1.3 Do we need a new metric specifically for HTS?

Four out of the five tables recorded individual voting on this question.

Disagree	Partly Disagree	Partly Agree	Agree	Number Voting
0%	6%	6%	88%	33

The fifth table did not discuss this question.

Written comments made against this question from all tables are shown in Table 4 where they are grouped according to the apparent agreement with the statement in the question.

Table 4. Recorded responses to Q1.3 Do we need a new metrics specifically for HTS?

Category	Comment
Agree	Logical conclusion from Q1.1 and Q1.2
	Needed in [my country]
	The current metric is not sufficient, but we should be careful to choose a new metric due to lack of evidence
Partly Disagree	To support science and research there is need for a new metric. Regarding health effects, it could be possible that the current metric is suitable for addressing the health risk

Question 2.1 Should we be looking at frequencies greater that 1250 Hz?

All five tables recorded voting on this question:

Disagree	Partly Disagree	Partly Agree	Agree	Number Voting
6%	3%	11%	80%	35

Only two written comments were made against this question and both appeared to be qualifying their individual vote. One, who voted against looking at frequencies above 1250 Hz, commented "For research yes". Another, who voted to agree with the statement, commented: "We should take a look at but if they are necessary to reflect medical disease I doubt".

Question 2.2 What is the upper frequency limit (5 k, 10 k, 50 k . . .)?

This question did not allow a simple vote on a statement. Some discussion was required around what the frequency limit ought to be. One table decided to ask for individual votes based on the frequencies given in the question. This resulted in a spread of responses from 1250 Hz to 50 kHz.

Two tables appeared to have held discussions and come to a collective agreement, and in both cases, 10 kHz came out as the preferred minimum upper frequency limit.

All tables provided comments, either from individuals or groups. These are summarised against the minimum upper frequency they have specified in Table 5.

Table 5. Recorded responses to Q2.2 What is the upper frequency limit (5 k, 10 k, 50 k . . .)?

Category	Comment
1250 Hz	1250 Hz, measurement equipment broadly available. People are trained to use such kind of equipment
2500 Hz	Due to technical restrictions during measurements
5 kHz	As low as necessary (<5 kHz) because of the quality of the measurement equipment and foreseeable mistakes. Higher frequencies increase difficulties in sampling
	Max. frequency (5 kHz) setup for raw data only, only for deeper analysis of transients
	The higher the frequency the harder it is to reproduce the results and 5 kHz could be a good compromise. Physiologically relevant = unknown
10 kHz	10 kHz
	10 kHz seems to be appropriate
	10 kHz seems to be good, but as high as necessary. Measure what is relevant for human body, which is unknown → hence rather higher, but compromise would be 10 kHz for practicability reason
	10 kHz to gather more data for today and for scientific reasons, foster development and hopefully find physiologically relevant frequency range, but main focus on reliable measurement
	10 kHz should be a minimum. Not enough data showing if it is sufficient, it might be dependent on the tool
	Do not see any problems
	For technical reasons, measurements above 10 kHz could be a problem. Maybe a minimum for 10 kHz
	Not less than 10 kHz
	[Table] all agree on 10 kHz as a good minimum requirement for a future standard and special industries could have special exceptions such as medical equipment
50 kHz	Do not see any problems

Table 5. *Cont.*

Category	Comment
No experience	I cannot answer the question, not enough knowledge/experience
Other	Different limits for different applications needed—Feld testing, lab testing, etc.
	For general measurements, if transients visible—go higher
	Limit should be frequencies that are possible to measure in the field (modification on tools for field measurements are not allowed). For higher frequencies, you need to define the filter characteristics for the bandwidth
	Research should be open to all frequencies
	The upper frequency for manufacturers has to guarantee that it is feasible or all to receive comparable results
	Upper frequency is/could be machine dependent.

Question 2.3 What are the measurement challenges for that upper frequency?

This question did not allow a simple vote on a statement. Comments were generally cautious, expressing concerns regarding transducers, mounting, calibration, reproducibility and other data handling issues. A small number expressed that they had no issues with the measurement at higher frequencies.

All tables provided comments, either from individuals or groups. The responses fell into categories relating to calibration, mounting, transducers, uncertainty/reproducibility, no problems, and other. They are summarised in Table 6.

Table 6. Recorded responses to Q2.3 What are the measurement challenges for that upper frequency?

