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Original Article

Relation of digital arterial dysfunction to alternative frequency weightings of hand-transmitted vibration

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Abstract: This study compared the relative performance of alternative frequency weightings of hand-transmitted vibration (HTV) to predict the extent of cold-induced vasoconstriction in the digital arteries of HTV workers. The cold response of digital arteries was related to measures of daily vibration exposure expressed in terms of r.m.s. acceleration magnitude normalised to an 8-h day, frequency weighted according to either the frequency weighting W_h defined in international standard ISO 5349-1:2001 ($A_h(8)$ in ms^{-2} r.m.s.) or the hand-arm vascular frequency weighting W_p proposed in the ISO Technical Report 18570:2007 ($A_p(8)$ in ms^{-2} r.m.s.). The measure of daily vibration exposure constructed with the frequency weighting W_p ($A_p(8)$) was a better predictor of the cold response of the digital arteries in the HTV workers than the metric derived from the conventional ISO frequency weighting W_h ($A_h(8)$). This finding suggests that a measure of daily vibration exposure constructed with the vascular weighting W_p, which gives more weight to intermediate- and high-frequency vibration (31.5−250 Hz), performed better for the prediction of cold induced digital arterial hyperresponsiveness than that obtained with the frequency weighting W_h recommended in ISO 5349-1 which gives more importance to lower frequency vibration (≤16 Hz).

Key words: Cold test, Finger systolic blood pressure, Frequency weighting, Hand-transmitted vibration, Vibration induced white finger

Introduction

Experimental studies have shown that the response of finger circulation to hand-transmitted vibration (HTV) is frequency-dependent[1, 2]. Vibration frequencies above 100 Hz can induce a stronger vasoconstriction than lower frequencies in either the human finger or animal models[3, 4]. Several epidemiological studies have reported that occupational exposure to intermediate- and high-frequency vibration is associated with an increased risk of a secondary form of Raynaud's phenomenon called vibration-induced white finger (VWF)[5]. These findings are in contrast with the frequency weighting W_h recommended by the ISO 5349-1 standard (2001)[6] which gives more weight to lower frequency vibration (≤16 Hz) for the assessment of vibration-induced health disorders.

Within the EU VIBRISKS project[7], the Italian research team studied the application of a supplementary hand-arm vascular weighting (W_p) proposed in the ISO/TR 18570 (2017)[8], which assigns more weight to intermediate- and high-frequency vibration. Findings showed that W_p performed better than the ISO W_h for the prediction of the incidence of subjective symptoms of VWF in a cohort of HTV workers (Fig. 1).

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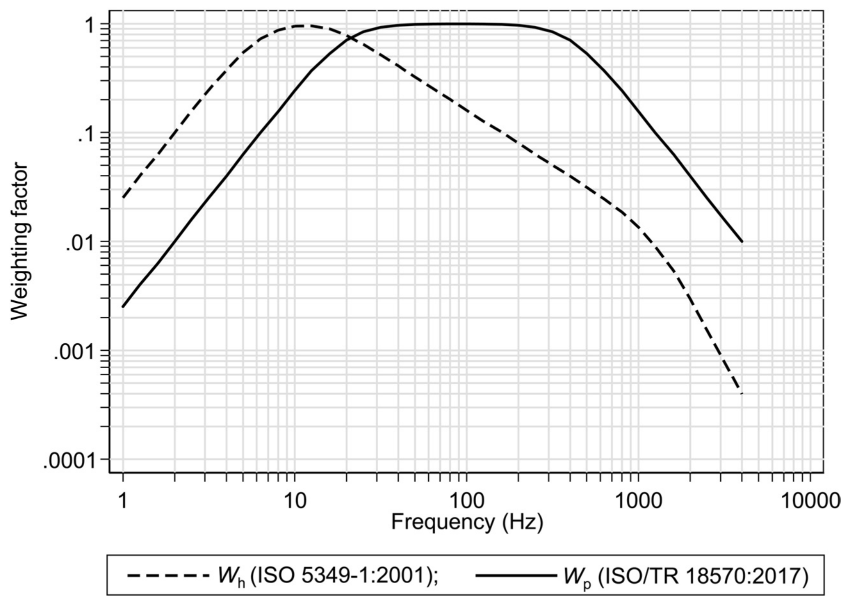

Fig. 1. Comparison of frequency weighting functions (W) for hand-transmitted vibration.
W_h: frequency weighting recommended in ISO 5349-1:2001[6].
W_p: hand-arm vascular weighting defined in ISO/TR 18570:2017[8].

