Review

Scand J Work Environ Health 2009;35(1):19-36

doi:10.5271/sjweh.1306

Associations between work-related factors and the carpal tunnel syndrome—a systematic review

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Refers to the following texts of the Journal: 1998;24(4):285-292 1997;23(5):364-369 1999;25 suppl 4:25-30

The following articles refer to this text: 2009;35(5):342-348; 2010;36(1):25-33; 2010;36(1):1-2; 2010;36(3):189-201; 2010;36(5):384-393; 2010;36(6):515-516; 2011;37(2):120-128; 2011;37(4):298-306; 2013;39(2):155-163; 2013;39(5):495-505; 2013;39(6):568-577; 2016;42(4):280-290; 2017;43(2):163-170

Key terms: carpal tunnel syndrome; force; hand–arm vibration; MSD; musculoskeletal disorder; nerve compression syndrome; repetitiveness; review; systematic review; work-related factor

This article in PubMed: www.ncbi.nlm.nih.gov/pubmed/19277433

Scand J Work Environ Health 2009;35(1):19–36

Associations between work-related factors and the carpal tunnel syndrome—a systematic review

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van Rijn RM, Huisstede BMA, Koes BW, Burdorf A. Associations between work-related factors and the carpal tunnel syndrome—a systematic review. *Scand J Work Environ Health* 2009;35(1):19–36.

Objectives The aim of this study was to make a quantitative assessment of the exposure–response relationships between work-related physical and psychosocial factors and the occurrence of carpal tunnel syndrome (CTS) in occupational populations.

Methods A systematic review of the literature was conducted on the associations of type of work, physical load factors, and psychosocial aspects at work to the occurrence of CTS. The associations between work factors and CTS were expressed in quantitative measures, namely, odds ratios (OR) or relative risks.

Results Jobs with the highest risk of CTS included work in the meat- and fish-processing industry, forestry work with chain saws, and electronic assembly work (OR 76.5, 21.3, and 11.4, respectively). The occurrence of CTS was associated with high levels of hand–arm vibration, prolonged work with a flexed or extended wrist, high requirements for hand force, high repetitiveness, and their combination. No association was found between any psychosocial risk factor and CTS. Contradictory findings were reported for associations between computer work and CTS.

Conclusions This review provides consistent indications that CTS is associated with an average hand force requirement of >4 kg, repetitiveness at work (cycle time <10 seconds, or >50% of cycle time performing the same movements), and a daily 8-hour energy-equivalent frequency-weighted acceleration of 3.9 m/s^2.

Key terms force, hand–arm vibration, musculoskeletal disorder, nerve compression syndrome, repetitiveness.

Hand–arm symptoms are a common problem in society, especially among the working population. Of these, carpal tunnel syndrome (CTS) is the most frequently reported neuropathy of the upper extremity (1–3). CTS results from the compromise of the median nerve function at the wrist as a result of increased pressure in the carpal tunnel (1). The clinical diagnosis of CTS is based on a history of nocturnal pins and needles, numbness, or pain in the median nerve in the innervated area of the fingers and hand, which often causes the patient to awaken at night, supported by abnormalities appearing in an electrodiagnostic examination (4). Provocation tests do not necessarily contribute to the clinical diagnosis of CTS (5).

CTS can have serious economic consequences. Feuerstein et al (6) stated that 57% of all costs associated with occupational upper-extremity disorders were due to CTS. Furthermore, Silverstein et al (7) reported an average yearly claim rate for CTS of 27.3 per 10 000 full-time workers.

A review of occupational populations showed a wide range in the prevalence of CTS (0.6– 61%), the lowest prevalence occurring for industrial workers and the highest for grinders, butchers, grocery store workers, and frozen food factory workers with workers using high-force, high-repetitive gripping (8). Hagberg et al concluded that exposure to physical load (such as repetitive and forceful gripping) is a major risk factor for CTS (8). Palmer et al (9) judged that there is reasonable evidence that regular and prolonged use of handheld vibrating tools increases the risk of CTS at least twofold and that there is substantial evidence for similar or even higher risks from prolonged and highly repetitious flexion and extension of the wrist, especially when combined with a forceful grip. At the same time, the balance of evidence concerning keyboard and computer work did not indicate

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an important association with CTS (9). Furthermore, the associations between physical risk factors (repetition, force, vibration) have been confirmed in several other reviews (10–12). The risk of developing upper-extremity symptoms is also influenced by psychosocial work characteristics. The reviews of Bongers et al (13) and Van den Heuvel et al (14) have presented evidence of an association between high job demands and low social support with upper-extremity symptoms. In addition, a review of the National Research Council concluded that high job demands and high job stress were associated with the occurrence of upper-extremity disorders (11). However, reviews on the association between psychosocial work characteristics and CTS are lacking.

The available reviews have presented overviews of the occupations in which workers are at risk of CTS and occupational risk factors for the occurrence of CTS, but they provide little guidance as to the duration and magnitude of exposure to risk factors that are associated with the development of CTS. Hence it remains a matter of debate whether it will be possible to derive exposure levels that will not increase the occurrence of CTS in occupational populations.

Therefore, this systematic review of the available evidence was conducted with the aim of providing a quantitative assessment of the exposure–response relationships between work-related physical and psychosocial factors and the occurrence of CTS in occupational populations.

Methods

Literature search

Comprehensive literature searches were conducted by the first author (RMvR) in MEDLINE (from 1966 to September 2007), EMBASE (from 1984 to September 2007), and the Cochrane Central Register of Controlled Trials (September 2007). The following keywords were used: (carpal tunnel syndrome OR median nerve) AND (work related OR physical load OR psychosocial load OR exposure) AND (association OR risk factors OR odds ratio OR relative risk). The result of the complete search strategy is available on request.

Two reviewers (RMvR and BMAH) independently selected the articles, initially based on title and abstract (figure 1). For final inclusion, the articles had to fulfill all of the following criteria: (i) the occurrence of CTS was reported in occupational populations, (ii) a quantitative description of measures of exposure or a description of a distinct exposure pattern at job level was presented, (iii) the association between work-related risk factors and CTS was expressed in a quantitative measure, such as odds ratio (OR) or relative risk (RR), or sufficient raw data were provided with which to calculate these associations, and (iv) the article was published in a peer-reviewed scientific journal written in English, German, French, or Dutch. A consensus method was used to resolve disagreements.

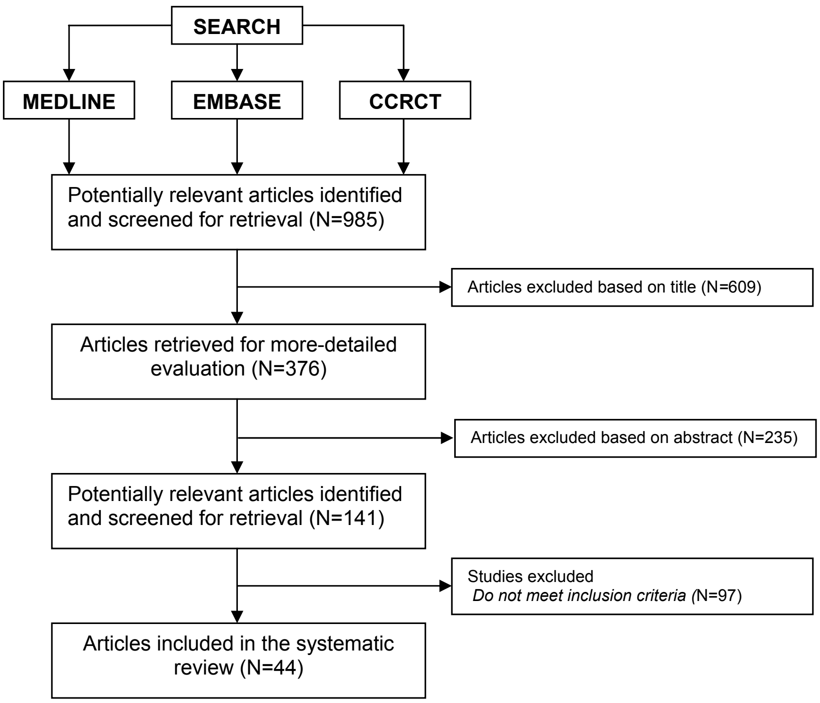

Figure 1. Flow chart of the selected articles. (CCRCT = Cochrane Central Register of Controlled Trials)

Assessment of methodological quality

A quality assessment list was constructed with the use of criteria from Huisstede et al (15), Lievense et al (16), Van Tulder et al (17) and the Dutch Cochrane Centre (18), which were adapted to the specific aim of this review (appendix I). The list covers five topics with 16 items concerning the study population, the assessment of exposure, the assessment of outcome, the study design and analysis, and the data presentation (table 1). Two reviewers (AB & BWK) independently assessed the quality of each study by scoring each criterion as positive, negative, or unclear. Disagreements were resolved by consensus. The quality score for every study was calculated by summing the number of positive criteria.