Category	Comment
Transducers	Special accelerometers that can manage both a high sample rate as well as very large amplitudes may be a problem.
	Destroying sensors, respectively, need for two different sensors. Multiple measurements needed.
Mounting	Fixture to the surface challenging.
	Local resonances could be a potential issue.
	Nearly all persons see problems due to resonance, mounting, position.
	Position of sensor is critical.
	Resonance of the material.
	Resonance.
	Sensor mounting
	The fastening of the sensors might be difficult.
Uncertainty/ reproducibility	Repeatability.
	Repeatability.
	Uncertainty could be relevant.
	Complexity of measurements, comparability might decrease.
Calibration	Calibration should be considered in the standard.
	Retraceable calibration.
	Calibration needs to be ensured.
No problems	No problems.
	No problems—full trust in [those promoting measurement at high frequencies].
Other	Amount of data.
	No knowledge about this topic.
	Teaching of measurement people, mounting type influence (damping).
	The higher you get, the more data you generate.
	Discrepancies between lab and field exposure measurements.
	Field measurements (modification on tools for field measurements are not allowed).
	For higher frequencies, you need to define the filter characteristics for the bandwidth.

Question 2.4 Do we need a time-domain metric? If so what metric?

Three out of the five tables recorded individual voting on this question:

Disagree	Partly Disagree	Partly Agree	Agree	Number Voting
23%	18%	14%	45%	21

One of the other two tables did not discuss this question, the other discussed it, but did not vote. One person voted both as "partly disagree" and "agree" (for single-impact machines).

There was some general uncertainty expressed on the meaning of "a time-domain metric" for this question. Many of the comments referred to the Vibration Peak magnitude (VPM) [8] as a promising metric, but other suggestions mentioned factors relating to the shock count.

Written comments made against this question from all tables are shown in Table 7, where they are grouped according to the apparent agreement with the statement in the question.

Table 7. Recorded responses to Q2.4 Do we need a time-domain metric? If so, what metric?

Category	Comment
Agree	It should be relevant to capture single shocks as well. Maybe a fixed time duration for all tools, maybe 10 s.
	It is important to know the characteristics of the time signal and later, it can be linked to health effects.
	Maybe we should also report the number of shocks per time signal.
	RMS and something.
	VPM and VSI seem promising. VSI also includes RMS.
	VPM is quite robust so far, but further ideas could be explored as well.
	Yes, for single impact.
Partly Agree	Combine the VPM with the number of impulses over a certain time.
	We need something to describe the peak value.
Partly Disagree	Due to the mounting problems.
Disagree	Time domain is an option, but not the only way (same response from three delegates). Today it works without.

6. Conclusions

The workshop included many experts in hand–arm vibration. They had all attended the workshop presentations and the preceding 15th International Conference on Hand–Arm Vibration. However, not all delegates were measurement specialists and very few had practical experience with the measurement of high-frequency vibration or hand-transmitted shock. Nor did many of the delegates have knowledge in the pathophysiology of vibration. This situation is natural and is the result of the constitution of the research field of vibration injuries since it is a truly multidisciplinary field.

The workshop recognised that there is a need for more work into high-frequency vibration and hand-transmitted shock. However, there was perhaps a lack of clarity as to whether the questions were related to the research, emission testing, or workplace exposure evaluation.

It is likely that there was some leading of the workshop, with information on the possible value of controlling shock and the practical measurement of higher-frequency vibration being given in presentations in both the workshop and the preceding conference. However, there were no presentations at the conference contradicting the importance of shock and high-frequency vibration.

The workshop did agree that it is likely that HTS presents a different health outcome to that presented by continuous vibration. The existing health risk assessment metrics defined in ISO 5349-1 are, therefore, not suitable for HTS and new metrics are required.

The workshop agreed that frequencies greater than 1250 Hz may be important when evaluating the risks from HTS and that it is desirable to include frequencies up to higher frequencies. In addition, 10 kHz appeared to be an upper frequency limit that had the greatest support. However, the workshop delegates recognised the significant challenges of measurements up to these higher frequencies.

The new parameter VPM was seen to be a possible metric and peak count was mentioned by some, but no other specific metrics were proposed.

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Appendix A. Summary of Presentations on Experience of Measurement of High-Frequency HTS

Appendix A.1. Atlas Copco

To investigate high-frequency vibrations, measurements were performed on different power tools. The measurement procedure was conducted according to the general guidelines described in the ISO 28927 standard series. However, the procedure was slightly simplified by using one machine run by only two operators. In addition, the time signals that were obtained from the triaxial accelerometer mounted on the tool handle by using double-sided tape and a cable tie were acquired with a sampling frequency of 65536 Hz. The recorded data were than analysed by applying a low-pass filter at 10 kHz in order to conform to the useable frequency range of the accelerometer. For the measurements, the power tools were operated in the appropriate rigs and conditions required in the ISO 28927 standards. Each of the two operators had to perform five runs of 10 s.