The aim of the present study was to compare the relative performance of the vibration metrics constructed with either the frequency weighting W_h (ISO 5349-1:2001)[6] or the frequency weighting W_p (ISO/TR 18570:2017)[8] to predict, in addition to VWF symptoms, the extent of cold-induced vasoconstriction in the digital arteries of the VIBRISKS workers.

Subjects and Methods

Subjects

The Italian VIBRISKS cohort included 249 vibration exposed workers (215 forestry operators and 34 stone workers) and 138 control men employed at the same companies and unexposed to HTV. They were investigated at baseline and annually in the autumn-winter seasons over a three year follow-up period. Of the vibration exposed workers, 177 participated in three follow-ups, 36 in two follow-ups, and 36 in one follow-up survey. All vibration exposed workers continued to work with vibratory tools during the follow-up.

The design of the VIBRISK prospective cohort study and the characteristics of the cohort workers have been described in details elsewhere[9]. Subjective symptoms of white finger were investigated according to the minimal requisites established at the Stockholm Workshop '94[10]; in addition, colour photographs were used to compare the various degrees of whiteness, cyanosis or redness of the fingers and hands[11]. A clinical diagnosis of white finger was made when the subject, in addition to a reliable history of subjective symptoms, indicated the photographs displaying well-demarcated blanching of the fingers.

The cold test

The cold test was performed with the subject in a supine position after a rest period of 20–30 min in a laboratory room with an air temperature of 20–22°C. The cold test was carried out by means of a strain-gauge plethysmographic technique according to the method recommended in international standard ISO 14835-2:2005[12]. The percentage change in finger systolic blood pressure (FSBP) from 30 to 10°C ($\%FSBP_{10°}$) in a test finger ($FSBP_t$), corrected for the change in systolic pressure in a reference finger ($FSBP_{ref}$) of the same hand, was calculated as:

$$\%FSBP_{10°} = (FSBP_{t,10°} \times 100)/[FSBP_{t,30°} - (FSBP_{ref,30°} - FSBP_{ref,10°})]\ (\%)$$

Arm systolic pressure (ASP) was measured by an auscultatory procedure with a mercury sphygmomanometer and a standard rubber cuff (12×23 cm). The digital pressure index (DPI) at 30 and 10°C (x°) was calculated as the ratio of FSBP in the test finger ($FSBP_{tx°}$) to $ASP_{x°}$:

$$DPI_{x°} = (FSBP_{tx°} \times 100)/ASP_{x°}\ (\%)$$

To avoid nicotine-induced vasoconstrictive effects on the digital vessels, tobacco users refrained from smoking for at least 2 h before testing. The subjects were invited to abstain from alcoholic beverages since the evening preceding the day of the cold test. The cold test at the cross-sectional and follow-up surveys was performed by the same health personnel who used the same method and apparatus (Digitmatic 2000, Medimatic A/S, Copenhagen, Denmark). The subjects underwent the cold test approximately in the same calendar period (± 2 wk) and FSBPs were measured in the same test and reference fingers at the various investigations.

Vibration exposure

Vibration measurements were made on the tools used by the forestry workers (chain saws, brush saws) and the stone workers (grinders, polishers, inline hammers) according to the recommendations of international standard ISO 5349-1:2001[6]. Triaxial (x, y, z) vibration magnitudes were measured as r.m.s. accelerations over the frequency range 1–4,000 Hz using the frequency weightings W_h and W_p displayed in Fig. 1.

