

Ergonomics and the effects of vibration in hand-intensive work

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ARMSTRONG TJ, FINE LJ, RADWIN RG, SILVERSTEIN BS. Ergonomics and the effects of vibration in hand-intensive work. *Scand J Work Environ Health* 13 (1987) 286–289. Along with ergonomic factors, such as forceful and repeated exertion and certain postures, vibration has been cited as a factor of chronic nerve and tendon disorders such as carpal tunnel syndrome and tendinitis. The arguments for the contribution of vibration come from epidemiologic studies, clinical case analyses, and studies of short-term effects. It is well established that vibration stimulates muscle contraction, which is called the tonic vibration reflex. It is also known that vibration reduces tactility and that tactility affects the amount of force exerted to hold or manipulate a given object. For localized vibration exposure of the hand and arm to occur, the hand must grip a vibrating object. Vibration may increase the risk of chronic tendon and nerve disorders by increasing the force exerted in repetitive manual tasks. This close relationship between force and vibration, and difficulties in measuring force and vibration in manual work, makes it very difficult to determine their relative contributions in epidemiologic and clinical studies.

Key terms: carpal tunnel syndrome, hand-arm vibration, tactility, tendinitis, tonic vibration reflex, vibration-induced white finger.

Along with ergonomic factors, such as forceful and repeated exertion and certain postures, vibration has been cited as an etiologic factor of chronic nerve and tendon disorders, including carpal tunnel syndrome and tendinitis (1, 2, 4, 13, 14). The arguments for the contribution of vibration come from epidemiologic studies, clinical case analyses, and studies of short-term effects. It is well established that vibration stimulates muscle contraction, this contraction being called the tonic vibration reflex. It is also known that vibration reduces tactility and that tactility affects the amount of force exerted to hold or manipulate a given object. For localized vibration exposure of the hand and arm to occur, the hand must grip a vibrating object. Vibration may increase the risk of chronic tendon and nerve disorders by increasing the force exerted in repetitive manual tasks. This close relationship between force and vibration, and difficulties in measuring force and vibration in manual work, makes it very difficult to determine their relative contributions in epidemiologic and clinical studies.

Tonic vibration reflex

Muscles exposed to vibration can exhibit a tonic vibration reflex (TVR) in the form of a gradually increasing involuntary contraction (3, 7). Hagbarth & Eklund (5) observed that, if a muscle is moderately active, vibrating its tendons causes a gradual increase in its

activity and simultaneous decrease in the activity of its antagonists. The results are either slow joint movement or a corresponding change in active tension. Matthews (9) concluded that primary afferent endings of the muscle spindle are the receptors responsible for the reflexive response. The reflex origin was the well-known stretch reflex, excited by a rather unusual form of stretching.

In the determination of how the tonic vibration reflex affects persons using powered hand tools in automobile assembly, vibration was measured from selected polishers, sanders, wrenches, and cutters (11). Most of the tested tools produced a distinctly dominant fundamental frequency at which the acceleration was typically 10 dB higher than that at other frequencies. Dominant frequencies ranged from 20 to 160 Hz. The tool weights were found to range between 15 to 30 N.

A laboratory study was then conducted in which grip force was measured for 14 subjects holding a cylindrical handle weighing 15 and 30 N, vibrating at 0, 40, and 160 Hz, 9.8 and 49 m/s², and three orthogonal axes (11, 12). Each combination of weight, frequency, amplitude, and direction was presented in random order. Each trial lasted 60 s, followed by 5 min of rest. Force was sampled with a computer during the second 20 s of the 60-s exertion. All the subjects washed and dried their hands to control sweating. The results were analyzed with repeated measures analysis of variance.

There were no significant main effects associated with vibration direction. The average results for all three directions are plotted in figure 1. There was a significant handle weight effect across all combinations for vibration; the average grip force increased 55 % from 22.5 (SD 12.7) N for the 15-N handle to 35.0 (SD 12.4) N for the 30-N handle. The vibration effect was

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only significant across the 40-Hz trials. Grip force was increased 21 % from 19.1 N and no vibration to 23.1 N for 40-Hz vibration and 9.8 m/s² for a weight of 15 N. Grip force increased 52 % to 29.1 N for 40-Hz vibration at 49 m/s². In other words, exposure to 40-Hz vibration at 49 m/s² had about the same effect as doubling the weight of a 15-N tool.

