*Occupational Medicine* 2007;**57**:57–66
Published online 2 November 2006 doi:10.1093/occmed/kql125

# Carpal tunnel syndrome and its relation to occupation: a systematic literature review

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**Objectives** To assess occupational risk factors for carpal tunnel syndrome (CTS), we conducted a systematic literature review.

**Methods** We identified relevant primary research from two major reviews in the 1990s and supplemented this material by a systematic search of the MEDLINE and EMBASE biomedical databases from the start of the electronic record to 1 January 2005. Reports were obtained and their bibliographies checked for other relevant publications. From each paper, we abstracted a standardized set of information on study populations, exposure contrasts and estimates of effect.

**Results** Altogether, we summarized 38 primary reports, with analyses based either on a comparison of job titles (22) or of physical activities in the job (13) or both (3). We found reasonable evidence that regular and prolonged use of hand-held vibratory tools increases the risk of CTS >2-fold and found substantial evidence for similar or even higher risks from prolonged and highly repetitious flexion and extension of the wrist, especially when allied with a forceful grip. The balance of evidence on keyboard and computer work did not indicate an important association with CTS.

**Discussion** Although the papers that we considered had limitations, a substantial and coherent body of evidence supports preventive policies aimed at avoiding highly repetitive wrist–hand work. There is a case for extending social security compensation for CTS in the United Kingdom to cover work of this kind.

**Key words** Carpal tunnel; classification; neuropathy; occupational risk factors.



## Introduction

Carpal tunnel syndrome (CTS) arises from compression of the median nerve where it passes through the carpal tunnel in the wrist. It is characterized by sensory and, less commonly, motor symptoms and signs in the peripheral distribution of the median nerve. Known causes include trauma, diabetes, rheumatoid arthritis, acromegaly, hypothyroidism and pregnancy [1].

Certain occupational activities also carry an increased risk of CTS. A review by Hagberg *et al.* [2] in 1992 identified 15 cross-sectional studies and 6 case–control studies that provided higher quality information on occupational associations. Most analysed risks according to job title, finding particularly high prevalence rates and relative risks in a number of jobs that were believed to involve repetitive and forceful gripping. A second systematic literature review in the 1990s concluded that there was 'evidence' of positive associations with work that entailed highly repetitive or forceful movements of the hands, and 'strong evidence' in relation to the combination of these exposures, but 'insufficient evidence' that the syndrome was caused by extremes of wrist posture [3]. A textbook from the same period, while not finding positive evidence on all the Bradford Hill criteria for causality, concluded that there was 'strong evidence supporting the contribution of work-related factors to the development of CTS' [4].

The aim of this report is to provide an updated review of the evidence linking CTS with work. The review was commissioned by the Industrial Injuries Advisory Council (the statutory body in the United Kingdom that advises on the prescription of occupational diseases for compensation through the social security system), and it focused particularly on the scope for revising and extending the current terms of prescription for CTS. It is also relevant, however, to preventive strategies in the workplace.

The circumstances under which an occupational disease can be prescribed for social security compensation in the United Kingdom are set out in detail elsewhere [5,6], but in essence, it must be possible to attribute the disorder to work with reasonable confidence (taken as 'on the

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balance of probabilities') in the individual case. Thus, unless there are individual clinical features that support such attribution, it is a requirement that risk of the disease should be at least doubled as a consequence of the relevant occupational exposure (a relative risk of two corresponding to an attributable fraction of 50% in exposed persons) [5,7].

## Methods

As a starting point for our review, we identified all papers referenced in two earlier comprehensive reports—a critical review of epidemiological evidence compiled by the National Institute of Occupational Safety and Health in the United States [3], and a textbook edited by Kuorinka and Forcier [4]—that provided independent estimates of the risk of CTS in specified occupational groups or by occupational activity. To ensure completeness, we retrieved and scrutinized papers referenced in relation not only to CTS explicitly but also to less specific diagnostic categories that might encompass CTS (cumulative trauma disorder [CTD]), repetitive strain injury [RSI] and occupational over-use syndrome).