The data provided by the triaxial accelerometer were used to evaluate the declared vibration emission value a_{hw} for the power tools. In addition, the Vibration Peak Magnitude (VPM) could be determined directly by means of a program implemented in the analysis software.

Acquisition of vibration data at frequencies up to 10 kHz can be performed by using regular accelerometers commercialised by the major manufacturers of sensors. The attachment of the accelerometer has to be ensured by suitable mounting on the structure. As a matter of fact, there are mounting methods appropriate to measure vibrations up to 10 kHz, as described in different publications [9,10].

Appendix A.2. Hilti

In preparation for the 15th Hand–Arm Vibration Conference in Nancy in June 2023, vibration measurements were carried out at Hilti using various hand-held power tools. The measurements were carried out in an ISO 17025 certified laboratory in accordance with the vibration tests described in the international standard for electric power tools (IEC 62841 and IEC 60745).

The accelerometers were glued to the hard cover of the device at the points defined by the standard. The data are acquired with a sampling rate of 52 kHz and filtered with a low-pass filter of 10 kHz. The laboratory is qualified according to ISO 8041-2 for frequencies up to 1250 Hz. The influence of measurements up to 10 kHz cannot be assessed at the present time.

In order to be able to map subjective differences as well as the possible, devices with different vibration characteristics were used. In addition to angle grinders and circular saws, devices such as hammer drills, chisel hammers, and impact wrenches were measured.

The results of the measurements were evaluated with different filters in order to check which method of shock vibrations and high amplitudes in the vibration profile can be reproduced, presumably, the best (according to a new requirement resulting from the revision of the European Machinery Directive).

In addition to the methods and evaluation filters described in the currently valid standards ("ISO 5349-1", "ISO/TR 18570", and "Crest-Factor"), evaluations were created which included a higher frequency range or a different filtering ("Draft ISO 5349-3" and "Draft ISO 5349-4"), or which followed a completely new mathematical approach ("VPM" and "VSI").

ISO 5349-1 and ISO/TR 18570 showed the most conclusive results regarding shock-like loading (lowest values for circular saws and angle grinders and highest values for impact wrenches). It was noticeable that in evaluations involving higher frequencies, the subjective perception did not correspond to the evaluation by, for example, the VPM. At the present time, it cannot be ruled out that deviations also occurred due to the measurement technology used. The measurements, especially with the inclusion of higher frequencies, should, therefore, be investigated further.

Appendix A.3. Politecnico di Milano

The Mechanical and Thermal Measurement group has long-term experience both in acceleration measurements at high frequencies [11] and in the field of human vibration measurements [12]. From an instrumental point of view, there are no particular problems in measuring vibration with a 10 kHz bandwidth in laboratory conditions, but both the measurement position and the fixation method require attention. Physically, a single vibration measurement is representative only of the translational motion of a rigid body, and this hypothesis does not apply to the tool handles at high frequencies; this consideration must be accounted in the choice of the metric and of the fixation point. The accelerometer must be fixed with cyano-acrylic glue to the handle in order to grant a flat frequency response function between the tool surface and the sensing element.

VPM and VSI were easy to compute, are easy to implement on any DSP-based measurement system, and, in our experience, their values were reasonably independent of the accelerometer fixation point.

Appendix B. Health Effects of High-Frequency Vibration and Shock—A Historical Overview by Ronnie Lundström

1. Health effects of high-frequency and percussive hand-held tools

In the late 1970s, some dentists reported that they were forced to quit their profession because their fingers became stiff and numb, making it impossible to maintain their required fine motor skills. These complaints led to the suspicion that exposure to hand-transmitted high-frequency vibration (HFV) produced by dental high-speed hand pieces was a possible cause. Measurement showed HFV acceleration levels up to 100 m/s^2, including frequencies up to 50 kHz [13]. In the early 1980s elevated vibrotactile perception thresholds were found on the "drilling" hand among dentists [14,15]. A similar effect was also found among physiotherapists exposed to HFV around 1 MHz from the handles of ultrasonic therapy devices [16]. These early observations that exposure to HFV can have harmful effects on humans fuelled my interest in deeper research into this area.

An in-depth review of the scientific literature published before 1986 clearly showed that an exposure to HFV or shock (HTS) from tools like impact wrenches, scalers, pedestal grinders, jack and riveting hammers have an underestimated influence on man [17]. A follow-up review conducted some years later included several studies that either demonstrated, or otherwise suggested, that percussive tools may have a more pronounced negative health effect on man when compared with non-percussive ones [18]. A relatively high prevalence of vascular and neurological disturbances, such as vibration-induced white finger (VWF) and impaired tactile sensibility, were observed. The reason for the high prevalence was not clear, but it seemed likely that vibrations that contained repetitive transients with high-peak acceleration levels and/or very-high-frequency components with high vibration levels were important contributors to the onset of disorders. Since then, and up until now, several other reviews have been published which point in the same direction. For references, see [4].