Data extraction

Relevant information on study population, study design, outcome ascertainment, exposure characteristics, measure of association, and confounding factors was extracted from the articles by the first author (RMvR) using a standardized form. The core findings in each article were expressed by measures of association (OR or RR value) with corresponding 95% confidence intervals (95% CI). Where possible, these associations were directly extracted from the original article. For articles in which this information was not presented, associations were calculated if sufficient raw data were provided.

Data analysis

In this review three types of statistical associations were distinguished. The association was described as positive when a higher value of the risk factor was statistically associated with the occurrence of CTS. In a negative association, a higher value of the risk factor was statistically associated with a lower occurrence of CTS. In null associations, the risk estimate did not differ statistically from unity. The null associations were further evaluated as to whether the results actually suggest the absence of an effect or whether the studies were inconclusive due to a lack of information or a lack of statistical power.

First, we focused on the association between type of work (based on job descriptions with a distinct exposure pattern) and the occurrence of CTS. Second, we evaluated the associations of five types of exposure, namely, force, repetitiveness, hand–arm vibration, combined exposure measure, and awkward postures, with the occurrence of CTS. Finally, we addressed the associations between psychosocial risk factors and the occurrence of CTS.

Pooling the results of individual studies was considered only when health outcomes were clinically homogeneous, the measures of exposure were sufficiently similar according to the reviewers, and comparable study designs were used. Furthermore, the outcome of the quality assessment was used in a sensitivity analysis to evaluate whether design characteristics and the methodological quality of the studies had an impact on the reported associations between work-related risk factors and CTS.

Results

Characteristics of included studies

Our search of the literature resulted in 985 potentially relevant articles (figure 1). Of these, 44 publications met our inclusion criteria (30 cross-sectional studies, 9 case–control studies, and 5 cohort studies (appendix II). A total of 22 articles compared the occurrence of CTS across occupations (table 2), and 23 articles reported on the association between physical risk factors and CTS (table 3), of which two articles also compared the occurrence of CTS across occupations. Four articles reported on the association between psychosocial factors and CTS (table 4), of which three articles also reported on the association between physical risk factors and CTS.

Methodological quality

Table 5 presents the methodological quality assessment of the included studies. The initial agreement of the two reviewers was 68% (480 of 704 items). The initial disagreements were all solved in a consensus meeting.

Table 1. Methodological quality assessment.

Criteria	Score
Study population	
1 Study groups (exposed and unexposed) are clearly defined	+ / – / ?
2 Participation ≥70%	+ / – / ?
3 Number of cases ≥50	+ / – / ?
Assessment of exposure	
Adequate description of the exposure	
4 Exposure definition	+ / – / ?
5 Assessment of exposure	+ / – / ?
6 Blind for outcome status	+ / – / ?
Assessment of outcome (specific disorder)	
Adequate description of the outcome	
7 Outcome definition	+ / – / ?
8 Assessment method	+ / – / ?
9 Blind for exposure status	+ / – / ?
Study design	
10 Prospective design	+ / – / ?
11 Inclusion and exclusion criteria	+ / – / ?
12 Follow-up period ≥1 year	+ / – / ?
13 Information between completers versus withdrawals	+ / – / ?
Analysis and data presentation	
14 Data presentation	+ / – / ?
Identifying confounders	
15 Consideration of confounders	+ / – / ?
16 Control for confounding	+ / – / ?

Table 2. Studies that report carpal tunnel syndrome (CTS) for one job title in comparison with another job title. (A = combination of typical symptoms and electrodiagnostic testing, B = symptoms and physical examination or electrodiagnostic testing, C = questionnaire only, CS = cross-sectional, CC = case–control, OR = odds ratio, 95% CI = 95% confidence interval)

Author	Design	Outcome assessment	Study population		Results	
			Exposed	Reference	OR	95% CI
Margolis & Kraus, 1987 (37)	CS	C	Female supermarket checkers using laser scanner (N=691)	Female supermarket checkers not using laser scanner (N=291)	1.05	0.74–1.49
Barnhart et al, 1991 (33)	CS	A	Ski manufacturing workers (N=106)	Repetitive jobs versus nonrepetitive jobs	1.63	0.83–3.21
Bovenzi et al, 1991 (21)	CS	A	Vibration-exposed forestry workers using chain saws (N=65)	Workers who performed maintenance activities in a hospital (N=31)	21.3	2.73–166.14
Moore & Garg, 1994 (39)	CS	A	Employees with hazardous jobs in a pork-processing plant (N=79)	Employees with safe jobs in a pork-processing plant (N=37)	3.34	0.92–12.18
Frost et al, 1998 (23)	Cohort	A	Slaughterhouse workers (N=743)	Repairmen or chemical workers in chemical plant (N=398)	4.24	1.77–10.13
Abbas et al, 2001 (19)	CS	A	Electronics assembly workers (N=104)	Clerical and administrative workers (N=94)	11.4	3.6–40.2
Kim et al, 2004 (25)	CS	A	Meat and fish processing workers (N=69)	Managers, secretary, and keepers (N=28)	76.5	9.68–604.5
Gell et al, 2005 (35)	Cohort	A	Industrial workers (N=173)	Clerical workers (N=259)	1.06	0.49–2.28
Bonfiglioli et al, 2007 (34)	CS	A	Cashiers	Office workers (N=98)		
			Part-time (N=155)		1.06	0.35–3.21
			Full-time (N=71)		1.81	0.52–6.34
McCormack et al, 1990 (38)	CS	B	Textile workers	Cleaners, sweepers, machinery and transport workers (N=468)		
			Boarding (N=296)		0.52	0.11–2.61
			Knitting (N=352)		0.66	0.16–2.67
			Packer or folder (N=369)		0.42	0.08–2.09
			Sewing (N=562)		0.97	0.32–2.91
Park et al, 1992 (30)	CC	B	Cases with ≥1 insurance claims for CTS	Controls with ≥1 insurance claims for other causes		
			Trim or chassis assembly work (N=60)		3.1	2.1–4.6
			Spray painting (N=3)		3.6	0.99–13.1
			Sewing work (N=21)		2.0	1.1–3.6
			Foundry work (N=17)		9.0	4.7–17.1
			Axle assembly work (N=9)		4.2	1.9–9.4
			Stamping and pressing work (N=29)		2.9	1.8–4.7
Liss et al, 1995 (28)	CS	C	Dental hygienists (N=950)	Dental assistants (N=108)	3.7	1.1–11.9
Pocekay et al, 1995 (31)	CS	C	Photolithography or etching in semiconductor industry	Nonfabrication room	4.22	1.83–9.17
Silverstein & Hughes, 1996 (40)	CS	B	Workers in power and recovery department in pulp and paper mill (N=23)	Paper machine operators (N=17)	7.0	0.77–63.6
Leclerc et al, 1998 (27)	CS	B	Employees in different branches of activity at the national level (assembly line, clothing and shoe industry, food industry, supermarket cashiers)	Jobs with repetitive tasks versus jobs without repetitive tasks	5.65	2.74–11.63
Gorsche et al, 1999 (36)	CS	B	Tool users in repetitive jobs in a meat packing plant (N=521)	Nontool users in repetitive jobs (N=89) and supervisors and clerical workers (N=55) in a meatpacking plant	1.2	0.75–1.92
Nordander et al, 1999 (66)	CS	B	Fish-processing workers (N=322)	Referents employed as caretakers, workers in community parks and gardens, workers repairing and maintaining equipment and machines, day nurses, caretakers (N=337)	5.3	0.62–45.61
Diaz, 2001 (22)	CS	B	Nurse anesthetists (N=63)	Operating room nurses (N=181)	3.32	1.27–8.17
Kutluhan et al, 2001 (26)	CS	B	Female carpet workers (N=140 hands)	Housewives (N=60 hands)	3.98	1.34–11.84
Jianmongkol et al, 2005 (24)	CS	B	Workers in a fishnet factory (N=550)	Office workers or housemaids (N=112)	1.84	1.03–3.29

(continued)

Table 2. Continued.