The root-sum-of-squares (also called “vibration total value”, a_v) of the r.m.s. accelerations of tool i frequency weighted according to W_h or W_p (W_f) for the x-, y- and z-axes was calculated as:

$$a_{vi\ (W_f)} = \sqrt{a^2_{xi\ (W_f)} + a^2_{yi\ (W_f)} + a^2_{zi\ (W_f)}}\ \left(ms^{-2}\ r.m.s.\right)$$

The results of the measurements of the tool r.m.s. acceleration magnitudes weighted with either W_h or W_p are reported in detail in a previous paper[7].

Daily vibration exposure was expressed in terms of r.m.s. acceleration magnitude normalised to an 8-h day ($A(8)$), frequency weighted according to W_h or W_p (W_f):

$$A(8)_{(W_f)} = \sqrt{\sum_{i=1}^{n} a^2_{vi\ (W_f)} \frac{T_i}{T_0}}\ \left(ms^{-2}\ r.m.s.\right)$$

where a_v is the vibration total value of the r.m.s. acceleration of tool i, T_i is the duration of the i^{th} operation with tool i in hours, and T_0 is the reference period of 8 h.

Measurements of daily exposure time were carried out by supervisors who used a stopwatch method and recorded the contact time the hands of the operators were actually exposed to the vibration from each tool[9].

Data analysis

The statistical analysis of data was performed with the Stata software, version 17.0 (Stata Corporation®, State College, TX, USA). Continuous variables were summarised with the median as a measure of central tendency and quartiles as a measure of dispersion. Comparison between unpaired data was carried out by means of non-parametric statistics. The relations of cold test outcomes (%FSBP$_{10°}$, DPI$_{10°}$) to measures of daily vibration exposure expressed in terms of either $A_h(8)$ or $A_p(8)$ were estimated by maximum-likelihood random-effects regression models for repeated measures over the follow up period. The Bayesian information criterion (BIC) was used to compare the fit of the regression models including alternative measures of daily vibration exposure[13]. According to the strength of evidence rules for the difference (Δ) in BIC between models, ΔBIC 0−2 suggests no difference in the fit between models, ΔBIC 2−6 tends to give positive support for the model with the smaller BIC, ΔBIC 6−10 provides strong evidence for the model with the smaller BIC.

Results

The occurrence of symptoms of white finger over the study period was 7.2% (n=10) in the controls and 21.7% (n=54) in the HTV workers (17.7% (n=38) in the forestry workers; 47.1% (n=16) in the stone workers). At baseline, there were no significant differences in age and anthropometric characteristics between groups, while current smoking was more prevalent in the HTV workers affected with VWF (Table 1). Daily vibration exposure in terms of either $A_h(8)$ or $A_p(8)$ was significantly greater in the VWF workers than in the HTV workers with no vascular symptoms ($p<0.001$). The duration of exposure (yr) was comparable between the two HTV worker groups.

Baseline FSBPs and ASPs at 30 °C were similar in the controls and the HTV workers with or without VWF symptoms (Table 2). The vasoconstrictor response of digital vessels to cold expressed as either %FSBP$_{10°}$ or DPI$_{10°}$ was stronger in the VWF workers than in the controls and the non-VWF workers ($p<0.0001$).

The relation of cold test outcomes (%FSBP$_{10°}$, DPI$_{10°}$) to measures of daily vibration exposure was investigated by means of three models with different sets of explanatory variables: (i) Model 1: $A_h(8)$ or $A_p(8)$ adjusted by survey time and %FSBP$_{10°}$ or DPI$_{10°}$ at baseline; (ii) Model 2: $A_h(8)$ or $A_p(8)$ and duration of exposure, adjusted by survey time, %FSBP$_{10°}$ or DPI$_{10°}$ at baseline; (iii) Model 3: $A_h(8)$ or $A_p(8)$, duration of exposure, and VWF, adjusted by survey time, %FSBP$_{10°}$ or DPI$_{10°}$ at baseline, and sev-

