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Necessity and Considerations for On-Body Vibration Measurement Equipment †

Setsuo Maeda [1,*], Ying Ye [2] and Shuxiang Gao [2]

[1] School of Science and Technology, Nottingham Trent University, Clifton Lane, Nottingham NG11 8NS, UK
[2] Human Factors Research Unit, Institute of Sound and Vibration Research, University of Southampton, Southampton SO17 1BJ, UK; y.ye@soton.ac.uk (Y.Y.); s.gao@soton.ac.uk (S.G.)
* Correspondence: setsuo.maeda@ntu.ac.uk; Tel.: +44-115-941-8418
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Abstract: The palmar surface (on tool surface) has been defined in ISO 5349-1 as a value of the amount of vibration transmitting to the hand and arm from on-body vibration magnitude. They showed the concept of on-body vibration measurement based on the relationship between the temporary threshold shift (TTS) of the vibrotactile perception threshold (VPT) and the on-body vibration measurement values. However, they did not show that the effectiveness of ISO 5349-1 Annex D for various factors transmitting to the hand was unknown. Therefore, the purpose of this paper is to clarify the new considerations of on-body vibration measurement equipment and to demonstrate the necessity of on-body measurement equipment.

Keywords: hand-transmitted vibration; on-body vibration; vibration measurement equipment; vibrotactile perception

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1. Introduction

A guideline for the measurement of hand-transmitted vibration was released internationally in ISO 5349-1 in 2001 [1], concerning the problem of hand–arm vibration exposure. At present, employers seek to follow the guidance within the ISO 5349-1 standard for preventing HAVS. Within clause 4.3 of this standard, it is stated that the acceleration measured at the surface of the vibrating tool in contact with the hand is used as the primary measurement to characterize the vibration exposure. Therefore, ISO 5349-1 assumes that the hand-transmitted vibration exposure magnitude is measured on the tool handle, although the hand-transmitted vibration is affected by many factors, as listed in Annex D of ISO 5349-1 standard. For many years, the factors outlined within Annex D of ISO 5349-1 have not been adequately accounted for when assessing hand-transmitted vibration exposure for the purposes of the prevention of hand–arm vibration syndrome (HAVS) in real work environments [2]. A desire by employers to adhere strictly to the ISO 5349-1 standard may be contributing to inaccurate dose assessments and inferior outcomes for the worker [3]. Although researchers have studied the effects of the vibration magnitude, their results cannot apply directly to evaluating and assessing the risk from hand-transmitted vibrations in a real work site. Since conducting a long-term study on a work site would present difficulties, as using a method such as on-tool measuring equipment would disturb work on-site, there is a need to develop a discreet new vibration exposure meter in order to understand the level of exposure of an individual at an actual work site. Based on these results, the vibration exposure dose transmitted to the worker's hand–arm system can be measured accurately, and consequently the development of vibration exposure equipment capable of vibration tool work is increasingly sought after. There are numerous factors which influence the vibration exposure, such as tool construction, tool condition, attachments used, attachment condition, material of the workpiece, direction of operation, operator posture, feed force, and grip force. Even if the same work was being conducted, the individual workers' vibration exposure level would also be highly dependent on their degree of skill, so the current risk assessment methods cannot take every influencing factor into consideration. Currently, the question of how to use the obtained vibration exposure data to predict workers' risk of hand transmitted vibration is the biggest problem.

Therefore, in this paper, the concept and necessity of equipment that predicts both on-tool vibration values that incorporate ISO 5349-1 Annex D from ISO 5349-1, and on-body vibration measurements, have been demonstrated.

2. Measurement on the Vibrating Surface

Measurements of hand–arm vibration in accordance with ISO 5349-1 and ISO 5349-2 require measurement on the interface between the vibrating surface and the hand. This usually requires a transducer set to be fixed to the gripping zone of a machine, with signal cables running to a measurement system positioned away from both the machine and the machine operator. Measurements on the vibrating surface using instrumentation that complies with ISO 8041-1 [4] or ISO 8041-2 [5] are required for compliance with ISO 5349-1. However, these measurements can be complex and require technical knowledge, skill, and experience to achieve reliable results. Full compliance with ISO 5349-1 may not be required if the purpose is to understand and control vibration exposure, or for research applications. In workplaces, workers are using tools in many ways and with different work postures. After prolonged tool usage, many workers suffer from hand-arm vibration syndromes, e.g., vascular diseases, neurological diseases, and musculoskeletal diseases.