Author	Design	Outcome assessment	Study population: Exposed	Study population: Reference	Results: OR	Results: 95% CI
Wang et al, 2005 (32)	CS	B	Female betel pepper leaf cullers (N=20)	Female noncullers (N=47)	9.78	2.24–42.63
Ali & Sathiyasekaran, 2006 (20)	CS	B	System administrators (N=50)	Data entry typists (N=244)	2.5	1.2–5.2
Ali & Sathiyasekaran, 2006 (20)	CS	B	Software developers (N=143)	Data entry typists (N=244)	1.0	0.6–1.9

Table 3. Studies of associations between physical risk factors (force, repetitiveness, hand–arm vibration, combined exposure measure, posture) and carpal tunnel syndrome (CTS). (A = combination of typical symptoms and electrodiagnostic testing, B = symptoms and physical examination or electrodiagnostic testing, C = questionnaire only, CS = cross-sectional, CC = case–control, OR = odds ratio, 95% CI = confidence interval)

Author	Design	Outcome assessment	Study population	Physical risk factor	Results: OR	Results: 95% CI
Force						
Wieslander et al, 1989 (46)	CC	A	Men operated upon for CTS (34 cases) versus other patients with surgery and general population referents (N=143)	Work causing great load on wrist 1–20 versus <1 year >20 versus <1 year	 1.7 2.1	 0.7–3.9 0.8–5.5
de Krom et al, 1990 (43)	CC	A	CTS patients in a neurology department of a hospital (156 cases) and a random sample from the general population (473 referents)	Pinch grasp 1–7 week versus 0 hours/week 8–19 versus 0 hours/week 20–40 versus 0 hours/week	 0.9 0.8 0.7	 0.8–1.1 0.5–1.3 0.3–1.6
Roquelaure et al, 1997 (42)	CC	A	Workers with CTS (65 cases) and workers without CTS (65 referents) in 3 plants where TV sets, shoes and automobile brakes were manufactured	High force (yes; no)	9.0	2.4–33.4
Lam & Thurston, 1998 (41)	CC	A	Workers operated upon for CTS (512 cases) and workers in the general population (1 400 403 referents)	Manual work Moderate versus light Heavy versus light	 2.36 2.11	 1.34–4.13 1.20–3.71
Abbas et al, 2001 (19)	CS	A	Electronics assembly workers (N=104)	Precision grip versus power grip Intermediate grip versus power grip	6.5 2.0	1.1–39.2 0.3–11.9
Nathan et al, 2002 (45)	Cohort	A	Industrial workers (steel mill, meat or food packaging, electronics, plastics) with 11-year fol-	Heavy lifting (1 to 5 Likert scale) Force (1 to 5 Likert scale)	0.99 1.00	0.76–1.29 0.75–1.34
Nathan et al, 2005 (44)	Cohort	A	Industrial workers (steel mill, meat or food packaging, electronics, plastics) with 17-year follow-up (N=148)	Heavy lifting (1 to 5 Likert scale) Force (1 to 5 Likert scale)	0.39 [a] 3.50 [b]	.. ..
Repetitiveness						
Wieslander et al, 1989 (46)	CC	A	Men operated upon for CTS (34 cases) versus other patients with surgery and other referents from the general population (N=143)	Repetitive movement of wrist 1–20 versus <1 year >20 versus <1 year	 1.5 4.6	 0.5–4.4 1.8–11.9
Chiang et al, 1990 (47)	CS	A	Frozen food factory employees (N=207)	High repetitive movements versus no cold and low repetitive movements Handling cold items (-12–15°C) and high repetitive movements versus no cold and low repetitive movements	2.18 9.39	0.23–21.27 2.37–37.19
Roquelaure et al, 1997 (42)	CC	A	Workers with CTS (65 cases) and workers without CTS (65 referents) in 3 plants where TV sets, shoes and automobile brakes were manufactured	Work cycle <10 seconds (yes; no)	8.8	1.8–44.4

(continued)

Table 3. Continued.

Author	Design	Outcome assessment	Study population	Physical risk factor	Results OR	Results 95% CI
Latko et al, 1999 (50)	CS	A	Manufacturing workers (N=352)	Medium repetitive work versus low repetitive work	1.95	0.38–9.96
				High repetitive work versus low repetitive work	3.13	0.87–11.25
Nathan et al, 2002 (45)	Cohort	A	Industrial workers (steel mill, meat or food packaging, electronics, plastics) with 11-year follow-up (N=471)	Repetition (1 to 5 Likert scale)	1.05	0.79–1.39
Nathan et al, 2005 (44)	Cohort	A	Industrial workers (steel mill, meat or food packaging, electronics, plastics) with 17-year follow-up (N=166)	Repetition (1 to 5 Likert scale)	0.50 [c]	..
Roquelaure et al, 2001 (49)	CS	B	Workers (N=134) in 5 production units of a large, modern mechanized footwear factory	Work cycle time <30 seconds (yes; no)	0.7	0.2–2.3
				Rapid trigger movements (yes; no)	2.8	0.6–11.5
Babski-Reeves & Crumtpon-Young, 2002 (48)	CS	B	Employees of a fish-processing facility (N=53)	High repetition (cycle time <30 seconds) versus low repetition	0.96	0.35–2.64
Hand–arm vibration						
Wieslander et al, 1989 (46)	CC	A	Men operated upon for CTS (34 cases) versus other patients with surgery and general populations referents (N=143)	Use of vibrating tools		
				1–20 versus <1 year	2.7	1.1–6.7
				>20 versus <1 year	4.8	1.5–15.6
Nathan et al, 2002 (45)	Cohort	A	Industrial workers (steel mill, meat or food packaging, electronics, plastics) with 11-year follow-up (N=471)	Vibrations (yes; no)	2.28	0.84–6.29
Nordstrom et al, 1997 (52)	CC	B	Workers with newly diagnosed CTS (182 cases) and random sample of workers from the general population (188 referents)	Power tools or machinery (mean)		
				0.08–0.75 versus 0 hours/day	0.60	0.27–1.36
				1–2 versus 0 hours/day	1.43	0.66–3.13
				2.5–5.5 versus 0 hours/day	1.20	0.59–2.45
				6–11 versus 0 hours/day	2.52	1.13–5.62
Roquelaure et al, 2001 (49)	CS	B	Workers (N=134) in 5 production units of a large, modern mechanized footwear factory	Vibration transmitted to the hand (yes; no)	1.8	0.2–10.8
Bovenzi et al, 2005 (51)	CS	B	Female furniture workers (N=100) and female office workers of the NHS (N=100)	Vibration (4.7 m/s^2) + physical stress factors versus no vibration or physical stress factors	3.8	1.0–13.7
				Vibration (3.9 m/s^2) + physical stress factors versus no vibration or physical stress factors	3.1	1.3–7.2
				Physical stress factors alone versus no vibration or physical stress factors	1.5	0.2–12.0
Combined exposure measure						
Chiang et al, 1993 (53)	CS	A	Workers in the fish-processing industry (N=207)	High force or high repetition versus low force and low repetition	2.02	0.71–5.72
				High force and high repetitive versus low force and low repetition	4.48	1.31–15.3
Silverstein et al, 1987 (54)	CS	B	Employees from 7 different industrial sites (N=652)	High force and low repetition versus low force and low repetition	1.62	0.15–17.99
				Low force and high repetition versus low force and low repetition	3.34	0.34–32.51
				High force and high repetition versus low force—low repetition	8.38	1.03–67.78
Yagev et al, 2001 (55)	CC	B	Workers with CTS diagnosed in the hospital (123 cases) and workers without CTS but referred for complaints (246 referents)	Low force and high repetitive job versus low force and low repetitive job	4.72	1.8–12.5
				High force and low repetitive job versus low force and low repetitive job	3.21	1.5–6.9
Cosgrove et al, 2002 (56)	CC	B	Railroad workers with confirmed CTS in a physical examination (389 cases) and railroad workers with CTS complaints but without a confirmed diagnosis (511 referents) from the compensation claim system	Low force and high repetition versus low force and low repetition	0.72	0.47–1.09
				High force and low repetition versus low force and low repetition	0.84	0.59–1.18
				High force and high repetition versus low force and low repetition	1.09	0.21–5.54

(continued)

Table 3. Continued.