Table 1. Characteristics of the controls and the HTV workers at the cross-sectional survey

	Controls (n=138)	HTV workers (n=249)	
		Non-VWF (n=195)	VWF (n=54)
Age (yr)	38.8 (34.1–45.9)	42.1 (33.6–6.8)	43.0 (34.8–52.2)
Body mass index (kg/m^2)	24.5 (23.0–27.2)	25.7 (23.2–27.4)	24.5 (23.2–26.8)
Current smokers (n)	29 (21.0)	85 (43.6)	28 (51.8)*
Drinkers (n)	104 (75.4)	145 (74.4)	47 (87.0)
$A_h(8)$ (ms^{-2} r.m.s.)	–	3.59 (2.48–5.21)	4.54 (3.44–7.94)**
$A_p(8)$ (ms^{-2} r.m.s.)	–	17.9 (12.5–27.4)	26.5 (16.1–78.9)**
Duration of exposure (yr)	–	15 (7–21)	17 (11–23)

Data are given as medians (quartiles) or numbers (%). The HTV workers are divided into two sub-groups according to the occurrence of VWF over the study period, (see text for the definitions of HTV, VWF, $A_h(8)$, and $A_p(8)$).
χ^2 test: *p<0.001.
Mann–Whitney test (VWF *vs.* non-VWF workers): **p<0.001.
HTV: hand-transmitted vibration; VWF: vibration-induced white finger.

Table 2. Baseline arm systolic pressure (ASP), digital pressure index (DPI) and finger systolic blood pressure (FSBP) in the test and reference fingers at 30 and 10°C ($FSBP_{t,30°}$, $FSBP_{ref,30°}$, $\%FSBP_{10°}$) in the controls and the hand-transmitted vibration (HTV) workers with or without vibration-induced white finger (VWF) symptoms over the study period

Pressure indices	Controls (n=138)	HTV workers (n=249)	
		Non-VWF (n=195)	VWF (n=54)
$ASP_{30°}$ (mmHg)	130 (120–140)	135 (125–140)	130 (120–140)
$FSBP_{t,30°}$ (mmHg)	120 (110–135)	130 (115–140)	125 (110–140)
$FSBP_{ref,30°}$ (mmHg)	130 (118–140)	130 (120–140)	130 (115–140)
$DPI_{30°}$ (%)	95.6 (88.0–100)	96.2 (89.7–104)	95.2 (87.5–100)
$ASP_{10°}$ (mmHg)	130 (120–135)	130 (120–140)	130 (120–140)
$\%FSBP_{10°}$ (%)	92.9 (85.7–100)	91.7 (81.8–100)	81.7 (60.0–94.7)**
$DPI_{10°}$ (%)	92.1 (80.0–100)	90.0 (76.9–100)	79.1 (57.9–100)*

Data are given as medians (quartiles), (see text for the definitions of HTV, VWF, FSBP and DPI indices).
Kruskal–Wallis test beween groups: *p<0.005, **p<0.0001.

eral other potential confounding factors (Tables 3 and 4).

After excluding the controls from data analysis, in all models one unit of increase in $A_h(8)$ (1 ms^{-2}) or $A_p(8)$ (10 ms^{-2}) was significantly associated with an increase in the vasoconstrictor response of the digital vessels to cold, i.e. decrease in either $\%FSBP_{10°}$ (Table 3) or $DPI_{10°}$ (Table 4). As expected, VWF symptoms were strongly related to the cold response of finger circulation. The BIC statistic suggests a better fit when $A_p(8)$ rather than $A_h(8)$ was included in the models as a predictor of cold-induced digital vasoconstriction (ΔBIC 6–7 for models with $\%FSBP_{10°}$ outcome, ΔBIC 8–9 for models with $DPI_{10°}$ outcome). When data analysis was limited to VWF workers alone (n=54), after adjustment for the severity of VWF score[14] and other potential confounders, there was positive evidence that $A_p(8)$ performed better than $A_h(8)$ for the prediction of the cold test outcomes (ΔBIC 3–4 for models with either $\%FSBP_{10°}$ or $DPI_{10°}$ outcomes, results not shown). Among the non-VWF workers (n=195), there was also positive evidence of a better fitting for the models including $A_p(8)$ compared to those with $A_h(8)$, (ΔBIC 3 for models with either $\%FSBP_{10°}$ or $DPI_{10°}$ outcomes, results not shown).