We then supplemented this material with a systematic search of the MEDLINE and EMBASE bibliographic databases, using OVID, and covering the period from inception of the electronic record until the end of 2004. Key words and medical subject headings were chosen to represent the outcome (Carpal Tunnel Syndrome, CTS, median nerve entrapment or neuropathy) and exposures of interest. For exposures, we chose medical subject headings and key words based on the following terms: work-related, occupation, repetitive, repetitious, RSI, cumulative trauma disorder, CTI, CTD and several specific occupational titles that had been prominent in earlier research (specifically [where $ represents a wild-card term]: poultry process$, meat cutt$, dental worker$, supermarket worker$, meat industry worker$, slaughterhouse$, assembly line$, assembly worker$, packer$, shoe manufactur$, sewing machine operat$, garment worker$, meat process$ butcher$, textile work$, forestry work$, fish process$, musician$ and vibrat$). The search was further refined by restricting attention to English language publications and to papers that included specified epidemiological terms among their key words, title or abstract—namely any of the following: risk$, rate$, odds, incidence, prevalence, ratio$, epidemiolo$, case-control or cohort$. Titles of papers were studied, duplicates and obviously irrelevant references were eliminated, and the remaining abstracts were read independently by two researchers (E.C.H. and K.T.P.) to decide on the papers to be retrieved (any differences of opinion were resolved by consensus). Papers that did not include a control group (case-only series) were noted but not scrutinized. The remaining papers were evaluated and their references were checked for further relevant primary research.

To test the adequacy of our search strategy we compared the outcome for the period up to the end of 1997 with the list of papers identified from the two earlier reviews. This led to minor refinement of the search criteria, and the search was then re-run.

From each paper that was finally reviewed, we abstracted a standard set of information, including details of the study populations, exposure contrasts, estimates of effect and confounders considered. Where prevalence estimates were provided but not relative risks, we calculated odds ratios (ORs) with exact 95% confidence intervals (CIs) using STATA 7.0 statistical software.

## Results

From the two earlier reviews which formed the starting point for our investigation, we identified 23 relevant papers. Our own independent search of the literature up to the end of 1997 identified 21 of these 23 papers, together with further three reports that also provided risk estimates for CTS by occupation or occupational activity. Finally, our literature search for the period from 1998 to 2004 revealed an additional 12 papers that were eligible for inclusion, giving a total of 38 primary research reports on which the current review was based.

The main findings from these reports are summarized in two tables, giving risks of CTS by job title (Table 1) and by occupational activity (Table 2).

In most studies the diagnosis of CTS was based on a combination of symptoms, signs and neurophysiological abnormalities, but the exact criteria applied varied between investigations. For example, some required the demonstration of abnormal conduction in the median nerve as a condition for inclusion, whereas others accepted positive physical signs as an alternative. A few studies took a reported or documented medical diagnosis of CTS as their case definition, and others defined cases on the basis only of symptoms.

Table 1 shows risks of CTS by job title. The occupations and industries studied ranged widely, but the majority fell into three broad classes—jobs entailing the use of vibratory tools, assembly work and food processing and packing.

The evidence on CTS and vibration is considered below. With regard to assembly work, a greater than doubling of risk was reported by the following people: (i) Barnhart *et al.* [9], in ski assembly workers employed for an average of 5.1 years in jobs that entailed 'repeated and/or sustained' flexion, extension or ulnar or radial deviation of the wrist (OR 4.0); (ii) Bystrom *et al.* [12] in automobile assembly workers (OR 2.9, but with wide confidence limits); (iii) Abbas *et al.* [8] in electrical assembly workers whose jobs involved a precision (pinch) grip and frequent repetition (OR 11.4); (iv) and Leclerc