Author	Design	Outcome assessment	Study population	Physical risk factor	Results	
					OR	95% CI
Posture						
de Krom et al, 1990 (43)	CC	A	CTS patients at a neurology department of a hospital (156 cases) and a random sample from the general population (473 referents)	Activities with flexed wrist 0–5 years ago		
				1–7 versus 0 hours/week	1.5	1.3–1.9
				8–19 versus 0 hours/week	3.0	1.8–4.9
				20–40 versus 0 hours/week	8.7	3.1–24.1
				Activities with extended wrist		
				1–7 versus 0 hours/week	1.4	1.0–1.9
				8–19 versus 0 hours/week	2.3	1.0–5.2
				20–40 versus 0 hours/week	5.4	1.1–27.4
				Activities with extended and flexed wrist in combination		
				1–7 versus 0 hours/week	1.1	0.9–1.2
				8–19 versus 0 hours/week	1.2	0.8–1.7
				20–40 versus 0 hours/week	1.4	0.7–2.9
				Typing		
				1–7 versus 0 hours/week	0.9	0.6–1.4
				8–19 versus 0 hours/week	0.8	0.3–2.5
				20–40 versus 0 hours/week	0.7	0.1–6.0
Lam & Thurston, 1998 (41)	CC	A	Workers operated upon for CTS (512 cases) and workers in general population (1 400 403 referents)	Clerical work (long keyboard use versus short keyboard use)	1.01	0.52–1.95
Stevens et al, 2001 (60)	CS	A	Computer users at a medical facility (N=249)	Occasionally mouse use versus no mouse use	1.5	0.32–7.04
				Frequently mouse use versus no mouse use	3.4	0.71–15.8
				Currently typewriter use versus no typewriter use	0.90	0.40–2.03
Nathan et al, 2002 (45)	Cohort	A	Industrial workers (steel mill, meat or food packaging, electronics, plastics) with 11-year follow-up (N=471)	Keyboard use (1 to 5 Likert scale)	0.95	0.74–1.23
Morgenstern et al, 1991 (29)	CS	C	Female grocery checkers (N=1053)	Workhours per week		
				26–34 versus <26 hours	1.53	0.95–2.44
				>34 versus <26 hours	1.86	1.12–3.08
				Years worked		
				5–9 versus <5 years	0.91	0.53–1.58
				>9 versus <5 years	1.74	0.96–3.16
Blanc et al, 1996 (58)	CC	C	Workers with self-reported CTS (384 cases) versus workers without self-reported CTS (27 260 referents)	Hand-bending more than 2 hours/day (yes; no)	1.3	1.2–1.4
Nordstrom et al, 1997 (52)	CC	B	Workers with newly diagnosed CTS (182 cases) and a random sample of workers from the general population (188 referents)	Bending hands or wrists (mean)		
				0.25–1.75 versus 0 hours/day	1.34	0.64–2.80
				2–3 versus 0 hours/day	1.23	0.60–2.53
				3.5–6 versus 0 hours/day	2.33	1.24–4.36
				7–16 versus 0 hours/day	2.47	1.38–4.43
Roquelaure et al, 2001 (49)	CS	B	Workers (N=134) in 5 production units of a large, modern mechanized footwear factory	Wrist deviation (yes/no)	1.0	0.4–3.1
				Wrist flexion >45 degrees (yes; no)	0.6	0.1–3.2
				Wrist extension >45 degrees (yes; no)	1.2	0.4–3.4
Andersen et al, 2003 (57)	Cohort	B	Professional technicians (N=5658) with a 1-year follow-up	Right-handed mouse use		
				2.5–<5 versus 0–<2.5 hours/week	0.7	0.3–1.9
				5–<10 versus 0–<2.5 hours/week	1.9	0.9–4.0
				10–<15 versus 0–<2.5 hours/week	1.6	0.8–3.3
				15–<20 versus 0–<2.5 hours/week	2.0	0.9–4.2
				20–<25 versus 0–<2.5 hours/week	2.6	1.2–5.5
				25–<30 versus 0–<2.5 hours/week	3.2	1.3–7.9
				≥30 versus 0–<2.5 hours/week	2.7	1.0–7.6
				Keyboard use		
				2.5<5 versus 0–<2.5 hours/week	0.9	0.4–1.8
				5<10 versus 0–<2.5 hours/week	0.8	0.4–1.5
				10<15 versus 0–<2.5 hours/week	1.2	0.6–2.5
				5<20 versus 0–<2.5 hours/week	0.8	0.4–1.5
				≥20 versus–<2.5 hours/week	1.4	0.5–4.3

(continued)

Table 3. Continued.

Author	Design	Outcome assessment	Study population	Physical risk factor	Results OR	95% CI
Ali & Sathiyasekaran, 2006 (20)	CS	B	Computer professionals (N=648)	Hand position		
				Flexed or extended versus neutral	1.3	0.8–2.1
				Computer work		
				8–1 versus <8 hours/day	3.6	1.3–10.3
				>12 versus <8 hours/day	4.4	1.3–14.9
				4–8 versus <4 years	2.1	1.3–3.6
				>8 versus <4 years	2.7	1.3–5.8
Hou et al, 2007 (59)	CS	C	Male operators of visual display terminal (N=340)	Daily keyboard operation hours		
				(≥4 versus <4 hours/day)	1.34	0.36–5.00
				Daily mouse operation hours (h/day)		
				(≥4 versus <4 hours/day)	0.85	0.27–2.65

[a] P-value 0.070.
[b] P-value 0.064.
[c] P-value 0.046.

Table 4. Studies on associations between psychosocial risk factors and carpal tunnel syndrome (CTS). (A = combination of typical symptoms and electrodiagnostic testing, B = symptoms and physical examination or electrodiagnostic testing, CS = cross-sectional, CC = case–control, OR = odds ratio, 95% CI = 95% confidence interval)

Author	Design	Outcome assessment	Study population	Psychosocial risk factor	Results OR	95% CI
Werner et al, 2005 (67)	Cohort	A	Auto assembly workers (N=166) with a 1-year follow-up	High social support versus low social support	0.69	0.48–0.99
Nordstrom et al, 1997 (52)	CC	B	Workers with newly diagnosed CTS (182 cases) and a random sample of workers from the general population (188 referents)	Job control (1 very little to 5 very much)		
				2.8–3.4 versus 1–2.7	0.80	0.44–1.47
				3.6–3.8 versus 1–2.7	0.36	0.18–0.71
				4–4.4 versus 1–2.7	0.46	0.24–0.86
				4.6–4.8 versus 1–2.7	0.42	0.21–0.83
Roquelaure et al, 2001 (49)	CS	B	Workers (N=134) in 5 production units of a large, modern mechanized footwear factory	Permanent time pressure (yes; no)	1.3	0.4–4.1
				Few possibilities to take breaks (yes; no)	2.5	0.8–8.1
				Work strongly controlled by superiors (yes; no)	0.5	0.2–1.3
				High score for work demand (yes; no)	1.7	0.5–5.4
				Low score for task control (yes; no)	1.3	0.4–3.8
				Low score for social support (yes; no)	1.6	0.5–4.9
Andersen et al, 2003 (57)	Cohort	B	Professional technicians (N=5658) with a 1-year follow-up	High demands (yes; no)	1.3	0.9–1.8
				Low control (yes; no)	0.9	0.7–1.4
				Low social support (yes; no)	1.2	0.9–1.8
				Time pressure (yes; no)	1.0	0.7–1.6

Studies reporting CTS by job title (table 2) in comparison with articles that reported the risk of CTS by physical and psychosocial risk factors (tables 3 and 4) had a lower mean quality score, although not significant, 8.05 versus 9.23, respectively. Figure 2 shows that the methodological quality score of the included articles did not improve over time. Furthermore, the methodological quality score is not related to the level of significance of the association between occupation or risk factors and the occurrence of CTS.

Outcome assessment

In tables 2–4, the included studies have been classified by the method of outcome assessment. In 19 studies (43%), the diagnosis of CTS included both the presence of typical symptoms (numbness, tingling, burning, or pain in median innervate fingers) and a positive electrodiagnostic finding (impairment of median nerve function at the wrist). In the rest of the articles, the diagnosis of CTS included symptoms (N=9, 20%), a physical examination (N=2, 5%), an electrodiagnostic examination (N=2, 5%), or a combination of symptoms and a physical examination (N=12, 27%). Of the studies with an accurate diagnostic method (ie, typical symptoms and electrodiagnostic examination), 58% (N=11) reported a significant association between work-related factors and CTS, against 64% (N=16) of the studies with a less accurate diagnostic method.

Table 5. Methodological quality scores of the included articles.