Discussion

In this study, the peripheral vascular function in the fingers of HTV workers was assessed by measuring FSBP during cold provocation with a strain-gauge plethysmographic technique. The methods and procedures for the measurement of FSBP during finger cooling were in accordance with the recommendations of international standard ISO 14835-2:2005[12]. In our previous laboratory investigation of the cold response of digital arteries in a large

Table 3. Relation of cold test outcome at 10°C (%FSBP$_{10°}$) to measures of daily vibration exposure expressed in terms of 8-h energy equivalent r.m.s. acceleration calculated by weighting the r.m.s. acceleration magnitudes of the tools according to either the frequency weighting recommended in ISO 5349-1 ($A_h(8)$) or the hand-arm vascular weighting defined in ISO/TR 15870 ($A_p(8)$)

Factors	Model 1[a]		Model 2[b]		Model 3[c]	
	$A_h(8)$ (× 1 ms^{-2})	$A_p(8)$ (× 10 ms^{-2})	$A_h(8)$ (× 1 ms^{-2})	$A_p(8)$ (× 10 ms^{-2})	$A_h(8)$ (× 1 ms^{-2})	$A_p(8)$ (× 10 ms^{-2})
$A_f(8)$ (ms^{-2} r.m.s.)	−1.23 (−1.63; −0.84)	−1.3 (−1.68; −0.92)	−1.21 (−1.60; −0.81)	−1.27 (−1.65; −0.89)	−0.98 (−1.38; −0.58)	−1.12 (−1.52; −0.71)
Duration of exposure (yr)	-	-	−0.11 (−0.25; 0.03)	−0.11 (−0.25; 0.04)	−0.07 (−0.25; 0.12)	−0.03 (−0.22; 0.15)
VWF[d]	-	-	-	-	−7.59 (−11.1; −4.03)	−7.02 (−10.6; −3.44)
Constant	38.2 (31.5; 44.9)	36.8 (30.5; 43.0)	39.7 (32.7; 46.6)	38.3 (31.7; 44.8)	30.6 (17.3; 43.9)	32.7 (20.5; 44.9)
LR test χ^2 ($A_f(8)$)[e]	34.7	41.1	25.7	34.2	20.4	26.8
Model fitting (BIC)	7746	7739	7750	7744	7780	7773
ΔBIC	7		6		7	

Regression coefficients (95% confidence intervals) are estimated by maximum-likelihood random-effects regression models for repeated measures over the follow up period. The likelihood ratio (LR) test for the significance of the measures of daily vibration exposure and the Bayesian information criterion (BIC) for the comparison between models are shown. See text for the definition of %FSBP$_{10°}$.

[a, b]Adjusted by survey time and %FSBP$_{10°}$ at baseline.

[c]Adjusted by age-at-entry, smoking, drinking, body mass index, hand trauma or surgery, systemic disorders, daily use of medicines, leisure activity with vibrating tools, survey time, and %FSBP$_{10°}$ at baseline.

[d]VWF: symptoms of vibration induced white finger at the medical interview assisted by colour photographs.

[e]$p<0.0001$ for $A_f(8)$ in all models.

