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Carpal Tunnel Syndrome and Hand-Arm Vibration

A Swedish National Registry Case–Control Study

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Objective: To investigate the increased risk for carpal tunnel syndrome (CTS) in men and women with hand-arm vibration (HAV) exposure. **Design:** Case–control study of CTS where 4396 cases was obtained from National Outpatient Register between 2005 through 2016. Cases were matched to controls and exposure was estimated using a job exposure matrix. **Results:** Exposure to HAV increased the risk of CTS with an OR of 1.61 (95% CI 1.46–1.77). The risk was highest in men <30 years of age and among women <30 years no increased risk was observed. The risk increased with a mean year exposure above 2.5 m/s^2 to OR 1.84 (95% CI 1.38–2.46). **Conclusions:** HAV exposure increase the risk of CTS in both genders, with highest risk increase in younger men. This emphasize identification of HAV exposure in patients with CTS.

Keywords: carpal tunnel syndrome, case–control study, hand-arm vibration, occupational exposure

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Per Vihlborg (the manuscript's guarantor) affirms that the manuscript is an honest, accurate, and transparent account of the study being reported, no important aspects of the study have been omitted; any discrepancies from the study as planned (and, if relevant, registered) have been explained.

The Corresponding Author has the right to on behalf of all authors and does grant on behalf of all authors.

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Clinical significance: The clinical significance of this paper is the statistically significant increased risk for carpal tunnel syndrome due to hand-arm vibration exposure. The highest increased risk was found among younger men. The results show the importance of investigating hand-arm vibration exposure among carpal tunnel syndrome patients.

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Learning Objectives

- Summarize current understanding of the association between hand-arm vibration (HAV) and carpal tunnel syndrome (CTS).
- Discuss the new study using a job-exposure matrix (JEM) to assess the risks of CTS associated with HAV exposure.
- Summarize the findings on worker characteristics associated with HAV-related CTS risk.

Hand-arm vibration (HAV) is a global work-related exposure that can cause different injuries.[1] Vibration white fingers (Raynaud's phenomena caused by HAV exposure) and vibration neuropathy are well known symptoms of HAV.[1,2] HAV exposure is also associated with carpal tunnel syndrome (CTS).

CTS is one of the most common peripheral entrapments and is caused by compression of the median nerve passing the carpal tunnel in the wrist.[3,4] Symptoms of CTS are neurological symptoms from the median nerve innervated area with numbness and tingling during the night or when the wrist is flexed.[4,5] Clinically, CTS is often diagnosed with provoking tests, such as Tinel's test (percussion on palmar side) and Phalen's test (flexion of the wrist), which may induce symptoms or decrease vibro-tactile sense.[3,4,6] Nerve conduction examination of the median nerve is often used to confirm the diagnosis prior to any treatment such as wrist brace, steroid injection, or surgery.[7] CTS is an important contributor to work disability and is important to prevent.[8,9]

In the majority of cases the cause of CTS is unknown, but risk factors include previous wrist fracture, female gender, rheumatoid arthritis or osteoarthritis of the wrist, pregnancy, genetic predisposition, obesity, diabetes, hypothyroidism, and monotonous wrist activity.[3,4,10,11] Occupational factors such as flexion, extension of the wrist, high grip force, repetitive work, and vibrating tools are also risk factors for CTS.[3,4] CTS associated with HAV exposure causes chronic disability and result in less improvement after surgical treatment than in CTS of other etiologies.[12] For the development of preventive measures, it is therefore important to further understand the relation between CTS and HAV.