An electromyographic (EMG) study indicated that the tonic vibration reflex was the most likely cause for increased grip force when vibration was present (11, 12). It was hypothesized that exertion of excessive force over time increases the risk of chronic nerve and tendon disorders.

Tactility

Westling & Johansson (17) showed that the static force exerted to hold objects between the thumb and forefinger is proportional to object weight and friction. Local anesthesia of the index finger and thumb (5 mg Marcain/digit) resulted in a loss of sensitivity to object surface characteristics, and the exertion of nearly twice the unanesthetized force for a given object weight.

Vibration has been shown to produce short-term sensory impairments (6, 16). Recovery is reported to be exponential (10) and can require more than 20 min (6). Further studies are required to test the hypothesis that vibration increases the risk of chronic tendon and nerve injuries by impairing tactility and increasing the amount of force exerted to perform a job.

Population studies

Lukáš (8) examined 108 workers with upper extremity neurological symptoms. Most of the subjects worked in ore quarries and were exposed to segmental vibration in the 20- to 80-Hz range. Fifty-three percent of the subjects showed pathological electromyographic changes. The author stated that it was not possible to conclude that vibration was the primary cause for the neurological signs and symptoms. The clinical neurological findings could be explained as secondary sequels to basic damage of the spinal section of the neck, the elbow joint, and its vicinity or to the carpal and ulnar tunnels.

Seppäläinen (14) reported on the neurophysiological examinations of nine lumberjacks who regularly used chain saws and eight men who regularly worked with pneumatic rock drills. Eight of the chain-saw users complained of numbness and presented neurophysiological deficits. Seven of the drill users complained of paresthesia and presented neurophysiological deficits. Although there was no formal description of the lumberjack and rock driller jobs, it can be assumed that, in addition to being exposed to vibration, these workers also performed repeated and sustained exertion, and possibly exerted high forces. The contribution of

the exertion to the neurophysiological deficits must be considered.

Rothfleisch & Sherman (13) studied carpal tunnel syndrome in 25 hands of 16 workers in an automobile assembly plant. Each of the workers was found to have, at some time, used pneumatic tools which vibrated between 8.3 and 33.3 Hz. They also found that awkward positioning of the hand and wrist during task performance was a common factor. Although there was no control population or attempt to perform statistical analyses, this study again shows that ergonomic and vibration factors occur together and that their effects are not easily separated.

Cannon et al (2) performed a retrospective case-referent study on 30 workers with carpal tunnel syndrome. The most significant factor was the use of vibrating hand tools (odds ratio 7.0). The tools used (buffers and grinders among others) vibrated from 10 to 60 Hz. Although performance of repetitive motion tasks was less important (odds ratio 2.1), it can be assumed that the exposure to vibration involved intensive use of the hands. Therefore sustained exertion, high forces, and posture could account for the apparent vibration effect.

Dimberg (4) conducted a questionnaire survey of 2 814 workers at an automobile plant in Sweden for symptoms and factors associated with chronic tendon and nerve injuries. The study found that 420 persons worked with vibrating hand tools. The prevalence of neck, shoulder, elbow, and hand symptoms (table 1) among these persons was about twice as high as among those who did not work with such tools. There was a small correlation ($r=0.06-0.08$), but highly sig-

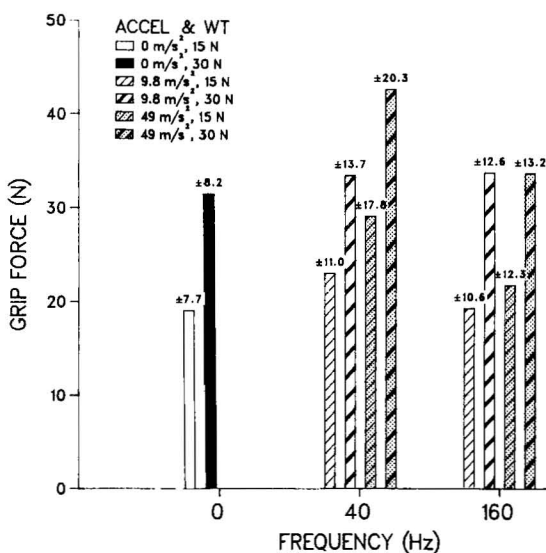


Figure 1. Average grip force exerted by 14 subjects holding a vibrating handle weighing 15 or 30 N and vibrating at 0, 40, or 160 Hz at acceleration magnitudes of 9.8 or 49 m/s². Grip force was averaged over three orthogonal vibration directions. Plus or minus one standard deviation appears above each bar. (ACCEL = acceleration, WT = weight).

