


# Dose-Response Relationship between Hand-Arm Vibration Exposure and Musculoskeletal Disorders of Upper Extremities: A Case-Control Study among German Workers <sup>†</sup>

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**Abstract:** In an epidemiological case-control study, exposure-response relationship between hand-arm vibration exposure and the risk of musculoskeletal disorders (MSDs) of the upper extremities were examined among 209 male cases and 614 controls in the German construction, mining, metal, and wood-working industries. To quantify individual vibration exposures, a database of industrial hygiene measurements of over 700 power tools was established. In addition, individual work histories were collected in detail. The dose-response relationships between hand-arm vibration exposure and the risk of MSDs were quantified based on multivariable logistic regression analysis. After adjusting for relevant confounders, statistically significant dose-response relationships between cumulative hand-arm vibration exposure doses and MSDs of the upper extremities could be established.

**Keywords:** hand-arm vibration; musculoskeletal disorders; dose-response relationship; epidemiology; risk assessment



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## 1. Introduction

Health related effects of hand-arm vibration exposure have three main clinical components: vascular, neurological, and musculoskeletal disorders [1]. Vascular and neurological disorders usually occur together and are the most extensively studied forms of hand-arm vibration syndrome [1]. In contrast, vibration induced musculoskeletal disorders (MSDs) of the upper extremities have been less extensively studied. Early studies and reviews indicate elevated risk of musculoskeletal symptoms (upper limb pain, stiffness, and muscle tendon syndrome) and osteoarthritis (OA) among vibration-exposed workers [1–4]. However, the exposure-response relationship between hand-arm vibration exposure and MSDs of upper extremities has been poorly established to date.

To quantitatively evaluate the exposure-response relationship between hand-arm vibration exposure and the risk of MSDs, an epidemiological case-control study was carried out among workers in the construction, mining, metal, and wood-working industries in Germany.

## 2. Material and Methods

### 2.1. Design and Study Population

In a multicentre industry-based case-control study, 209 consecutive male cases and 614 controls were recruited during the time between 2010 and 2021. Cases were newly reported patients with the following six clinical outcomes: hand OA, elbow OA, shoulder OA, Kienböck's disease, Elbow Osteochondrosis, Scaphoid fracture, and scaphoid pseudoarthrosis. Controls were a random sample of persons with compensable occupational injuries resulting in at least 3 days away from their job. They were matched to the cases in a ratio of about 1:3 for birth year, industrial sectors, and reporting years. Standardized personal interviews were carried out among cases and controls by well-trained safety engineers. In addition to leisure activities and comorbidities, work histories of all participants were collected in detail.

### 2.2. Exposure Assessment

To quantify hand-arm vibration exposures, a database of industrial hygiene measurements of over 700 power tools was established. This database allows for detailed quantification of vibration exposures over time. The cumulative vibration doses are quantified as the sum-of-squares of daily vibration exposure over the period of whole working life:

$$\begin{aligned} D_{hv} &= \sum a_{hvi(8)}^2 d_i \\ D_{hw} &= \sum a_{hwi(8)}^2 d_i \end{aligned} \quad (1)$$

where

- $D_{hv}$  = cumulative vibration doses in three measuring directions;
- $D_{hw}$  = cumulative vibration doses in the direction along the forearm;
- $a_{hvi(8)}$  = daily vibration exposure of three measuring directions at day  $i$ ;
- $a_{hwi(8)}$  = daily vibration exposure in the direction along the forearm at day  $i$ ;
- $d_i$  = number of working days with a daily exposure of  $a_{hvi(8)}$  ( $a_{hwi(8)}$ ).