Reference	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	Score
Andersen et al, 2003 (57)	+	+	+	+	+	+	+	+	+	+	?	+	+	+	+	+	15
Frost et al, 1998 (23)	+	+	+	+	+	+	+	+	–	–	+	+	+	+	+	+	14
Silverstein et al, 1987 (54)	+	+	–	+	+	+	+	+	+	–	+	–	+	+	+	+	13
Roquelaure et al, 2001 (49)	+	+	–	+	+	?	+	+	?	+	+	+	+	+	+	+	13
Barnhart et al, 1991 (33)	+	–	–	+	+	+	+	+	+	–	+	–	+	+	+	+	12
Gorsche et al, 1999 (36)	+	+	–	+	–	–	+	+	–	+	+	+	+	+	+	+	12
Latko et al, 1999 (50)	+	+	–	+	+	+	+	+	+	–	+	–	–	+	+	+	12
Gell et al, 2005 (35)	+	+	–	+	–	+	+	?	?	+	+	+	+	+	+	+	12
Bovenzi et al, 2005 (51)	+	?	–	+	+	+	+	+	+	–	+	–	–	+	+	+	11
Leclerc et al, 1998 (27)	+	+	+	+	+	–	+	+	–	–	+	–	–	+	+	+	11
Nathan et al, 2002 (45)	+	–	–	+	–	+	+	+	?	+	+	+	–	+	+	+	11
Werner et al, 2005 (67)	+	–	–	+	+	?	+	+	?	+	+	+	–	+	+	+	11
Wieslander et al, 1989 (46)	–	+	–	+	–	–	+	+	+	–	+	–	+	+	+	–	10
Chiang et al, 1990 (47)	+	?	+	+	?	+	+	+	+	–	–	–	–	+	+	+	10
Chiang et al, 1993 (53)	+	?	–	+	+	+	+	+	?	–	+	–	–	+	+	+	10
Roquelaure et al, 1997 (42)	+	?	+	+	+	+	+	+	+	–	+	–	–	+	–	–	10
Bovenzi et al, 1991 (21)	–	+	–	+	+	–	+	+	?	–	+	–	+	+	+	+	10
Nathan et al, 2005 (44)	–	–	–	+	–	+	+	+	?	+	–	+	+	+	+	+	10
Ali & Sathiyasekaran, 2006 (20)	–	+	+	+	–	–	+	+	–	–	+	–	+	+	+	+	10
Nordstrom et al, 1997 (52)	+	+	+	+	–	–	+	–	?	–	+	–	–	+	+	+	9
Nordander et al, 1999 (66)	–	+	+	+	+	+	+	+	–	–	+	–	–	+	–	–	9
Jianmongkol et al, 2005 (24)	+	+	+	–	+	?	+	+	?	–	+	–	+	+	–	–	9
Bonfiglioli et al, 2007 (34)	–	+	–	+	+	?	+	+	–	–	+	–	–	+	+	+	9
de Krom et al, 1990 (43)	–	+	+	?	–	–	+	+	?	–	+	–	?	+	+	+	8
Liss et al, 1995 (28)	+	–	+	+	–	–	+	–	–	–	+	–	–	+	+	+	8
Abbas et al, 2001 (19)	+	+	–	–	–	?	+	+	?	–	–	–	+	+	+	+	8
Kim et al, 2004 (25)	+	+	+	+	–	–	+	+	?	–	+	–	?	+	–	–	8
McCormack et al, 1990 (38)	+	+	–	+	–	?	+	+	?	+	–	–	–	+	–	–	7
Morgenstern et al, 1991 (29)	–	+	+	–	+	?	+	–	–	–	–	–	–	+	+	+	7
Moore, & Garg, 1994 (39)	–	?	–	+	+	+	+	–	+	–	+	?	?	+	–	–	7
Stevens et al, 2001 (60)	+	+	–	–	–	–	+	+	?	–	+	–	+	+	–	–	7
Yagev et al, 2001 (55)	–	?	+	+	–	–	+	+	–	–	–	–	–	+	+	+	7
Cosgrove et al, 2002 (56)	?	?	+	+	?	?	+	+	?	–	+	–	?	?	+	+	7
Park et al, 1992 (30)	–	?	+	–	–	?	+	–	?	–	+	–	–	+	+	+	6
Blanc et al, 1996 (58)	–	?	+	+	+	–	+	–	–	–	+	–	–	+	–	–	6
Diaz, 2001 (22)	+	?	–	?	+	?	+	+	–	–	+	–	–	+	–	–	6
Hou et al, 2007 (59)	+	–	–	+	?	–	–	–	–	–	+	–	–	+	+	+	6
Margolis & Kraus, 1987 (37)	–	+	+	–	+	–	–	–	–	–	+	–	–	+	–	–	5
Pocekay et al, 1995 (31)	–	+	+	+	–	–	+	–	–	–	–	–	–	+	–	–	5
Silverstein & Hughes, 1996 (40)	–	–	–	+	–	?	+	+	?	–	+	–	–	–	–	–	4
Lam & Thurston, 1998 (41)	–	–	+	+	–	–	+	–	?	–	–	–	–	+	–	–	4
Kutluhan et al, 2001 (26)	–	?	–	–	+	?	+	+	?	–	?	–	?	+	–	–	4
Babski-Reeves & Crumtpon-Young, 2002 (48)	–	?	–	+	+	?	+	–	+	–	–	–	–	–	–	–	4
Wang et al, 2005 (32)	–	–	–	–	–	?	+	+	?	–	+	–	–	+	–	–	4

Job title and carpal tunnel syndrome

A total of 14 articles described significant differences in the occurrence of CTS between occupations, the OR values ranging from 1.86 to 76.5 (19–32). In eight studies, no significant differences were observed, the OR values ranging from 0.91 to 1.63 (33–40). Jobs with the highest increased occurrence of CTS included work in the meat- and fish-processing industry (OR 76.5), forestry work with chain saws (OR 21.3), and electronic assembly work (OR 11.4). Other jobs with an elevated occurrence of CTS (OR 2.0–5.0) were work in slaughterhouses, carpet work, and dental work. In these occupations the prevalence of CTS ranged from 6.3% to 22.8%.

Exposure and carpal tunnel syndrome

Force. Three articles found a significant association between exposure to force and CTS, with OR values of 2.11 to 9.0 (19, 41, 42). In the case–control study of Roquelaure et al (42), handling loads of >1 kg at least 10 times/hour was a risk factor for CTS. Moderate and heavy manual work, as reported by Lam et al (41), and

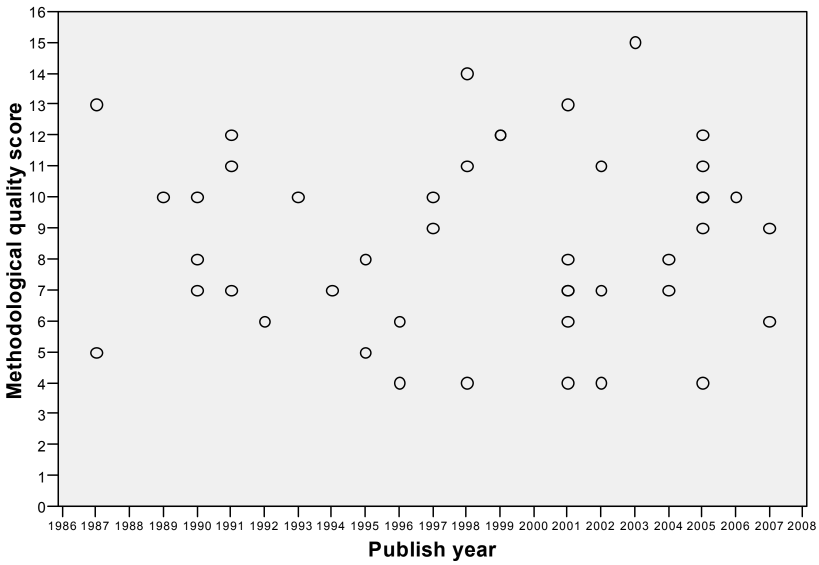

Figure 2. Association between methodological quality and the year of publication for all of the articles that evaluated the association between job title or risk factors and the development of carpal tunnel syndrome.

precision grip, as reported by Abbas et al (19), were associated with CTS, but these factors were not described in more detail. Null associations were reported in four articles, in which the duration of work with high loads on the wrist, the duration of using a pinch grasp, heavy lifting, and the relative intensity of force were described, the OR values ranging from 0.39 to 3.50 (43–46).

Repetitiveness. Five articles found a significant association between exposure to repetition and CTS, the OR values ranging from 0.50 to 9.39 (42, 44–47). The strongest associations were found for jobs with a work cycle of <10 seconds (42, 47). Contradictory results were observed for jobs with work cycles of <30 seconds, one study reporting an elevated OR value of 2.18 and other studies reporting OR values close to unity, with 0.7 and 0.96, respectively (47–49). Five articles reported null associations between exposure to repetitiveness and CTS (46–50).

Hand–arm vibration. Three articles reported a significant association between exposure to vibration and CTS, with OR values of 2.52 to 4.8 (46, 51, 52). An increased risk of CTS was found for workers using vibrating tools (1–20 years and >20 years) and power tools or machinery (6–11 hours/day) (46, 52). In the cross-sectional study of Bovenzi et al (51), 8-hour time-weighted exposures of 4.7 m/s^2 and 3.9 m/s^2 to hand–arm vibration were associated with CTS. Positive associations between hand–arm vibration and CTS, although not significant, were described by Roquelaure et al (49) and Nathan et al (45), with OR values of 1.8 and 2.28, respectively. The reported prevalence of CTS in both studies was around 14% with a prevalence of exposure to hand-arm vibration of 17%.

Combined exposure measure. Three cross-sectional studies found a significant relationship between exposure to a combination of risk factors (force, repetitiveness) and CTS (53–55). Silverstein et al (54) and Chiang et al (53) reported a significant relationship between exposure to high force–high repetition and CTS, with OR values of 8.38 and 4.48, respectively. In a study by Yagev et al (55) significant associations were also found between exposure to low force–high repetition (OR 4.72) and high force–low repetition (OR 3.21) and CTS, but these associations were not confirmed in other studies. The case–control study of Cosgrove et al (56) did not corroborate any of these findings.