**Table 1.** Studies that report the risk of carpal tunnel syndrome by occupational title and in comparison with another occupation

| Author (date) | Exposed group | Reference group | Diagnostic criteria | Subgroup | RR (95% CI) | Potential confounders |
|---|---|---|---|---|---|---|
| Abbas *et al.* (2001) [8] | 104 electrical (TV) assembly workers | 94 clerical workers | Symptoms and nerve conduction | | 11.4 (3.6–40.2) | |
| Barnhart *et al.* (1991) [9] | 106 ski-manufacturing workers in repetitive jobs | 67 non-repetitive jobs | Electrophysiology + physical signs | | 4.0 (1.0–15.8) | a, b |
| Bovenzi *et al.* (1991) [10] | 65 forestry workers | 31 mixed blue-collar workers | Symptoms and signs | | 21.3 ($P$ = 0.002) | a, b, d |
| Bovenzi (1994) [11] | 145 quarry drillers and 425 stonecarvers | 258 polishers and machine operators (not exposed) | Symptoms and signs | | 3.4 (1.4–8.3) | a, b, e, l, m |
| Bystrom *et al.* (1995) [12] | 60 female automobile assembly workers | 90 female general population referents | Symptoms and signs | | 2.9 (0.1–60.0) | a, b |
| Cannon *et al.* (1981) [13] | Cases—30 cases of CTS in aircraft engine workers | Controls, 90 workers from the same plant randomly selected | Workman's compensation claims and medical records of CTS | | 7.0 (3.0–17.0) | b, g, h |
| Chatterjee *et al.* (1982) [14] | 16 rock drillers | 15 matched controls (basis of selection unclear) | Electrodiagnosis—abnormal amplitude digit action potentials in fingers supplying median nerve | | 10.9 (1.0–5.2) | a, b |
| Chiang *et al.* (1990) [15] | 121 frozen-food packers | 49 office staff and technicians | Symptoms, signs and/or delayed nerve conduction | | 11.7 (2.9–46.6) | a, b, g |
| Farkkila *et al.* (1988) [16] | 79 chain-saw workers randomly chosen from 186 forestry workers with >500 h of sawing/year | No comparison group | Symptoms and nerve conduction | | Present in 26% of subjects | l |
| Frost *et al.* (1998) [17][a] | 743 slaughterhouse workers | 398 referents | Symptoms and nerve conduction or previous surgery for CTS | All | 4.0 (1.7–9.3) | a, b, d, e, j, m |
| | | | | Non-deboning | 3.1 (1.3–8.0) | |
| | | | | Deboning | 4.9 (2.0–11.8) | |
| Garland *et al.* (1996) [18] | US Naval personnel—internal comparison by occupation relative to all workers | | CTS according to computerized hospital discharge record | Aviation-support equipment technician | 2.60* (9 cases) | a, b |
| | | | | Engine man | 1.96* (21 cases) | |
| | | | | Whole-maintenance technician | 1.90* (27 cases) | |
| | | | | Boatswain's mate | 1.73* (27 cases) | |
| Kim *et al.* (2004) [19] | 69 fish processors | 28 managers and secretaries | Symptoms + nerve conduction | | Prevalence 26% (exposed) versus 0% (unexposed) | |
| Koskimies *et al.* (1990) [20] | 217 forestry workers using chain-saws >500 h in the past 3 years | No comparison group | Symptoms and nerve conduction | | Prevalence 20% | j |
| Kutluhan *et al.* (2001) [21] | 70 carpet layers from workshops in Turkey | 30 healthy housewives | Nerve conduction and symptoms | | CTS in 31 hands of carpet layers (22%) and 4 hands of controls (7%), $P$ = 0.008. | b, j |
| Leclerc *et al.* (1998) [22] | Workers from assembly lines (479), the clothing and shoe industry (264), the food industry (307) and packaging (160) | 337 controls (source unclear) | Signs or positive nerve conduction | Assembly | 4.5 (2.3–9.1) | a, b, d, f |
| | | | | Clothing | 4.1 (2.0–8.7) | |
| | | | | Food | 3.1 (1.4–7.2) | |
| | | | | Packaging | 6.6 (3.0–14.2) | |
| Leclerc *et al.* (2001) [23] | Longitudinal study of 598 workers from five sectors—assembly, clothing manufacture, food and packaging and cashiers—estimates for baseline prevalence and incidence over 3 years | | Signs or positive nerve conduction | | Prevalence and incidence varied by <2-fold between the comparison groups. | |