Many researchers have worked on clarifying the relationship between dose and human responses to vibration, such as diseases, for many years. The vibration measurements were made in the field during real operating conditions performed by workers. The vibration was measured in three orthogonal directions according to the international standard ISO 5349-1 procedure (ISO 2001) on the tool handle. The vibration magnitudes were expressed as root–mean–square (r.m.s.) acceleration, and were frequency-weighted using frequency weighting W_{h} in accordance with ISO 5349-1 [1]. The root-sum-of-squares (vibration total value) of the frequency-weighted acceleration values a_{hv} for the x-, y-, and z-axes were calculated as shown in Equation (1).

$$a_{\mathrm{hv}} = \left(a_{\mathrm{hwx}}^2 + a_{\mathrm{hwy}}^2 + a_{\mathrm{hwz}}^2\right)^{\frac{1}{2}} \quad (1)$$

3. Necessity and Considerations of On-Body Vibration Measurement Equipment

In dealing with some of these aforementioned issues, on-body vibration measurement equipment presents some attractive characteristics.

- Small size, light weight, and possibility of attachment to vibration measurement equipment.
- Solid structure that does not damage workability.
- Able to measure the vibration acceleration magnitude when added to a hand palm surface (on tool handle).
- Able to indicate a measured variable or to indicate an exposure point.
- Able to show a warning when exceeding the EAV (exposure action value) or ELV (exposure limit value).

The response of the vibration measured on the wrist is an alternative method proposed to evaluate the vibration exposure [3]. This estimated value gives a higher correlation with that of the palm surface, and from this it is judged to be a target value for evaluation, which is the reason the wrist was considered at a work site for vibration measurement.

It is extremely difficult to determine these effects of the vibration exposure magnitude on the human body during work. Annex D of ISO 5349-1 identifies several factors that impact the hand-transmitted vibration magnitude. The proposed consideration of this study, to account for factors affecting the transfer of the vibration magnitude from the tool handle to the on-body measurement equipment (on wrist), is to estimate the tool vibration magnitude by using Equation (2).

$$\textit{Estimated on tool vibration magnitude} = fw * TR\left(\frac{A_{\text{handle}}}{A_{\text{wrist}}}\right) * a_{\text{wrist}} \tag{2}$$

where fw is the frequency weighting of ISO 5349-1 W_h, $TR(A_{\text{handle}}/A_{\text{wrist}})$ is the inverse of the transfer function from the tool handle on to the wrist, and a_{wrist} is the vibration magnitude on the wrist, including all affecting factors in Annex D of ISO 5349-1.

4. Experiment and Results and Discussion

The experiment was conducted using the same methods as paper [3], and the same experiment was used as in paper [2]. The experimental setup, procedure, and the subjects were the same as in these papers. The following, Table 1, shows the results.

Table 1. Test results summary (average of all participants).

	Posture 1			Posture 2			Posture 3		
Subject	**On Tool**	**On Subject**	**TTS (dB)**	**On Tool**	**On Subject**	**TTS (dB)**	**On Tool**	**On Subject**	**TTS (dB)**
Mean	5.33	8.82	20.42	3.95	8.51	17.50	3.44	10.57	21.88
SD	0.20	2.25	2.70	0.32	3.99	3.00	0.73	5.16	3.20

From the results of Table 1, it is believed that the TTS value increases with the vibration value of the tool handle vibration magnitude, according to ISO 5349-1, increases. As can be observed in Figure 1a,b of Paper [2], although the vibration value is small, the TTS value is large in the case of posture 3. From this, it is concluded that the vibration value evaluation method of the tool handle cannot be used to evaluate the effects on the human body. In addition, it is thought that the TTS value will increase according to the different posture, as shown in Table 1, so the value measured by the concept device [3], which is a concept that easily predicts the vibration value of the tool handle, corresponds to the TTS of the VPT. Therefore, it was clear that it can prevent HAVS in workers during tool work from the vibration value on the wrist, based on this paper's methodology [3].

Although the characterization of the vibration exposure currently uses the acceleration of the surface in contact with the hand as the primary quantity, it is reasonable to assume that the biological effects depend to a large extent on the coupling of the hand to the vibration source. It should also be noted that the coupling can considerably affect the measured vibration magnitudes. The vibration measurements should be made with forces which are representative of the coupling of the hand to the vibrating power tool handle or workpiece in typical operation of the tool or process.

Forces between the hand and gripping zone should be measured and reported. It is also recommended that a description of the operator's posture should be reported for individual conditions and/or operating procedures (see annexes D and F). The method for evaluation of vibration exposure described in this part of ISO 5349-1 [1] takes into account the vibration magnitude, the frequency content, the duration of exposure in a working day, and the cumulative exposure to data.

5. Conclusions

In the current study, the experiment was performed to clarify whether the a_{hv} can assess the risk from real tool work vibration exposure. From these experiments, the following conclusion was drawn:

Although the values from the test protocol and ISO 5349-1 a_{hv} values cannot apply to the all postures or subjects in real work conditions, it should be emphasized that the new evaluation method of the wearable equipment [3] can monitor the hand-transmitted vibration magnitude in real work for preventing HAVS, instead of the usage of the a_{hv} in the real work site.

Additionally, it was shown that it is necessary to carry out vibration measurement in a form that takes Annex D on-body vibration measurement equipment into consideration.

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