Increased prevalence of CTS is reported in vibration-exposed workers as compared to unexposed workers, with an increased risk of OR 2.93 (95% CI 1.74–4.95).[1] However, exposure to HAV is also associated with concomitant exposure to various ergonomic factors such as static load, power grip, and unfavorable hand posture, which themselves increase the risk of CTS.[3,13] In research, the coexisting ergonomic factors from hand-held tools are therefore difficult to differentiate from HAV.[2,13] The mechanism according to which HAV causes CTS is not fully understood, though biopsies from exposed workers show structural damage to nerves and oedema formation.[14] In HAV-exposed workers, sensory nerve conduction was reduced compared to heavy manual workers and controls, which suggests that HAV exposure is a separate contributing exposure for peripheral nerve disorder.[15] Furthermore, a prolonged latency time has been observed for CTS segments in nerve conduction for HAV and manual workers compered to office workers.[16]

Another study did not indicate decreased nerve conduction in large myelinated fibers in the hands of HAV-exposed workers compared with controls.[17]

A job exposure matrix (JEM), where exposure is calculated by occupational codes, provides an opportunity to study larger numbers of subjects and receive enough statistical power for the study.[18] CTS is a common disorder, but the difficulty lies in how to separate ergonomic exposure from HAV exposure in the mechanism of CTS.[1,16]

The aim of this study was to use a JEM to investigate CTS in relation to HAV exposure.

METHODS

Sweden is well suited to conduct epidemiological register studies due to the unique personal identification number that every resident holds. This unique personal identification number makes it possible to link to register data, and Sweden holds various national registers. In this case–control study, which investigated the period between 2005 and 2016, all individuals in Sweden within the age span of 20 to 65 years, that was diagnosed for the first time with CTS (G56.0) according to the International Classification of Diseases (ICD 10) were included. All cases were derived from the National Board of Health and Welfare's Outpatient Register (SoS).

For each case of Carpal tunnel syndrome, one control from the general population were assigned by Statistics Sweden (SCB). The controls were selected to match the cases by age, sex and the county of residence at diagnosis. The study population was derived from a previous study and thus has the same exclusion criteria: not be first-degree relatives or have one or more of the following diseases, seropositive rheumatoid arthritis-M05, other artritis-M06, Bechterews-M45, Crohn disease-K50, Ulcerative colitis-K51, or Sarcoidosis-D86.[18]

Information on the employment length and occupation of the individuals (between 1992 and 2016) were obtained from Statistics Sweden (SCB). The individual's occupations and employment time were then linked to a Swedish job-exposure matrix (JEM) with time-specific estimates of HAV exposure for different occupational codes. Based on the length of employment of each occupation, HAV exposure before time of diagnosis was calculated according to the JEM for each individual. The Cause of Death Register and Emigration Register was linked to SCB data to identify individuals who died or emigrated during the study period.

HAV exposure was calculated as a daily 8-hour equivalent vibration level (A(8)) for each occupation. The A(8) value is calculated by multiplying the acceleration, for each hand-held vibrating machine used for each occupation, with the average operating duration for each machine, according to international standards (ISO 5349–1).[19] The vibration levels for each handheld tools included in the given occupation was obtained from the Swedish National Vibration Database (https://www.vibration.db.umu.se/app/) and reports on measurements from different organizations ($n = 27$). A(8) values and vibration levels from specific hand-held machines was gathered from literature reviews, scientific articles, and occupational medicine clinic reports ($n = 63$). The JEM thus consists of the occupational code and the assigned A(8) value. The occupational code is assigned according to the occupational classifications of the National Labor Market Board (Arbetsmarknadsstyrelsens yrkesklassificering). The occupational classification code is developed from the International Standard Classification of Occupations ISCVO-88-code system and described in more detailed elsewhere.[20] The SSYK12 classification was used from 2014 to 2017 and SSYK96 was used from 2001 to 2013. Both had a four-digit code. Between 1980 and 1990, the FOB80 classification was used. A researcher in occupational health and an occupational hygienist classified the A(8) values for each occupational codes.

Data Processing and Analysis

The study populations background data are presented with descriptive statistics with number of individuals, mean years exposed to HAV, numbers of years with HAV exposure, mean age at death and also number of deaths, for cases and controls. A conditional logistic regression model was used to calculate the odds ratio (OR) for HAV exposure between cases and controls as an estimate of risk, complemented with 95% confidence intervals (CI 95%).

Also, a conditional logistic regression analysis was used to evaluate the OR with mean HAV exposure (m/s^2). Exposure to HAV was defined as the average exposure per year in m/s^2 and categorized into three dose groups: unexposed and exposed below or above the legislate action value of 2.5 m/s^2.