Table 1. Symptom prevalence, tool usage patterns, correlations, and significances for a survey of 2 814 Swedish auto workers [from Dimberg (4)].

Location of symptoms	Number of workers	Users of vibrating tools (%)	Nonusers of vibrating tools (%)	Correlation	Significance
Neck	293	17	9	0.08	$P < 0.001$
Shoulder	370	19	13	0.07	$P < 0.001$
Elbow	169	10	5	0.07	$P < 0.01$
Hand	199	11	7	0.06	$P < 0.01$

nificant relation, between the use of vibrating hand tools and symptoms. It is not possible to determine, from the information presented, if there were differences in repetitiveness, forcefulness, or posture between jobs requiring vibrating tools and nonvibrating tools that could account for these differences. The author concluded that vibration was an important factor and recommended vibration damping sleeves for the tools.

A cross-sectional study was performed on 652 active workers in 39 jobs located in seven different industrial plants in the United States to investigate occupational risk factors of carpal tunnel syndrome (1, 15). The study design included two levels each of forcefulness and repetitiveness. Nine sets of jobs, each including four combinations of extreme forcefulness and repetitiveness, were selected from seven companies including telecommunications, investment casting, garment, home appliances, foundry, and bearing manufacturing plants. Repetitiveness and forcefulness were determined initially on the basis of work content, cycle times, and the weight of the handle of the object. Later these initial classifications were verified through the analysis of video tapes and surface electromyography. Each combination of repetitiveness and forcefulness included approximately 20 workers. The overall study population was approximately equally divided between men and women although specific jobs were not equally divided. An interview and physical examination were performed on each subject to identify those with a history of recurring problems that indicated carpal tunnel syndrome or hand and wrist tendinitis.

The prevalence of carpal tunnel syndrome ranged from 0.6 % for workers in the low-force/low-repetitive reference jobs to 5.1 % for those in the high-force/high-repetitive study jobs. The crude odds ratios showed that workers performing the high-force/high-repetitive jobs were 8.4 times more likely to have carpal tunnel syndrome than those performing the reference jobs. Four of the nine high-force jobs involved nearly continuous exposure to vibration (buffing, grinding, cutting), while none of the reference jobs involved vibration exposure. The crude odds ratio for the workers in the high-force/high-repetitive jobs with vibration versus those in reference jobs was 11.3 ($P < 0.02$). The odds ratio for the workers in the high-force/high-repetitive jobs with no vibration versus those in the same reference jobs was only 5.9

($P < 0.10$). When workers in high-force/high-repetitive jobs with vibration were compared with those in jobs without vibration, the odds ratio was 1.9 ($P < 0.30$). The lack of significance could be due to the small sample sizes.

In summary, these data suggest that the risk of carpal tunnel syndrome is increased by a factor of 6 for workers performing high-repetitive/high-force work over low-repetitive/low-force work and that risk is elevated by a factor of 2 by nearly continuous vibration exposure. While hand and wrist tendinitis was highly associated with high-force/high-repetitive work (odds ratio 18.9, $P < 0.01$), no association with vibration was found (15).

Conclusions

It is generally accepted that ergonomic factors, such as repeated or sustained exertion, in combination with certain postures cause, precipitate or aggravate chronic upper extremity tendon and nerve disorders. It has been suggested that vibration may also contribute to these disorders. There is evidence that vibration produces short-term neurological effects including muscle contractions and paresthesia. As a result excessive force may be exerted to hold vibrating tools and parts and thus increase the risk of a tendon or nerve disorder. Vibration has been observed as a common factor in persons undergoing clinical evaluation for chronic nerve disorders. In addition there are some epidemiologic data that support the contribution of vibration. Unfortunately, these studies are often confounded by the co-mingling of ergonomic and vibration exposure variables. If there is a direct contribution of vibration to chronic nerve and tendon disorders, it probably is not large. In either case, future research will be required to settle the issue.

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