Posture. Six articles presented significant associations between postural load and CTS (20, 29, 43, 52, 57, 58). Significant associations were found for activities with a flexed wrist for 1–7, 8–19 and 20–40 hours/week, activities with an extended wrist for 1–7, 8–19 and 20–40 hours/week, and bending hands or wrists for 3.5–6 and 7–16 hours/day, the OR values ranging from 1.3 to 8.7 (43, 52 ,58). In contrast are the results of Roquelaure et al (49) and Ali et al (20), who reported null associations between CTS and wrist deviation, wrist flexion, and wrist extension, the OR values ranging from 0.6 to 1.3.

In two studies, self-reported exposure to computer work for >8 hours/day and mouse use for >20 hours/week were associated with CTS, with OR values of 3.6 and 2.6, respectively (20, 57). In contrast, in five studies, no significant associations were found between CTS and the duration of keyboard use, the duration of mouse use, or the frequency of mouse use (OR 0.9–3.4) (41, 45, 57, 59, 60).

Psychosocial risk factors and carpal tunnel syndrome

Table 4 presents the characteristics of four studies that reported associations between psychosocial risk factors and CTS. None of the reported associations were statistically significant.

Discussion

This review evaluated the associations between exposure to physical and psychosocial risk factors and CTS. Frequent handling of loads, highly repetitive work with and without force requirements, hand–arm vibration, and activities with a flexed or extended wrist were associated with CTS. Occupations with the highest prevalence of CTS were jobs in the meat- and fish-processing industry, forestry work with chain saws, and electronic assembly work. Contradictory findings were observed for the duration of computer work.

The aforementioned conclusions are primarily based on evidence presented in cross-sectional and case–control studies, since only a small number of cohort studies was identified. Therefore, the causality of the reported associations between exposure and the occurrence of CTS cannot be established, especially since most of the studies relied on self-reported measures of exposure. The lack of cohort studies can partly be explained by the relatively modest incidence of CTS in occupational populations at risk. Nathan and his colleagues found 34 incident CTS cases among 256 industrial workers during an 11-year follow-up, resulting in an estimated incidence of 12.0 per 1000 person-years (45). In the prospective study of Gell et al (35) among 432 industrial and clerical workers with an average follow-up of 5.4 years, a similar incidence of 12.4 per 1000 person-years was observed. Given this low incidence, cohort studies with a low exposure prevalence will be strongly underpowered with respect to demonstrating significant associations, even with OR values of 2.0 or higher, unless very large populations are studied. The lack of sufficient power in studies is also demonstrated by the large confidence intervals in many cross-sectional studies, whereby even a study population with 652 workers was not sufficiently large enough to establish the significance of a meaningful association (OR 3.3) (54).

A larger heterogeneity among the studies was observed in the assessment of exposure to physical and psychosocial risk factors. With respect to exposure assessment, only 4 of 14 articles on the influence of force and repetitiveness used the same definition, based on the classical study of Silverstein and her colleagues from 1986 (61). Another important drawback is that 29 studies (66%) used questionnaires or interviews to determine the magnitude, frequency, or duration of exposure, and there is ample evidence that self-reports will introduce substantial misclassification in exposure and, thus, considerable attenuation of true associations (62). The heavy reliance on questionnaires for exposure assessment is also reflected in the fact that 20 of the 32 (67%) exposure measures with a significant association with CTS (as reported in table 3) were defined by duration in terms of hours per week or years, which is the exposure dimension with the least random misclassification when estimated by a questionnaire (62).

In about half of the studies (N=25, 57%) in this review, the diagnosis of CTS was determined with the use of a questionnaire, a physical examination, or an electrophysiological examination. In the remaining studies (N=19, 43%), the diagnosis was based on both symptoms and the results of an electrophysiological examination. The combination of a positive electrodiagnostic study and characteristic symptoms appears to have the best predictive value for a case definition of CTS (4). However, this strict method of diagnosing CTS leads to a low prevalence of the outcome. For example, in a large prospective study by Gerr et al (63), only three prevalent cases, and three incident cases were reported among 630 workers. It is of interest to note that only six studies (14%) relied on questionnaires only to estimate the presence of CTS, whereas 29 studies (66%) used questionnaires for exposure assessment. Thus it is reasonable to assume that the heterogeneity among studies is much larger for exposure assessment than for the ascertainment of CTS.

The scores on the methodological quality assessment ranged from 4 to 15 (on a scale from 0 to 16). As a result of a lack of cohort studies, items 12 (follow-up period ≥1 year) and 13 (prospective or retrospective study design) scored positive in only eight articles. Other critical items were "blinding to exposure status" during the verification of CTS (N=10) and "blinding of case status" during the exposure assessment (N=14). Blinding to exposure often failed since the physicians were aware of the occupation of the worker under examination, and blinding of CTS status often failed since the diagnostic procedure started with a questionnaire with self-reported exposure measures. The quality assessment of the exposure assessment strategy was restricted to three items, and therefore did not take into account several other issues that are important in the evaluation of exposure assessment, such as measurement error and the contrast in exposure magnitude and duration (64). The methodological quality was not associated with the presence of a significant association between work-related factors and CTS. It is an interesting observation that the methodological quality score of the included articles did not improve over time (figure 2), predominantly due to the publication of various studies in recent years that only compare the CTS prevalence across different jobs without any further investigation into underlying exposure patterns and, thus, exposure–response relationships.

Factors that may influence whether a study reports a significant association or not between a physical risk factor and CTS are lack of power, low incidence of outcome, low exposure prevalence, measurement error, and presence of confounding factors. However, the results of our review support the conclusions presented by Palmer et al (9). An excess risk to CTS was reported for assembly workers, meat-processing workers, and food-processing workers. In addition, prolonged use of handheld vibratory tools and prolonged and highly repetitious flexion or extension of the wrist increased the occurrence of CTS. The current review extends existing knowledge with a quantitative assessment of exposure–response relationships between work-related factors and CTS.

A meta-analysis with a pooling of data was considered only for the duration of computer work for >20 hours/week (20, 57, 59) and combined exposure to high force–high repetitiveness (53–55). With regard to computer work, the procedures for case ascertainment differed too much across studies, as was reflected in the prevalence estimates, which varied from 1.4% (57) to 13.1% (20). The contradictory findings for computer use and the development of CTS are in agreement with the conclusion of a recent review (65). In two cross-sectional studies (53, 54), a similar definition of force and repetitiveness was used, but, although significant associations were reported in the separate studies, the large heterogeneity of the risk estimates across studies made the pooling of results not possible. In comparison with other studies on repetitive jobs, it is suggested that harmful cycle times with repetitive movements are <10 seconds (42) rather than <30 seconds (48, 49).

Pooling study results was not possible for exposure to hand–arm vibration and the duration of flexion or extension of the wrist, although several studies have been carried out on these risk factors. With respect to hand–arm vibration, all of the studies consistently reported increased OR values, albeit not always significant associations. A comprehensive exposure assessment strategy was used by Bovenzi and his colleagues (51), who showed that an 8-hour energy-equivalent frequency-weighted acceleration of 3.9 m/s^2 was associated with CTS (51). This value is well above the action value of 2.5 m/s^2 described in the European directive on physical agents (68). The studies on flexion or extension of the wrist show large differences in exposure levels that are already associated with an increased occurrence of CTS, as was found for three case–control studies. Nordstrom et al (52) presented an increased risk of CTS with bending the wrist for >3 hours/day, Blanc et al (58) reported hand bending >2 hours/day as a risk factor, whereas, in the study of De Krom et al (43), the risk was already elevated when the wrist was extended or flexed for 1 hour/week. These results, all based on self-reported exposure, are too contradictory for drawing any meaningful conclusion about harmful exposure levels. In addition, the four studies on psychosocial risk factors have presented no indications for an association with CTS.

In summary, this systematic review provides consistent indications that CTS is associated with the following physical risk factors: average requirements for a hand force of >4 kilograms, repetitiveness at work (cycle time <10 seconds, or >50% of a cycle time during which the same movements are performed), and a daily 8-hour energy-equivalent frequency-weighted acceleration of 3.9 m/s^2. Prolonged or repeated flexion and extension of the wrist is a risk factor under scrutiny, but the available evidence does not permit us to provide some guidance on the levels of hazardous exposure levels.

Acknowledgments

Funding for this project was gratefully received from WorksafeBC, Richmond, Canada (grant RS2006-SR05).