### 2.3. Statistical Analysis

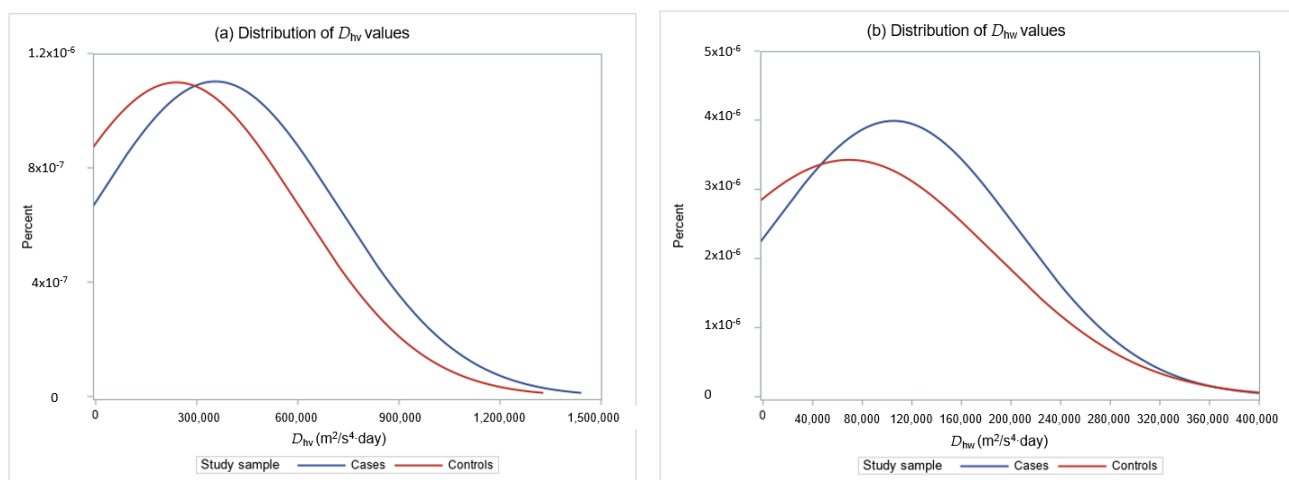
The dose-response relationship between hand-arm vibration exposure and MSDs of the upper extremities was quantified by conditional logistic regression analyses adjusting for age, sex, study centre, generalized OA, injury, and inflammatory disorder of hand, elbow, and shoulder joints.

## 3. Results

The study sample ( $n = 823$ ) has an average age of about 52 (range: 22–84) years, and an average employment duration of around 24 (range: 0.49–49.43) years. The individual work history contains a total of 5115 exposure sections over an exposure period of about 50 years. A total of 423 technical power tools were identified which induce hand-arm vibration exposures.

Cases have, on average, about 48% more cumulative working hours with hand-held technical power tools than the controls. This leads to higher cumulative vibration exposure doses among the cases than among the controls (Figure 1).

Table 1 gives the estimated exposure-response relationships between cumulative vibration exposure ( $D_{hv}$  and  $D_{hw}$ ) and the risk of musculoskeletal disorders of the upper extremities. The statistical models demonstrate consistent and significant exposure-response relationships between cumulative hand-arm vibration exposure ( $D_{hv}$  and  $D_{hw}$ ) and the risk of musculoskeletal disorders. Due to the strong correlation of the  $D_{hv}$  and  $D_{hw}$ , there are similar effect sizes in exposure-response relationships for the  $D_{hv}$  and  $D_{hw}$  (s. Table 1).



**Figure 1.** Distribution of cumulative vibration doses ( $D_{hv}$  and  $D_{hw}$ ) among cases and controls ( $n = 823$ ).

**Table 1.** Dose-response relationship between cumulative vibration exposure ( $D_{hv}$ ,  $D_{hw}$ ) and musculoskeletal disorders.

Cases/N		Unadjusted		Adjusted *	
		OR	95%CI	OR	95%CI
$D_{hv}$ (m <sup>2</sup> /s <sup>4</sup> · day)					
1. Quintile	20/165	1	–	1	–
2. Quintile	35/164	2.14	1.17–3.90	2.08	1.12–3.85
3. Quintile	46/165	3.10	1.72–5.59	2.66	1.45–4.88
4. Quintile	40/164	2.77	1.52–5.06	3.31	1.78–6.13
5. Quintile	68/165	5.03	2.83–8.93	5.65	3.06–10.42
Trend-test		$p < 0.0001$		$p < 0.001$	
100 m <sup>2</sup> /s <sup>4</sup> · year increase		1.015	1.008–1.023	1.013	1.006–1.021
$D_{hw}$ (m <sup>2</sup> /s <sup>4</sup> · day)					
1. Quintile	16/165	1	–	1	–
2. Quintile	27/164	1.93	1.02–3.67	1.73	0.89–3.33
3. Quintile	44/165	3.57	1.92–6.62	3.19	1.70–6.01
4. Quintile	58/164	4.91	2.68–8.99	3.92	2.10–7.32
5. Quintile	64/165	5.08	2.80–9.22	4.43	2.39–8.21
Trend-test		$p < 0.0001$		$p < 0.0001$	
100 m <sup>2</sup> /s <sup>4</sup> · year increase		1.036	1.015–1.058	1.028	1.006–1.050

\* Adjusted for study centers, generalized OA, injuries, and inflammatory disorders of hand, elbow, and shoulder joints.

Based on the effect estimates given in Table 1, smooth lines of exposure-response curves were quantified with the conventional log-linear exposure-response assumptions (s. Figure 2). According to the estimated smooth lines of dose-response curves, a 10%, 30%, and doubled increased risk of musculoskeletal disorders can be expected, as shown in Figure 3. A combination of working days and expected daily vibration exposure gives the exact vibration doses that can lead to the expected excess risk of musculoskeletal disorders (s. Figure 3).