**Table 1.** *Continued*

| Author (date) | Exposed group | Reference group | Diagnostic criteria | Subgroup | RR (95% CI) | | Potential confounders |
|---|---|---|---|---|---|---|---|
| Liss *et al.* (1995) [24] | 1066 Canadian dental hygienists | 157 dental assistants | Self-reported doctor-diagnosed CTS | | 5.2 (0.9–32.0) | | a, b, j, n |
| | | | Median nerve symptoms | | 3.7 (1.1–11.9) | | |
| McCormack *et al.* (1990) [25] | Textile workers involved in boarding (296), knitting (352), packaging/folding (369) and sewing (562) | Non-office workers (468) (maintenance, transport, cleaning and sweeping) | Symptoms and signs | Boarding | 0.5 (0.05–2.9) | | a, b, g, h |
| | | | | Sewing | 0.9 (0.3–2.9) | | |
| | | | | Packaging | 0.4 (0.04–2.4) | | |
| | | | | Knitting | 0.6 (0.1–3.1) | | |
| Morgenstern *et al.* (1991) [26] | 1058 female grocery cashiers | None (internal comparison) | Self-reported symptoms | <26 h/week | 1.0 | | a, b |
| | | | | 26–34 h/week | 1.5 (1.0–2.4) | | |
| | | | | >34 h/week | 1.9 (1.1–3.1) | | |
| Osorio *et al.* (1994) [27] | 56 supermarket workers—bakery icers, meat cutters and cashiers working ≥20 h/week | Low-exposure group (others) | Symptoms | | 8.3 (2.6–26.4) | | a, b, l |
| | | | Symptoms and nerve conduction | | 6.7 (0.8–52.9) | | |
| Punnett *et al.* (1986) [28] | 162 female garment workers (85% sewing and trimming by hand) | 76 hospital workers (nurses, lab technicians and therapists) | Median nerve symptoms | | 2.7 (1.2–7.6) | | a, h, n |
| Schottland *et al.* (1991) [29] | 93 poultry workers | 85 job applicants for poultry jobs | Prolonged motor or sensory median nerve latencies (no symptoms needed) | | 2.9 (1.1–7.9) | | a, b |
| Rosecrance *et al.* (2002) [30] | Apprentice construction workers from a US trades union: sheet metal workers (136), operating engineers (486), plumbers/pipe fitters (330) | Apprentice electricians (163) | Symptoms and nerve conduction | Sheet metal workers | 2.0 (0.8–5.0) | | a, d |
| | | | | Engineers | 1.0 (0.5–2.2) | | |
| | | | | Plumbers/pipe fitters | 1.2 (0.5–2.0) | | |
| Rossignol *et al.* (1997) [31] | Rates of first surgery for CTS by occupation, Island of Montreal; established from provincial health insurance database | | Record of surgery for CTS | | Women | Men | a, b |
| | | | | Housekeeping & cleaners | 9.0 (4.0–20.1) | 143.4 (42.3–485.3) | |
| | | | | Data-processing operators | 4.0 (1.6–10.1) | 29.5 (6.2–140.8) | |
| | | | | Material handlers | 7.5 (3.2–17.8) | 12.3 (3.7–41.1) | |
| | | | | Food and beverage | | | |
| | | | | Processing | 8.5 (3.0–23.9) | 5.7 (1.2–27.0) | |
| | | | | Service | 4.6 (2.1–10.3) | 7.9 (1.0–63.9) | |
| | | | | Lorry & bus drivers | – | 6.4 (2.2–18.6) | |
| Werner *et al.* (2002) [32] | 305 volunteers attending the 2000 American Dental Hygiene Association Annual Conference, Washington DC | 142 clerical and 219 industrial workers (data collected in another study) | Symptoms, signs and nerve conduction | | Prevalence of CTS: 3%, 4% and 5%, respectively | | |

a, Age; b, sex; d, obesity; e, smoking; f, psychosocial; g, duration of employment; h, race; j, other rheumatic illness/medical disorder; l, alcohol; m, upper limb injury; n, pill use/hormone status; o, industry/plant.

[a]Retrospective cohort study.

*$P < 0.05$.