Statistical calculations were made with STATA version 14.0 and SPSS version 22.

The study protocol was approved by the Swedish Ethical Review Authority (Dnr 2021–03243). This study is a retrospective register study where no individual data can be distinguished from the study population. SoS and SCB had anonymized the data before our acquisition.

RESULTS

The study population consisted of 4396 cases diagnosed with carpal tunnel syndrome (G56.0 ICD-10) and as many healthy controls (Table 1), giving a total study population of 8,792. Among these, there were 2218 males and 6574 females. In the population, 2802 had HAV exposure and 5990 were unexposed. Among the females, 1653 were exposed and 4921 were unexposed, among males 1149 were exposed and 1069 were unexposed. Mean exposure time before diagnosis for all CTS cases were 3.3 years, with a mean yearly exposure of 0.3 m/s^2. However, the CTS cases with

TABLE 1. Background Variables of the Study Population

	Cases/Controls	*N*	Mean	Median	Std. Deviation	Min	Max
Age at diagnosis	Controls	4396	49.1*	51.0	10.07	20	65
	Cases	4396	49.1	51.0	10.07	20	65
Year of exposure before diagnosis	Controls	4396	2.4*	0	4.47	0	19
	Cases	4396	3.3	0	4.90	0	21
Mean exposure	Controls	4396	0.2	0	0.66	0	11
	Cases	4396	0.3	0	0.73	0	6
Deceased, mean age	Controls	111	60.4	61	7.06	40	74
	Cases	97	60.8	62	8.22	31	75

*Based on the time of diagnosis of matched case.

TABLE 2. Odds Ratio for Exposed with Carpal Tunnel Syndrome in Different Age Class and Gender

Carpal Tunnel				Cases	Controls	OR	*P*	95% CI
(G56.0)	Total		Unexposed	2783	3207	1		
			Exposed	1613	1189	1.61	<0.001	1.46–1.77
		≤30	Unexposed	136	150	1		
			Exposed	75	61	1.40	0.13	0.91–2.16
		31–50	Unexposed	1158	1402	1		
			Exposed	799	555	1.76	<0.001	1.54–2.02
		51+	Unexposed	1489	1655	1		
			Exposed	739	573	1.49	<0.001	1.29–1.71
	Men							
		Total	Unexposed	442	627	1		
			Exposed	667	482	1.98	<0.001	1.67–2.36
		≤30	Unexposed	17	27	1		
			Exposed	28	18	2.43	0.05	1.01–5.86
		31–50	Unexposed	169	261	1		
			Exposed	290	198	2.23	<0.001	1.70–2.92
		51+	Unexposed	256	339	1		
			Exposed	349	266	1.78	<0.001	1.41–2.26
	Women							
		Total	Unexposed	2341	2580	1		
			Exposed	946	707	1.47	<0.001	1.31–1.65
		≤30	Unexposed	119	123	1		
			Exposed	47	43	1.14	0.61	0.69–1.90
		31–50	Unexposed	989	1141	1		
			Exposed	509	357	1.62	<0.001	1.38–1.90
		51+	Unexposed	1233	1316	1		
			Exposed	390	307	1.35	<0.001	1.14–1.60

HAV exposure had a mean exposure time of 8.9 year (std 3.9) before diagnosis. The matched controls had 2.4 years of exposure at the time of diagnosis of their respective cases and a mean exposure of 0.2. There was no difference in mean age of in cases and controls who were deceased (Table 1).

There was an overall increase in CTS among HAV exposed, with an OR of 1.61 (95% CI 1.46–1.77) (Table 2), compared to nonexposed individuals. CTS was more common in women compared to men, but men had higher OR for CTS among HAV exposed as compared to nonexposed, with OR 1.98 (95% 1.67–2.36) in men and OR 1.47 (1.31–1.65) in women. Also, for men the OR for CTS in exposed versus nonexposed was higher in the younger group compared to the older. In women on the contrary, there was no increased risk of CTS among HAV exposed below 30 years of age, but in the age group 31 to 50 the CTS risk was significantly increased to OR 1.62 (95% CI 1.38–1.90) with HAV exposure and likewise in women older than 50 years the OR is 1.35 (95% CI 1.14–1.60).