It is known that the transmission and propagation of vibration decrease with increasing frequency with respect to both the level and propagation length. It has, therefore, been argued that exposure to HFV is unlikely to have any harmful effect. This opinion has unfortunately been used as an argument for not taking exposure to HFV into account in risk assessment models, such as the one in ISO 5349-1 [2]. I think this opinion must be questioned. One must be aware of the fact that HFV energy will more or less be transmitted through the contact area between the handle of the hand-held power tool to the skin which may affect superficial tissues and structures such as vessels, peripheral nerves, and mechanoreceptive units in a negative way.

2. Health effects of diagnostic and therapeutic ultrasound

In medical applications of ultrasound, mechanical waves with frequencies from 20 kHz to 100 MHz, i.e., high-frequency vibration (HFV) produced by one or several piezoelectric elements in the ultrasonic applicator head, are transmitted from the applicator head into the body [19]. Wave velocity, degree of tissue absorption, and the scattering and reflection of the acoustic wave make it possible to predict in what way and to what extent bodily organs or structures will interact. Ultrasonic waves propagate as longitudinal waves in soft tissues, whereas hard tissues also support shear waves. The propagating wave will thus cause an alternating local pressure on the tissue (SI-unit: Pascal, Pa). Biological tissues and fluids can withstand relatively high-pressure levels, i.e., several MPa, but biological effects may occur when a critical limit is exceeded. An example is when small gas bubbles that are developed (i.e., cavitation) in exposed tissues collapse. These collapses release violent mechanical activity that may lead to biological effects on nearby cells and structures. The destruction of kidney stones and induced necrosis of soft tissues are some examples. Thermal and mechanical (non-thermal) effects are thus the main biological response to an exposure to ultrasonic vibration. The amount of transmitted ultrasonic energy is presented as a thermal index (TI) and mechanical index (MI). TI provides an estimate of the ultrasonic power required to produce a temperature rise of 1 °C. MI is an indicator for the potential risk for an adverse non-thermal bio-effect which includes cavitation. The BMUS safety guidelines state that an MI > 0.3 equals a risk of capillary bleeding, an MI > 0.7 is a risk for cavitation, and a TI > 0.7 equals an embryonic/foetal exposure limit [20].

The medical use of HFV is divided into two main categories—diagnostic and therapeutic ultrasound. Diagnostic ultrasound is the use of an HFV-based imaging technique for visualising muscles, tendons, soft tissues, internal organs, and more. With this imaging technique it is possible to non-invasively capture size, structures, and pathological lesions. Vibration frequencies higher than 3 MHz are predominantly used for this application. The therapeutic application of HFV is used for the treatment of diseased or injured body organs or structures. The frequency range for therapeutic applications varies from 20 kHz to about 3 MHz.

A vast number of ultrasonic applications are routinely used in health and medical care, such as in the fields of physiotherapy, orthopaedics, surgery, chemotherapy, and drug delivery, and more recently also in lithotripsy and cancer therapy through high-intensity focused ultrasound (HIFU) [19]. HFV at a high-power level can thus break up stony deposits or tissue, accelerate the effect of drugs in a targeted area, assist in the measurement of the elastic properties of tissue, and can be used to sort cells or small particles for research. Shockwave lithotripsy was the first ultrasonic application that demonstrated significant bio-effects in mammalian tissues due the effect of cavitation and included haemorrhage and injury in the kidney. In addition, this type of shockwave may also cause haemorrhages in the lungs and intestines by the activation of pre-existing gas bodies in these tissues. Diagnostic ultrasound is recognised as a safe, effective, and highly flexible imaging modality capable of providing clinically relevant information about most parts of the body in a rapid and cost-effective fashion. AGNIR states in their report that an exposure to ultrasound at high levels can induce biological effects in mammalian tissues through heating, a non-thermal mechanism, or cavitation [21]. At higher-pressure amplitudes, violent mechanical activity may occur due to the inertial collapse of microbubbles (i.e., cavitation) that may lead to biological effects on nearby cells and structures.