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Received for publication: 31 July 2008

Appendix I

Operationalization of the methodological quality assessment

Criteria

Study population

1 Positive if at least 2 of the following 3 items in both groups were reported at baseline:
  a. Age [mean (standard deviation or 95% confidence interval), or dichotomized groups]
  b. Gender (number, percentage or both)
  c. Sport or leisure-time exposure

2 Positive if the participation of the exposed group and unexposed group was ≥70%

3 Positive if the total number of cases was ≥50

Assessment of exposure

Adequate description of the exposure

4 a. Positive if the exposure was clearly defined

5 b. Positive if the assessment of exposure was described

6 c. Positive if the exposure was assessed by an independent person and was not based on self-reported exposure

Assessment of outcome (specific disorder)

Adequate description of the outcome

7 a. Positive if the outcome was clearly defined

8 b. Positive if the method of assessment was suitable

9 c. Positive if the outcome was measured without knowledge of the exposure status by an independent person, thus not based on self-reported symptoms

Study design

10 Positive if the study design was prospective or a retrospective cohort

11 Positive if the inclusion and exclusion criteria were described

12 Positive if the follow-up period was ≥1 year

13 Positive if demographic information was given between completers versus withdrawals

Analysis and data presentation

14 Positive if risk estimates were presented or when raw data were given which allowed the calculation of risk estimates, such as odds ratios, prevalence ratios or relative risks

Identifying confounders

15 a. Positive if the considered confounders were described

16 b. Positive if the method used to control for confounding was described

Appendix II

Outcome criteria and assessment and exposure definition and assessment for each included study

Author	Outcome		Exposure	
	Criteria	Assessment	Definition	Assessment
Margolis & Kraus, 1987 (37)	Self-reported pain in hands or wrists; pain in wrist or hand that awakened at night; or numbness in hands or wrists or tingling in hands and fingers	Questionnaire	Use of laser scanner (yes; no)	Questionnaire
Silverstein et al, 1987 (54)	Pain, numbness or tingling in the median nerve distribution of the hand and nocturnal exacerbation and symptoms occurring >20 times or lasting >1 week in the previous year and no history of acute traumatic onset of symptoms and of rheumatoid arthritis and onset of symptoms in current job and positive Phalen's test or Tinel's sign and ruling out of cervical root, thoracic outlet, pronator teres syndromes	Interview, physical examination	High force (average hand force requirements >4 kg); repetition (low: cycle time of >30 seconds and <50% of cycle time involved in performance of the same kind of fundamental cycles; high: cycle time of <30 seconds or >50% of the cycle time involved in performance of the same kind of fundamental cycles)	Jobs were identified by plant walk-through, postural data from videotapes of at least 3 cycles for 3 subjects per job, electromyographic recordings used to estimate requirements for hand force
Wieslander et al, 1989 (46)	Diagnosis by hand surgeon and confirmed electroneurographically by measurement of the conduction velocities in the median nerve at the wrist level	Physical examination, electrodiagnostic examination	Duration of use of vibrating tools (year); duration of repetitive movement of wrist (year); duration of work causing great load on wrist (year)	Interview by telephone

(continued)

Author	Outcome		Exposure	
	Criteria	Assessment	Definition	Assessment
Chiang et al, 1990 (47)	Symptoms of numbness, pain or tingling in the fingers innervated by the median nerve and onset of CTS since working on current job and positive Tinel's sign or Phalen's test and no evidence of CTS-related systemic diseases or injuries	Interview, neurological screening and electrodiagnostic examination	Cold [handling frozen foods with temperature between –12 to –15°C (yes; no)]; repetition (low: cycle time of >30 seconds and <50% of cycle time involved in performance of the same kind of fundamental cycles; high: cycle time of <30 seconds or >50% of the cycle time involved in performance of the same kind of fundamental cycles)	Job analyses made by the industrial hygienist of the frozen food factory
de Krom et al, 1990 (43)	Tingling, pain, numbness or a combination of the three in the fingers innervated by the median nerve with a frequency of twice a week or more, which in most cases woke the patient up at night, and confirmation in electrodiagnostic examination	Questionnaire, electrodiagnostic examination	Activities with flexed wrist (hours/week); activities with extended wrist (hours/week); activities with extended and flexed wrist (hours/week); pinch grasp (hours/week); typing (hours/week)	Questionnaire
McCormack et al, 1990 (38)	Positive Tinel's sign and Phalen's test confirmed by physician	Physical examination	Rapid repetitive finger, wrist and elbow motions (yes; no)	Expert opinion based on job title
Barnhart et al, 1991 (33)	Electrophysiological criterion (increased median nerve latency of at least 0.5 ms) and Phalen's or Tinel's sign or ever having had hand pain, tingling, numbness or nocturnal hand pain or a combination of the symptoms.	Questionnaire, physical examination, electrodiagnostic examination	Repetitive jobs (repeated or sustained activities that involved flexion, extension or ulnar deviation of the wrist by 45 degrees or both; radial deviation >30 degrees; or use of pinch type grip)	Job analyses made by the industrial hygienist
Bovenzi et al, 1991 (21)	Pain, numbness or tingling in the median nerve distribution of the hand, positive Tinel's sign or Phalen's test, diminished sensitivity to touch or pain in three-and-a-half fingers on the radial side of the hand, weakness in pinching or gripping	Interview and complete neurological and orthopedic assessment by physiatrist	Hand–arm vibration (m/s^2)	Measurements of chain saws
Morgenstern et al, 1991 (29)	Pain in the hands or wrists or nocturnal pain in the wrists or hands that awakened the patients or numbness in the hands or fingers, or tingling in hands of fingers	Questionnaire	Duration of work as checker (hours/week, year)	Questionnaire
Park et al, 1992 (30)	CTS in insurance claim	Medical records	Job title	Expert opinion based on job title
Chiang et al, 1993 (53)	Symptoms of numbness, pain, or tingling in the fingers innervated by the median nerve and onset of CTS since working on current job and positive Tinel's sign or Phalen's test and no evidence of CTS-related systemic diseases or injuries	Interview, neurological screening and electrodiagnostic examination	High repetitive jobs (cycle time of <30 seconds or > 50% of the cycle time involved in performance of the same type of fundamental cycles); high force jobs (an estimated average hand force of >3 kg)	Jobs were identified by plant walk-through, postural data from videotapes per job, electromyographic recordings used to estimate hand force per job
Moore, & Garg, 1994 (39)	Presence of numbness or tingling in the hands and electrodiagnostic confirmation	Interview, electrodiagnostic examination	Hazardous jobs (yes; no), based on 8 potential risk factors for CTS	Jobs identified by plant walk-through, postural data from videotapes per job, hand–force measurements
Liss et al, 1995 (28)	Presence of CTS being told by care providers	Questionnaire	Job title	Questionnaire
Pocekay et al, 1995 (31)	Physician diagnosed CTS in the past year	Questionnaire	Job title	Questionnaire
Blanc et al, 1996 (58)	Self-reported condition affecting the wrist and hand called CTS	Questionnaire	Repetitive hand bending >2 hours/day (yes, no)	Questionnaire
Silverstein & Hughes, 1996 (40)	Symptoms of pain, numbness or tingling in the hand more than once or lasting >1 week in past 12 months and positive Phalen's test or Tinel's sign in addition to a negative Spurling test and a negative hyperabduction test	Interview, physical examination	Job title	Interview and video analyses
Nordstrom et al, 1997 (52)	Diagnosis of CTS by a physician or any explicit treatment for CTS and numbness, tingling, pain, or paraesthesia in the hand, wrist, arm or forearm within 1 month of the date of the CTS diagnosis	Medical record	Duration of use of power tools or machinery (hours/day); duration of bending hands or wrists (hours/day); job control (7 items with ordinal scale of 1 to 5)	Telephone interview
Roquelaure et al, 1997 (42)	At least 3 of the following conditions: tingling, pain, or numbness in the median nerve distribution of the hand with nocturnal exacerbation with >20 occurrences or lasting >3 weeks in the previous year, a positive Tinel's sign and a positive Phalen's test or hypoesthesia in the region of the median nerve, slowing of the sensory or motor conduction velocities (<40 m/s) in the median nerve at the wrist level, or surgical release of the transverse carpal ligament	Medical records based on interview, examination and electrodiagnostic examination	High force [load was >1 kg with a frequency of exertion in excess of 10 times/hour (yes; no)]; work cycle [<10 seconds (yes; no)]; changes in activity or breaks <15% of worktime (yes: no); no job rotation (yes; no)	Weight of the tools of the parts handled, direct observation

(continued)