**Table 2.** Surveys with risk estimates of CTS according to physical activities in the job

| Author (date) | Study population | Definition of the outcome | Activity | RR | (95% CI) | Potential confounders |
|---|---|---|---|---|---|---|
| Abbas *et al.* (2001) [8] | 104 electrical (TV) assembly workers; 94 clerical workers | Symptoms and nerve conduction | Precision grip (versus power grip) | 6.5 | (1.1–39.2) | |
| Andersen *et al.* (2003) [33] | Members of the Danish Association of Professional Technicians from 3500 workplaces: 6943 workers surveyed cross-sectionally and 5658 followed up at 1 year | Self-reported symptoms in the median nerve distribution | Prevalence at baseline: | | | a, b, d, e, f, j |
| | | | Keyboard use (h/week versus ≤2.5): | | | |
| | | | 2.5 to <20 | ≤1.0 | | |
| | | | ≥20 | 1.6 | (0.7–3.7) | |
| | | | Mouse use (h/week versus ≤2.5): | | | |
| | | | ≥5 | 2.2–3.6 | ($P < 0.05$) | |
| | | | Incidence at follow-up: | | | |
| | | | Keyboard use (h/week versus <2.5): | | | |
| | | | >2.5 | ≤1.4 | | |
| | | | Mouse use (h/week versus <2.5): | | | |
| | | | ≥20 | 2.6–3.2 | ($P < 0.05$) | |
| Chiang *et al.* (1993) [34] | 146 workers on a fish-processing production line; 61 managers, office staff and craftsmen | Symptoms and signs | In women: | | | a, b, j, m, n |
| | | | Repetitive arm movement | 1.5 | (0.8–2.8) | |
| | | | Sustained forceful arm movement | 1.6 | (1.1–3.0) | |
| de Krom *et al.* (1990) [35] | 28 CTS cases from a community sample, 128 hospital cases; 473 community non-cases | History and neurophysiological tests | Activities with flexed wrist, 20–40 h/week (in the past 0–5 years) | 8.7 | (3.1–24.1) | a, b, d, j, m, n |
| | | | Activities with extended wrist, 20–40 h/week (in the past 0–5 years) | 5.4 | (1.1–27.4) | |
| Leclerc *et al.* (2001) [23] | Longitudinal study of 598 workers from five sectors—assembly, clothing manufacture, food and packaging and cashiers'—estimates for baseline prevalence and incidence over 3 years | Signs or positive nerve conduction | Tightening with force (in men) | 4.1 | (1.4–11.7) | |
| Leclerc *et al.* (1998) [22] | Workers from assembly lines (479), the clothing and shoe industry (264), the food industry (307), and packaging (160); 337 controls (source unclear) | Signs or positive nerve conduction | Cycle time <10 s (versus >1 min) | 1.9 | (1.0–3.5) | |
| Moore *et al.* (1994) [36] | 230 workers from 32 job categories | CTS in OSHA logs/medical records plus symptoms and nerve conduction | Hazardous job, as judged by force, wrist position, grip and pace of work | 2.8 | (0.2–37) | |
| Nathan *et al.* (1988) [37] | 27 trades from four industries (steel mills, food packaging, electronics and plastics) | Impaired sensory nerve conduction | High exposure (very heavy resistance and high rate of repetition) versus low exposure (very light resistance and low repetition). (The highly exposed group was a mixture of trades [furnace crew, bricklayers, grinders, plant repair welders etc.]) | 2.0 | (1.1–3.4) | a, b |