Table 4. Relation of cold test outcome at 10°C (DPI$_{10°}$) to measures of daily vibration exposure expressed in terms of 8-hr energy equivalent r.m.s. acceleration calculated by weighting the r.m.s. acceleration magnitudes of the tools according to either the frequency weighting recommended in ISO 5349-1 ($A_h(8)$) or the hand-arm vascular weighting defined in ISO/TR 15870 ($A_p(8)$)

Factors	Model 1[a]		Model 2[b]		Model 3[c]	
	$A_h(8)$ (× 1 ms^{-2})	$A_p(8)$ (× 10 ms^{-2})	$A_h(8)$ (× 1 ms^{-2})	$A_p(8)$ (× 10 ms^{-2})	$A_h(8)$ (× 1 ms^{-2})	$A_p(8)$ (× 10 ms^{-2})
$A_f(8)$ (ms^{-2} r.m.s.)	−1.13 (−1.54; −0.71)	−1.27 (−1.67; −0.86)	−1.09 (−1.51; −0.68)	−1.24 (−1.64; −0.84)	−0.93 (−1.37; −0.49)	−1.14 (−1.58; −0.70)
Duration of exposure (yr)	-	-	−0.15 (−0.31; −0.002)	−0.15 (−0.30; −0.003)	−0.03 (−0.23; 0.17)	−0.007 (−0.19; 0.20)
VWF[d]	-	-	-	-	−6.02 (−9.80; −2.23)	−5.41 (−9.16; −1.65)
Constant	34.2 (27.7; 40.7)	34.1 (27.9; 40.3)	36.7 (29.8; 43.7)	36.7 (30.0; 43.3)	35.6 (21.2; 49.9)	36.9 (22.9; 50.9)
LR test χ^2 ($A_f(8)$)[e]	26.8	35.3	25.7	34.2	16.9	24.9
Model fitting (BIC)	7740	7731	7743	7734	7784	7776
ΔBIC	9		9		8	

Regression coefficients (95% confidence intervals) are estimated by maximum-likelihood random-effects regression models for repeated measures over the follow up period. The likelihood ratio (LR) test for the significance of the measures of daily vibration exposure and the Bayesian information criterion (BIC) for the comparison between models are shown. See text for the definition of DPI$_{10°}$.

[a,b]Adjusted by survey time and DPI$_{10°}$ at baseline.

[c]Adjusted by age-at-entry, smoking, drinking, body mass index, hand trauma or surgery, systemic disorders, daily use of medicines, leisure activity with vibrating tools, survey time, and DPI$_{10°}$ at baseline.

[d]VWF: symptoms of vibration induced white finger at the medical interview assisted by colour photographs.

[e]$p<0.0001$ for $A_f(8)$ in all models.

sample of 874 male workers representative of nine groups occupationally exposed to HTV and in one control group of 455 healthy men, the sensitivity and specificity of the cold test for detecting digital arterial hyperresponsiveness to cold were 87% and 94%, respectively, for %FSBP$_{10°}$, and 80% and 94% for DPI$_{10°}$[15]. The positive and negative predictive values of the cold test were 75% and 97%, respectively, for %FSBP$_{10°}$, and 73% and 96% for DPI$_{10°}$. The repeatability of the FSBP measurements during finger cooling in a sample of healthy men over a 5-d period was acceptable, the coefficient of variation averaging 6.2% for both %FSBP$_{10°}$ (range 3.8%–9.2%) and DPI$_{10°}$ (range 2.2%–11.6%). On a group basis, the cold test with FSBP measurements could differentiate between healthy controls and HTV workers, and within these latter FSBP indices (%FSBP$_{10°}$ or DPI$_{10°}$) were significantly lower in the subjects affected with VWF than in those without vascular symptoms. These findings suggest that strain-gauge plethysmographic recording of FSBP during local cooling is a valid laboratory method for a quantitative evaluation of cold-induced arterial vasoconstriction in the fingers of HTV workers.

In this study, the metric $A_p(8)$ performed better than $A_h(8)$ for the assessment of the vasoconstrictor effect of cold in the digital arteries of HTV workers. This is consistent with our previous epidemiological findings that $A_p(8)$ was a better predictor of the occurrence over time of VWF symptoms in the VIBRISKS cohort compared to the measure of daily vibration exposure $A_h(8)$ recommended by ISO 5349-1:2001[6, 7].