Author	Outcome		Exposure	
	Criteria	Assessment	Definition	Assessment
Frost et al, 1998 (23)	A combination of symptoms, occurring at least 1 night a week and current symptoms involving at least 1 of 3 radial fingers, and positive neurophysiological criteria or previous operation for CTS	Questionnaire, physical and electrodiagnostic examination	Job title	Questionnaire
Lam & Thurston, 1998 (41)	Diagnosis on the basis of history and clinical examination and confirmed by a nerve conduction study	Questionnaire, physical examination, electrodiagnostic examination	Duration of keyboard use (long; short); heavy manual work (low; medium; high)	Questionnaire
Leclerc et al, 1998 (27)	Positive Tinel's sign or Phalen's test or if a definite diagnosis based on nerve condition velocity had been established before the medical examination	Questionnaire, physical examination	Jobs with repetitive work (yes; no)	Jobs assigned by an ergonomist, based on a questionnaire
Gorsche et al, 1999 (36)	History of pain and numbness along the median nerve distribution of the hand lasting >1 week at the time of the examination and a positive Tinel's sign or a positive Phalen's test	Interview, physical examination	Tool use (yes; no)	Interview
Latko et al, 1999 (50)	Positive hand diagram and difference in peak latency of 0.5 ms between the ulnar and median nerves	Questionnaire, electrodiagnostic examination	Repetitive work (visual analogue scale of 0–10 cm) (low: 0–3.3 cm; medium: 3.3–6.6 cm; high: 6.6–10 cm)	Visual analogue scale (0–10 cm) for repetition
Nordander et al, 1999 (66)	Pain before provocation and palpation of the tissues and complaints in the neck and upper limbs during the past 12 months and past 7 days, as well as an inability to work during the past 12 months and clinical signs	Interview, physical examination	Job title	Questionnaire, ergonomic workplace analysis
Abbas et al, 2001 (19)	Pain or paresthesia or both in the median nerve distribution and a decrease in the NCV of 42 ms or more or a delay of >4.2 seconds and confirmed by a physician or both	Interview, physical examination, electrodiagnostic examination	Job title [grip: precision versus power (yes; no); intermediate versus power (yes; no)]	Grip assigned at job title level by industrial hygienist in a walk-through
Diaz, 2001 (22)	History of surgical median nerve decompression or a combination of nocturnal hand pain, a positive hand pain diagram, positive Tinel's sign and Phalen's test	Questionnaire, physical examination	Job title	Questionnaire
Kutluhan et al, 2001 (26)	A distal latency difference of greater than 0.5 ms between the median and ulnar sensory nerves	Electrodiagnostic examination	Job title	Interview
Roquelaure et al, 2001 (49)	Presence of paresthesia, pain, or numbness affecting at least part of the median nerve distribution of the hand occurring for at least 1 week or, if intermittent, occurring at least 10 times during the previous 12 months, positive Tinel's sign or Phalen's test or diminished or absent sensation to pin prick in the median nerve distribution, and absence of other causes of hand numbness or paresthesia.	Questionnaire, interview and physical examination	Job analyses [work cycle time <30 seconds (yes; no); wrist deviation (yes; no); rapid trigger movements (yes; no); vibration transmitted to the hand (yes; no); wrist flexion >45 degrees (yes; no); wrist extension >45 degrees (yes; no)]: questionnaire [permanent time pressure (yes; no); few possibilities to take breaks (yes; no); work strongly controlled by superiors (yes; no); high work demands (yes; no); low task control (yes; no); low social support (yes; no)	Questionnaire and job analyses by observations at the workplace
Stevens et al, 2001 (60)	Pins and needles sensations or numbness in the hands and orthodromic median midpalmar latency of >2.2 ms or a median–ulnar palmar latency difference of >0.4 ms using a distance of 8 cm and >2 positive responses to 4 times: awakened from sleep by paresthesia, or hand goes to sleep during driving, hand goes to sleep during reading or relief by shaking hand.	Questionnaire, electrodiagnostic examination	Mouse use (no; occasionally; frequently); current typewriter use (yes; no)	Questionnaire
Yagev et al, 2001 (55)	Sensory latency longer than 3.9 ms or motor latency longer than 4.5 ms or both	Electrodiagnostic examination	High repetitive jobs (a cycle time of <30 seconds or >50% of the cycle time involved in performance of the same type of fundamental cycles); high force jobs (an estimated average hand force >4 kg)	Questionnaire
Babski-Reeves & Crumtpon-Young, 2002 (48)	Positive for Phalen's sign or the carpal compression test and pain, numbness, or tingling in the median nerve distribution of the hand or wrist	Questionnaire, physical examination	Repetition: cycle time <30 seconds (yes; no)	Observation and video assessment for 30 cycles for each hand per participant

(continued)

Author	Outcome		Exposure	
	Criteria	Assessment	Definition	Assessment
Cosgrove et al, 2002 (56)	Positive Tinel's sign and Phalen's test, or thenar atrophy	Physical examination	High force (average hand force requirement of >4 kg); repetition (low: cycle time of >30 seconds and < 50% of the cycle time involved in performance of the same kind of fundamental cycles; high: cycle time of <30 seconds or >50% of the cycle time involved in performancd of the same kind of fundamental cycles)	Written job analysis, videotaped job analysis, deposition transcripts and interview
Nathan et al, 2002 (45)	Abnormal nerve conduction (latency difference ≥0.40 ms), confirmed by two or more specific CTS symptoms (numbness, tingling, or nocturnal awakening) or one specific symptom and two or more nonspecific symptoms (pain, tightness, or clumsiness) present two or more times per month or a history of carpal tunnel release surgery	Questionnaire, electrodiagnostic examination	Repetition (1 to 5 Likert scale); heavy lifting (1 to 5 Likert scale); keyboard use (1 to 5 Likert scale); force (1 to 5 Likert scale); hand–arm vibration (yes; no)	Observation
Andersen et al, 2003 (57)	Tingling or numbness at night at least once a week within the last 3 months in the areas of the right hand innervated by the median nerve	Questionnaire, interview	Duration of right-handed mouse use (hours/week); duration of keyboard use (hours/week); high job demands (yes; no); low job control (yes; no); low social support (yes; no); time pressure (yes; no)	Questionnaire
Kim et al, 2004 (25)	Symptom in the fingers and the wrist that continued for >1 week or more than once a month during the last year with positive Tinel's sign, Phalen's test or NCS	Questionnaire, physical examination, electrodiagnostic examination	Repetitive movements (yes; no)	Assigned by job title
Bovenzi et al, 2005 (51)	Numbness, tingling, burning, or pain in at least two of digits 1, 2, 3 and nocturnal symptoms and positive Tinel's sign or Phalen's test	Interview, physical examination	Hand-arm vibration (m/s^2)	Direct measurements on orbital sanders
Gell et al, 2005 (35)	Diagnosis made by physician or numbness, tingling, burning or pain in the distribution of the median nerve with ipsilateral median nerve conduction slowing (difference of ≥0.5 ms between the ipsilateral ulnar and median sensory peak latency)	Questionnaire, physical examination, electrodiagnostic examination	Job title	Expert opinion
Jianmongkol et al, 2005 (24)	Pain, paresthesia or sensory loss along the median nerve distribution and positive for Tinel's sign or Phalen's test or nocturnal exacerbation of symptoms or motor loss with wasting of abductor pollicis brevis or abnormal nerve conduction times	Questionnaire, interview, physical examination	Job title	Interview
Nathan et al, 2005 (44)	Abnormal nerve conduction (latency difference ≥0.40 ms) confirmed by ≥2 specific CTS symptoms (numbness, tingling or nocturnal awakening) or one specific symptom and ≥2 nonspecific symptoms (pain, tightness or clumsiness) present ≥2 times per month, or a history of carpal tunnel release surgery	Questionnaire, electrodiagnostic examination	Repetition (1 to 5 Likert scale); heavy lifting (1 to 5 Likert scale); force (1 to 5 Likert scale)	Observation
Wang et al, 2005 (32)	Pain and paraesthesia at the wrist, hand and fingers, compatible with the sensory distribution of the median nerve, and a positive Phalen test or the cross-sectional area of the median nerve at the level of the pisiform bone on ultrasonography was >0.11 cm^2 in combination with compression sign on an longitudinal scan	Questionnaire, physical examination, ultrasonography	Job title	Questionnaire
Werner et al, 2005 (67)	Numbness, tingling, burning or pain in the median distribution and a median sensory-peak latency difference of ≥0.5 ms compared with the ipsilateral ulnar sensory peak latency	Questionnaire, physical examination, electrodiagnostic examination	High social support (yes; no)	Questionnaire
Ali & Sathiyasekaran, 2006 (20)	Pain or numbness on the anterior surface of the index, middle or radial half of the ring finger for the past week and a Tinel's sign or Phalen's test	Questionnaire, physical examination	Hand position (neutral; flexed; extended); duration of computer work (hours/day); duration of computer work (years)	Observation, questionnaire
Bonfiglioli et al, 2007 (34)	Nocturnal or diurnal numbness or both, tingling, burning, or pain involving at least 1 of the first 3 fingers within the last month, and abnormal nerve conduction	Questionnaire, electrodiagnostic examination	Job title	Questionnaire
Hou et al, 2007 (59)	Symptoms in upper extremities	Questionnaire	Duration of keyboard use (hours/day); duration of mouse use (hours/day)	Questionnaire