**Table 2.** *Continued*

| Author (date) | Study population | Definition of the outcome | Activity | RR | (95% CI) | Potential confounders |
|---|---|---|---|---|---|---|
| Nathan *et al.* (1992) [38] | Longitudinal survey of 315 workers from multiple jobs across four industries | Impaired sensory conduction | High exposure (very heavy resistance and high rate of repetition) versus low exposure (very light resistance and low repetition). (The highly exposed group was a mixture of trades [furnace crew, bricklayers, grinders, plant repair welders etc.]) | 1.0 | (0.5–2.2) | b, g, o |
| Nordstrom *et al.* (1998) [39] | 206 cases of CTS identified from hospital and clinical databases in the Marshfield area, WI, USA; 211 randomly sampled residents with no diagnosis of CTS | Physician diagnosis, with compatible symptoms | Power tools or machinery (h/day versus 0) | | | b, d, g, f |
| | | | 2.5–5.5 | 1.6 | (0.6–4.0) | |
| | | | >6 | 3.3 | (1.1–9.8) | |
| | | | Bending/twisting hands/wrists (h/day versus 0) | | | |
| | | | 3.5–6 | 2.7 | (1.8–5.9) | |
| | | | >6 | 2.1 | (1.0–4.5) | |
| | | | Home typewriter | 0.7 | (0.1–1.1) | |
| Roquelaure *et al.* (1997) [40] | 65 cases of CTS identified from OH records covering plants manufacturing, TV sets, shoes and automobile breaks; 65 age-, sex- and plant-matched referents | ≥3 of; (i) regular symptoms in the median nerve distribution, (ii) signs, (iii) slowed nerve conduction and (iv) surgery for CTS | Hand force >1 kg (≥10 times/h) | 9.0 | (2.4–33.4) | a, b |
| | | | Short elemental cycle (≤10 s) | 8.8 | (1.8–44.4) | |
| | | | No job rotation | 6.3 | (2.1–19.3) | |
| Silverstein *et al.* (1987) [41] | 652 workers in 39 jobs from seven different industrial categories (electronics assembly, appliance manufacturing, investment casting, apparel sewing and bearing manufacture) | Carpal tunnel symptom diagnosis. Symptoms plus Phalen's/Tinel's test positive | Four groups by degree of force and repetition (assessed by EMG and video analysis of jobs): high-repetition, high-force group versus low-repetition, low-force group | 15.5 | (1.7–142) | a, b, g, n, o |
| Tanaka *et al.* (1997) [42] | Multi-stage probability sample of US households | Self-reported medically called CTS | Bending/twisting hand or wrist many times/h | 5.9 | (3.4–10.2) | a, b, h |
| | | | Hand-powered tools or machinery | 1.9 | (1.2–2.8) | |
| Wieslander *et al.* (1989) [43] | 34 surgically treated cases of CTS matched with patients receiving other operations | Surgeon-diagnosed CTS, confirmed by nerve conduction | Use of hand-held vibratory tools: | | | a, b |
| | | | <1 year | 1.0 | | |
| | | | 1–20 years | 4.3 | (1.4–12.9) | |
| | | | >20 years | 16.0 | (2.8–90.2) | |
| | | | Repetitive movements of wrist: | | | |
| | | | <1 year | 1.0 | | |
| | | | 1–20 years | 2.3 | (0.7–7.9) | |
| | | | >20 years | 9.6 | (2.8–33.0) | |

EMG, electromyography.

a, Age; b, sex; d, obesity; e, smoking; f, psychosocial; g, duration of employment; h, race; j, other rheumatic illness/medical disorder; l, alcohol; m, upper limb injury; n, pill use/hormone status; o, industry/plant.

*et al.* [22] in workers assembling small electrical appliances, motor vehicles and ski accessories (OR 4.5). In the food-processing and food-packing industries, excess risks were reported by the following people: (i) Schottland *et al.* [29] in poultry workers (OR 2.9); (ii) Frost *et al.* [17] in slaughterhouse workers (OR 3.3–5.5); (iii) Kim *et al.* [19] in food processors and (iv) Chiang *et al.* [15] in frozen-food packers (OR 11.7). Although diverse, many of these occupations will have involved prolonged or repeated flexion and extension of the wrist.

Table 2 presents estimated risks of CTS according to occupational activities. In keeping with the findings on risk by job title, four studies—by de Krom *et al.* [35], Nordstrom *et al.* [39], Wieslander *et al.* [43] and Tanaka *et al.* [42]—found that repeated flexion and extension of the wrist (defined in various ways) more than doubled the risk of physician-confirmed CTS. Moreover, three studies point to wrist flexion or extension for at least half the working day as carrying a particularly high risk. In the study by de Krom *et al.* [35], risks were elevated 5- to 8-fold when the self-reported time spent in activities with the wrist flexed or extended was ≥20 h/week, while in the study by Nordstrom *et al.* [39] the OR for CTS was more than doubled for those estimating that they bent/twisted their wrists for >3.5 h/day versus 0 h/day. Silverstein *et al.* [41], in a well-known and careful survey that spanned several industries and included videotaped job analysis, reported associations both with repetitive and with forceful hand–wrist work. For repetitive work (hand–wrist flexion and extension), defined by a cycle time of <30 s or >50% of cycle time involved in performing the same fundamental activities, the OR was 2.7 (95% CI 0.3–28) in low-force jobs (hand force <1 kg) and 15.5 (95% CI 1.7–142) in high-force jobs (hand force >4 kg).