Vascular investigations have revealed that acute exposures to vibration with equal frequency weighted acceleration magnitude can provoke stronger reduction in the blood flow of the human finger for frequencies between 31.5 and 250 Hz compared with vibration at 16 Hz[1]. The reduction of finger blood flow increased with increasing frequency both during and after the delivery of vibration stimuli. There is experimental and clinical evidence that exposure to vibration with a frequency of 125 Hz has a powerful constrictive effect on the digital vessels of the human fingers[2, 16]. It has been suggested that 125 Hz vibration can elicit a sympathetic vasospastic reflex mediated by subcutaneous Pacinian receptors which are highly responsive to this frequency[16]. Biodynamic and mathematical models of the human finger have shown that the finger resonant frequencies vary from 100 to 250 Hz[4, 17]. Exposure to this frequency range is associated with increased vibratory stress and enhanced local absorption of mechanical energy resulting in greater strain and risk of injury to the soft tissues of the fingers. In animal models, exposure to high frequency vibration (250 Hz) was found to induce both functional (increased oxidative stress) and structural (arterial remodelling and narrowing) changes in the ventral tail arteries of rats[4]. The findings of these biodynamic, pathophysiological and morphological investigations provide biological plausibility to the epidemiological evidence of an increased occurrence of vascular disorders in HTV workers operating power tools generating high frequency vibration.

Overall, the present study and our previous epidemiological surveys suggest that the evaluation of vibration exposure by means of W_p frequency weighting is more appropriate for the assessment and the prediction of subjective symptoms and objective signs of vibration related vascular disorders compared to the W_h frequency weighting recommended by the current ISO 5349-1 standard[6]. W_p assigns more weight to intermediate- and high-frequency vibration while W_h does not reflect the frequency-dependence of the vascular response of the fingers to vibration and tends to overestimate the vascular effects of lower frequency vibration (≤16 Hz)[5, 18].

It should be noted that the findings of this study apply only to vibration-induced vascular disorders and not to other adverse health effects (e.g. sensorineural and musculoskeletal) caused by occupational exposure to hand-transmitted vibration. This notion is pointed out in the document ISO/TR 18570:2017[8] and confirmed in our previous epidemiological studies of either neurosensory symptoms or neck and upper limb musculoskeletal disorders in the Italian cohort of the VIBRISKS research[19, 20].

The VIBRISKS prospective cohort study suffers from some limitations that deserve attention, such as, for instance, (i) vibration measurements limited to currently used tools, (ii) daily vibration exposure expressed according to an energy equivalent time dependency, (iii) possible recall or feedback bias for both outcomes and exposure variables, (iv) short duration of the follow-up time (three years), (v) pattern of missing data for dropping out of the study. These potential sources of uncertainty have been discussed in details in previous papers of the VIBRISKS study to which the reader may refer[7, 9].

Conclusions

In this study of the Italian VIBRISKS cohort, a measure of daily vibration exposure ($A_p(8)$) constructed with a frequency weighting (A_p) that gives more weight to intermediate- and high-frequency vibration than the conventional ISO frequency weighting (A_h) performed better than the derived ISO metric $A_h(8)$ for the assessment of vibration-induced peripheral circulatory dysfunction as revealed by an abnormal response of the digital arteries to finger cooling in the HTV workers. This is consistent with our previous epidemiological findings that $A_p(8)$ was a better predictor of the occurrence of VWF symptoms in the same cohort compared to the ISO $A_h(8)$[7]. However, further experimental and epidemiological research is needed to validate the hand-arm vascular weighting A_p and the derived metric $A_p(8)$ as preferred measuring methods for the evaluation of daily vibration exposure and the assessment of vibration induced adverse vascular outcomes.

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Ethics

The study was conducted according to the guidelines of the Declaration of Helsinki, and obtained ethical approval by the Local Health Autorities of the Italian NHS.

Informed Consent

Signed informed consent was obtained from all subjects involved in the study.

Conference Presentation

Data from this study were partially presented in the form of abstract at the 14th International Conference on Hand-Arm Vibration, Bonn (Germany) 21–24 May 2019.

Conflict of Interest

The authors declare no conflict of interest.

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