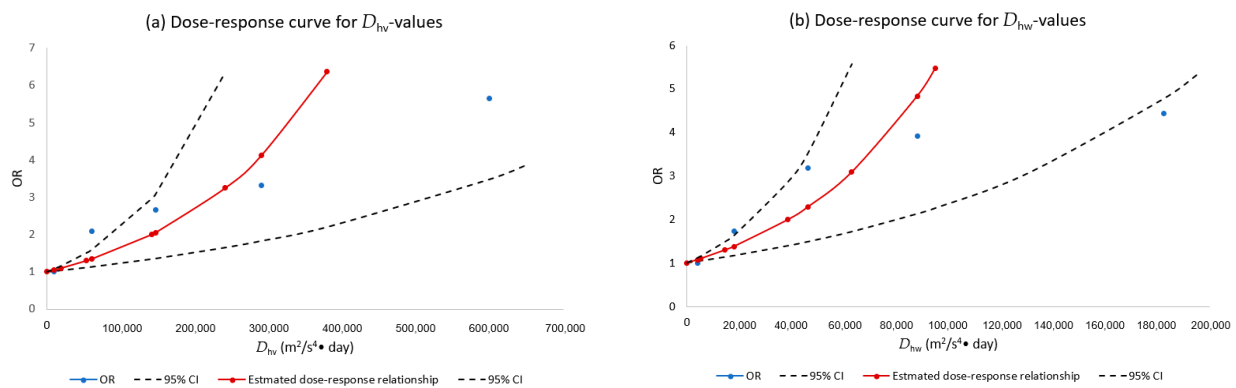


Figure 2. Estimated exposure-response curves for  $D_{hv}$  and  $D_{hw}$  values.

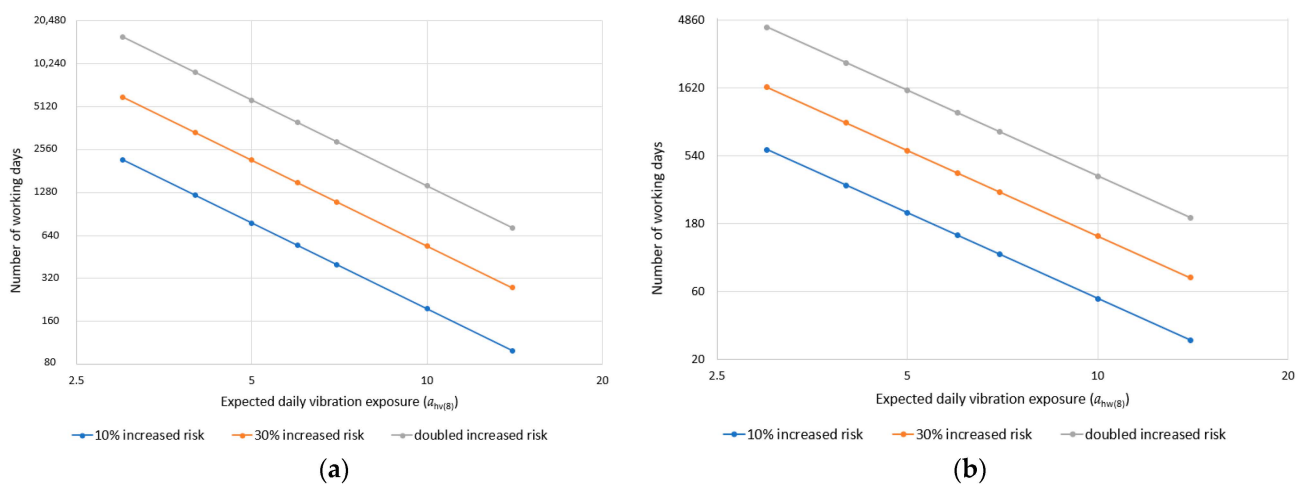


Figure 3. Expected 10%, 30%, and doubled increased risk of musculoskeletal disorders. (a) Dose-response-relationship for daily vibration exposure of three measuring directions ( $a_{hv(8)}$ ). (b) Dose-response-relationship for daily vibration exposure in the direction along the forearm ( $a_{hw(8)}$ ).

#### 4. Conclusions

Overall, this study has a large sample size and high methodological quality and shows for the first time an exposure-response-relationship between hand-arm vibration exposure and the risk of musculoskeletal disorders of the upper limb based on clearly defined morphological changes. The findings of this study provide useful guidance in the prevention and compensation of work-related and vibration-induced musculoskeletal disorders of the upper limbs.

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**Informed Consent Statement:** Informed consent was obtained from all subjects involved in the study.

**Data Availability Statement:** Due to the nature of this research, participants of this study did not agree for their data to be shared publicly, so supporting data is not available.

**Conflicts of Interest:** The authors declare no conflict of interest.

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