A study by Wieslander *et al.* [43] suggested that risk may double after >1 year in a job involving 'repetitive wrist movement', while another by Tanaka *et al.* [42] found that risks were increased nearly 6-fold in workers bending/twisting the hand or wrist 'many times per hour'. Two other studies, by Leclerc *et al.* [22,23] and Roquelaure *et al.* [40], found associations with assembly work that involved a short elemental cycle time (<10 s per repetition, RRs 1.9 and 8.8).

None of the studies estimated risks from persistent static postures of the wrist, although some examined associations with cumulative duration of wrist flexion or extension over the course of a working day.

A carefully conducted study by Andersen *et al.* [33], involving the follow-up of 5658 members of a Danish professional technicians union, found an association between incident, self-reported sensory symptoms in the median nerve distribution and use of a right-handed mouse, with ORs of 2.6–3.2 for exposures of ≥20 h/week. However, no association was found with use of keyboards, and the overall incidence of symptoms was low. The authors drew a cautious conclusion, stating that 'The study emphasizes that computer use does not pose a severe occupational hazard for developing symptoms of CTS.' Nordstrom *et al.* [39] also found no elevation of risk in users of keyboards. In a small Japanese survey involving 45 regular computer users, 16 hands were found to be affected, the severity of symptoms being correlated with the angle of wrist extension at the keyboard [44]. However, when Stevens *et al.* [45] conducted a survey of frequent computer users and other employees, affected and unaffected workers had a similar duration of computer use, and the estimated prevalence of CTS was similar to that in the general population.

In the United Kingdom, the current prescription of CTS as an occupational disease for social security purposes is limited to occupational use of hand-held vibratory tools. We found seven reports that support a substantially elevated risk from work of this kind. Four studies related to specific occupations (Table 1) (quarry/rock drillers [11,14], stonemasons [11], forestry workers [10] and aircraft engine workers [13]—mainly grinders, polishers and buffers), while two case–control studies and one household community survey (Table 2) suggested an association with hand-held vibratory tools in general. Among these investigations, one confirmed the diagnosis of CTS in cases by measuring nerve conduction, two focused on cases identified through hospital and surgical records, one involved self-reported but 'medically called' CTS and the remainder relied on clinical history and examination. Two other papers [16,20] reported a high prevalence of CTS (20–26%) in male forestry workers, but without providing comparative data on controls.

Where details were given, exposures to vibratory tools tended to be relatively prolonged and intense. In a study by Chatterjee [14], for example, cases had used rock drills for a mean of 10 years; in Bovenzi's study of foresters [10], the mean duration of occupational chain-saw use was 11.3 years and in the two other studies of foresters, the estimated cumulative exposures exceeded 16 000 h (>8 years, assuming 240 workdays/year and an 8-h shift of continuous tool use) [16,20]. A case–control study of surgically treated CTS by Wieslander *et al.* [43] found a more than doubling of risk after 1–20 years of work with hand-held vibratory tools, and another case–control study by Nordstrom *et al.* [39] suggested a relative risk of 3.3 for exposure to power tools or machinery for >6 h/day, although the duration of such employment was not specified.

## Discussion

We found reasonable evidence that regular and prolonged use of hand-held vibratory tools increases the risk of CTS >2-fold. Evidence on lesser durations and degrees of exposure was limited and does not exclude a doubling of risk. There is also a substantial body of evidence that prolonged and highly repetitious flexion or extension of the wrist materially increases the risk of CTS, especially when allied with a forceful grip. The balance of evidence on keyboard and computer work does not indicate an important association with CTS.