There was an increased OR for CTS in both low exposed work and higher exposed (above 2.5 m/s^2). The risk increases from OR 1.6 (95% CI 1.45–1.76) to OR 1.84 (95% CI 1.38–2.46) (Table 3). Stratified by sex, the odds further increased with increasing exposure in males with OR 1.95 (95% CI 1.63–2.33), with a dose–response in higher exposed with OR 2.3 (95% CI 1.62–3.25). For women, there was only increased odds for CTS at low but not high HAV exposure levels.

DISCUSSION

In this case–control design study, we used JEM for assessment of CTS risk at vibration-exposed work, and is to the best of our knowledge, the first study to use this method of investigation. The results show an increased risk for CTS in HAV-exposed work and the risk is further increased in high-exposed males.

These results are in line with previous studies on CTS among HAV-exposed workers, although these studies had higher exposure than the current group.[1,21,22] This study identified an overall increased risk of CTS in association with HAV exposure and there were differences between genders.

For females, there is lower increased risk than for males. This can be explained with a lower mean year exposure and other risk

TABLE 3. Mean Yearly Exposure Divided into Categories 0, 0.01–2.5 m/s^2, or Above 2.5 m/s^2, Stratified by Gender in Cases and Controls

Sex	Mean Exposure (m/s^2)	Case	Control	OR	*P*	95%CI
Total	0	2 783	3207	1		
	0.01–2.5	1 494	1107	1.60	<0.001	1.45–1.76
	2.5+	119	82	1.84	<0.001	1.38–2.46
Men	0	442	627	1		
	0.01–2.5	573	421	1.95	<0.001	1.63–2.33
	2.5+	94	61	2.30	<0.001	1.62–3.25
Women	0	2 341	2580	1		
	0.01–2.5	921	686	1.48	<0.001	1.32–1.66
	2.5+	25	21	1.29	0.40	0.72–2.30

factors such as pregnancy, though there is still a significant increase of risk by 1.47 (95% CI 1.31–1.64). The risk for females seems to be age-dependent, where younger females below 30 years of age have no increased risk of CTS combined with HAV exposure, though the age group but in the age group above 30 there is an association between the risk of CTS and HAV. These results shows that both genders have an increased risk of CTS combined with HAV exposure, even if females have lower risk of CTS combined with HAV exposure.

In males, there is a dose–response relationship between mean exposure and CTS, while for women no dose response was identified (Table 3). Even if it should be acknowledged that the there were fewer cases in total in the younger group. There is a high proportion of women who have CTS without vibration exposure, which indicates that risk factors other than HAV might be more important for women than for men.[23,24] There is also the possibility that men with HAV exposure have a higher grip force, which increases the risk for CTS.[25] Risk factors for CTS is often increased with age, and HAV can therefore be a more important risk factor for younger individuals.[26] These findings underline the importance of treating HAV exposure as a distinct risk factor to have in mind during clinical consultations, in particular when younger men present clinical signs of CTS.

The result shows an increased risk in most age groups except among younger women. The highest risk was among males, especially in males below 30 years of age although the number of cases and controls were few. In women above 30 years of age, there is a significant increased risk, which indicates that HAV also increases the risk of CTS in women, though lower than for males. This can be explaining by increases in other risk factors for CTS. CTS has a higher incidence with age and is found to have a bimodal age peak at 50 to 54 and between 75 and 84 years.[27,28] The peak differs in studies between women and men, which could support the fact that there are different risk factors for CTS between genders.[29,30]