3. Standard and directive for high frequency and shock

The ISO 5349-1 standard specifies methods for measurement and risk assessment for vibration in terms of frequency-weighted acceleration up to about 1250 Hz [2]. The risk of developing health effects when being exposed to vibrations at higher frequencies (HFV) is thus considered to be negligible. It also clearly stated in the ISO-standard that it is only provisionally applicable for HTS. A risk assessment of exposure to shock-type vibration (HTS) is thus not covered by the standard. The European directive for vibration is mainly based on ISO 5349 [2]. Based on the current knowledge regarding the effects of HFV and HTS, it is very clear that the ISO standard does not take into account this type of exposure in an acceptable way and is, therefore, in great need of reform. The measurement procedure and exposure metrics for HFV and HTS needs to be specified and added to the standard. Separate exposure-response models for vascular and neurosensory complaints that also cover possible health effects of HFV and/or HTS should be included in future versions of the ISO 5349. Carefully targeted epidemiological studies on possible health effects caused by HFV and HTS exposure are definitely asked for.

Appendix C. Comments from German National Mirror Committee to ISO/TC108/SC4/WG3, (NA 001-03-12 AA)

The abstract of the workshop report refers to the mean value of the peak amplitude from repeated shock vibration, while peak amplitude and shock vibration are yet to be clearly defined. The keys to the asterisks attached to these two need to be included. Furthermore, it is found that the statement that there is a need for different metrics for HTS for a correct risk assessment is not representative of the discussions at the workshop. At the tables that members of the German standardization committee were a part of, the opinions were not as final as that. In the discussions on the need for a different metric, it appeared possible. Still, members of the German committee want to highlight that it was stated by multiple people that the values of a_{hv}, as defined in ISO 5349-1:2001, are high for tools that obviously emit shock vibration. Another issue that was raised in the discussion is that there are inconsistencies when the proposed VPM/VSI-value is used in the assessment of shocks. The protocol so far does not reflect that the ISO TC 108/SC4/WG3 is committed to addressing ultravibrations and their measurement in ISO 5349-4.

While the inclusion of the statement on the effectiveness of quantification of risk depending on the measurement metric and the understanding of the damage mechanism is important, it appears necessary to point out the lack of knowledge on the effect of high-frequency vibration and shocks in contrast to continuous vibrations.

In comparison to the workshop that took place in 2015 in Beijing, in this workshop, only the comments of the participants were collected and are represented here in a shortened version. And despite one of the presentations having addressed high-frequency continuous vibrations, as they are emitted by dentist drills, they are not addressed in the protocol.

Furthermore, previous work on higher frequencies and shocks appears to be missing from this document, such as the limit of shock sensation found by Thomas Schenk or ISO/TS 15694 or the research project of the IFA (“Hand-Arm Vibration Exposure Assessment for a Case-Control Study among German Workers”).

The presentations that started the workshop off either focused on high-frequency vibrations as the only source of observed health effects or were theoretical studies. It may help the reader to include slightly more information on these presentations.

As not all participants of the workshop did not consider themselves experts on hand-arm vibration and knowledge regarding their health effects or their measurements varied greatly, it appears more accurate to refer to participants instead of experts in the protocol. The lack of experience in measurements or knowledge of the health effects was also reflected in the responses to the questions discussed during the workshop. This should be emphasized in the reports of the votes on the different questions as the standardization will be influenced by the results.

It appears important to either include the names of the participants if that is possible while adhering to data protection laws, or at least the institutions they represented, or a list of interest groups.

On question 1.1 no consensus was found. Outcome #1 is not as clear as stated. Its statement does not reflect the lack of knowledge and the need for more research, both of which are mentioned in the comments.

Outcome #2 is not in line with reference [7] given in the protocol and measurements done by Hilti. Though a majority disagreed with the A(8) being a suitable metric for health risk evaluations, there was no consensus and the comments show assumptions or uncertainties. Question 1.2 appears somewhat biased due to the previous presentations and the need for more data.

In Outcome #4 it is important to include that it was agreed upon for research purposes and a respective definition will be part of ISO 5349-4.

It is asked that for Question 2.2 it is included that presentations at the conference have shown that the transmission from 440 Hz onwards is zero.

The challenges in the measurements at higher frequencies highlight the need for further research and the challenges in the work on ISO 5349-4. The detailed comments on Question 2.3 show that only two of them do not see problems with the measurement of high frequencies leading to the conclusion that there is no suitable equipment available for all necessary environmental conditions needed for workplace measurements or certifications.

We would like it noted in Outcome #7 that in some of the groups that did not come to a conclusion and criticism on and uncertainties about VPM were voiced.

The adjustment of the votes post hoc on the assumption that Question 1.1 was answered differently from how it was asked appears questionable. The unedited results should be included.

It would be helpful if the study from Bovenzi referred to in Table 2 in the sixth line in "Disagree" were to be specified.

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