The studies reviewed were not without their individual limitations. In particular, almost all collected information about exposures retrospectively, with consequent potential for information bias. Some were small, limiting their statistical power, and some may not fully have controlled for confounding (although apart from sex and age, the known non-occupational causes of CTS seem unlikely to have major potential for confounding). It is possible that some investigations were prompted by the observation of workplace clusters, which would lead to unrepresentatively high risk estimates. Spuriously, high estimates of risk could also have arisen in studies that recruited cases through hospital attendance, since the occurrence of symptoms may be more troublesome in workers carrying out certain occupational tasks, leading them to seek medical treatment more readily. Diagnostic misclassification, particularly in studies that based case definition only on symptoms, was another possible source of error. Case definitions varied substantially, sometimes being based on nerve conduction and sometimes on clinical history and examination, appearance on a surgical list or a combination of these measures.

The method that we used to identify studies also had limitations. In particular, our search may not have been fully comprehensive. It did not, for example, encompass the non-peer review ('grey') literature or publications in languages other than English. Also, selective publication of positive studies, or of positive findings within studies, may have produced an overestimate of risks (although the smaller studies were not obviously more positive than the average, as might be expected if there were major publication bias).

Notwithstanding these limitations, the body of evidence as a whole seems consistent. In particular, the risks associated with hand-transmitted vibration and repetitive wrist movements were typically more than doubled, whichever the case definition employed. It is also notable that the stronger studies, including those that undertook direct assessments of exposure rather than relying on self-report, point to the same conclusions. Furthermore, from a biomechanical viewpoint it is highly plausible that excessive flexion and extension of the wrist could lead to CTS. Besides the median nerve, nine flexor tendons of the fingers pass through the carpal tunnel. There are therefore constraints of space, and in principle, raised pressure within the tunnel could cause ischaemic or direct mechanical injury to the nerve. Experimental studies in human cadavers and animals suggest that carpal tunnel pressure is strongly influenced by forearm, wrist and finger postures [46]. For example, a laboratory experiment in which the radiocarpal joint of the rabbit was flexed and extended at a rate of 80 cycles/min induced swelling in the tunnel over 10 h and slowed median nerve conduction over a period of days [47]. Although this exposure was more extreme than those encountered in real work, the investigation confirms the potential of wrist flexion and extension to induce relevant pathology.

The message for prevention is clear. Assuming a precautionary line, the necessity for highly repetitive wrist–hand work should be avoided by ergonomic design of tasks and tools, and by appropriate scheduling of work and rest periods. The last decade of evidence has only added weight to earlier conclusions in the 1980s and 1990s. It is also important to avoid prolonged use of hand-held vibratory tools insofar as this is practical. It is unclear from current evidence whether the increased risk of CTS extends to fixed sources of hand-transmitted vibration as well as hand-held vibratory tools, but exposures to these other sources of vibration require control anyway to prevent hand–arm vibration syndrome.

The potential to extend compensation for CTS within the UK Industrial Injuries Benefits Scheme is more complicated, as several other issues must be taken into account as well as the strength of evidence for occupational causation [6,7]. One practical requirement would be to define the qualifying occupational exposure—either in terms of job title or occupational activities—in a way that could be corroborated by simple inquiry. The studies in Table 1 seem too heterogeneous to support the first of these options, while the second requires understanding of the frequency, duration and time course of wrist activities for which risks appear to be more than doubled.

Broadly, there is support for substantially more than a doubling of risk when repetitive wrist movements occupy a major part of the working day. Precise definition, however, requires interpolation, as different studies have defined repetitiveness in different ways. A possible option, based on a conservative reading of the evidence presented here, might be as follows: repeated palmar flexion and extension of the wrist (every 30 s or more often) for at least 20 h/week [22,23,35,39–42]. Forceful gripping can also more than double the risk of CTS, but reliable verification of the forces applied in a job might entail costs that were disproportionate to the levels of benefit that would be received by successful claimants.

In summary, a useful body of research now supports and extends previous conclusions that certain occupational hand-wrist activities materially increase the risk of CTS. Prolonged exposure to highly repetitive flexion and extension of the wrist should be avoided, and a case can be made to extend the current prescription of CTS for social security compensation to include work of this kind.

## Acknowledgements

This review was supported by a grant from the UK Industrial Injuries Advisory Council. We wish to thank Denise Gould who prepared the manuscript. The views expressed are those of the authors and not necessarily those of the Council.

## Conflicts of interest

None declared.

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