For HAV exposure, the mechanism that causes CTS is still unclear, but is believed to be a combination of both vibration and ergonomic factors. HAV is known to cause neuropathic disorders and biopsies have shown neuropathic changes in nerves while vibration has shown an induction of neural oedema.[31] While ergonomic factors are known risk factors for CTS, especially in the meat industry where hand-intensive work shows an increase in CTS, there is also an increase in HAV-exposed work.[1,11,32,33] Increased volume of CTS tunnel content can cause compression of the median nerve. Repetitive movement or compression of the carpal tunnel can cause increased volume of CTS tunnel content via the mechanism of hypertrophy of the tendons or surrounding synovium.[34] In biopsies of HAV-exposed individuals, structural nerve changes in hand nerves proximal to the wrist have been shown, and vibration has also been shown to induce neural oedema, which may contribute to CTS among HAV-exposed individuals via more neuropathic mechanisms.[14,31]

This combined mechanism with neuropathy and compression of the median nerve from the combined exposure of HAV and ergonomic factors may be the explanation for a relatively high risk of CTS already at low HAV exposure (OR 1.45 as compared to OR 1.67 in higher-exposed work). These concomitant ergonomic risk factors associated with occupational HAV exposure[21,22,35] (such as highly repetitive flexion or extension of the wrist, especially with high grip force)[22] makes preventive consultations important. Our findings underline that HAV exposure should be considered during clinical consultations, especially when younger men present clinical signs of CTS. Furthermore, since other neurological symptoms such as numbness and tingling are common in HAV-exposed individuals, it is important to distinguish treatable or curable conditions such as CTS from neuropathy caused by HAV exposure(which has limited treatment option as compared to CTS).[1,36] Moreover, the surgical result for CTS has been shown to have lower improvement in HAV-exposed individuals, which shows the importance of identifying HAV exposure in CTS patients.[12]

The use of JEM opens new opportunities to study larger numbers of HAV-exposed individuals. CTS is a diagnose suitable for this type of register study where operations of CTS are carried out in specialist care units and are registered. In this study there was an increased OR in low-exposed work with OR 1.45 (95% CI 1.34–1.58), compared to OR 1.67 (95% CI 1.30–2.14) in higher-exposed work. The explanation for a higher risk of CTS at low HAV exposure is the contributing ergonomic factors.[21,22,35] There is evidence that regular use of hand-held vibrating tools increase the risk for CTS, but also highly repetitive flexion or extension of the wrist (especially with high grip force).[22] As HAV is known to cause distal neuropathy, it is possible that it exacerbates the compression from tissue swelling from repetitive movement.

The main strengths of this study is the large size material that is nationwide, including different occupations, which diminishes regional and occupation-specific exposures. The controls are matched regarding age and gender, which are two separate risk factors for CTS. The material is also adjusted for county, which will to some extent adjust for socioeconomic and healthcare factors. The use of JEM yields the exposure data independently of the disease status, which decreases the risk for reporting bias.

Limitations of this study are that the JEM-based measures of exposure are estimates and do not represent individual or measured exposure. There are no data on possible confounders such as pregnancy, hypothyroid disease, lifestyle factors, and diabetes. The main limitation, shared with several other studies, is more importantly that ergonomic factors that coincide with HAV exposure cannot be adjusted for. The same JEM is used for both men and women according to their job titles. The JEM have no information about wheatear men or women might have the same exposure on the job titles.

In this study, mean exposure per year was use as exposure assessment; however, this do not take year of exposure in consideration. Prolonged exposure can have low mean year exposure but high life time exposure which might impose a risk. In the exposed group with CTS, there was a mean exposure time of 8.9 years but the material is not stratified both in year of exposure and level of exposure.

Utilizing a JEM can however be a future method overcoming this obstacle, as the JEM includes several occupations with low HAV and with different manual workloads. The National Board of Health and Welfare's Outpatient Register include all CTS patients who have visited specialized care such as neurologists, hand surgeons, or occupational medicine clinics, and is thus well suited for conducting studies using JEM for characterization of the exposure. This could in a future help to specify different ergonomic factors for different occupations and to be used for adjustments in analyses of HAV exposure effects.

CONCLUSION

HAV exposure is associated with a significant increased risk for CTS for both men and women, particularly in younger men. There is no association in younger women. These results are in line with earlier studies and show that assessment with a JEM is adequate. This approach can be used to further attempt to distinguish between ergonomic factors and HAV for CTS. The results also show the importance of investigating HAV exposure among CTS patients.

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