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Research Paper

PAIN

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Personal, biomechanical, psychosocial, and organizational risk factors for carpal tunnel syndrome: a structural equation modeling approach

Yves Roquelaure[a], Ronan Garlantézec[b], Bradley A. Evanoff[c], Alexis Descatha[a], Jean-Baptiste Fassier[d], Julie Bodin[a,*]

Abstract

This longitudinal study aimed at exploring the direct and indirect relationships between organizational, psychosocial, biomechanical, and personal factors and carpal tunnel syndrome (CTS) in French workers. Between 2002 and 2005, 3710 workers were included in the Cosali cohort. Between 2007 and 2010, 1611 workers were re-examined using the same standardized clinical protocol. Subjects free from CTS at baseline were studied (804 men and 563 women). We used structural equation models to examine the relationships between incident CTS cases and organizational (machine-paced work or work pace dependent on customers' demand), psychosocial (job strain model), biomechanical (Borg's rating perceived exertion, wrist bending, pinching, and hand-transmitted vibrations), and personal factors at baseline. Symptomatic CTS risk was directly increased by biomechanical factors (standardized coefficient = 0.19, $P = 0.011$), female gender (0.25, $P < 0.001$), and age (0.15, $P = 0.042$). No psychosocial factors had a direct impact on CTS, but decision authority and skill discretion had an indirect impact by influencing biomechanical exposure. Exposure to machine-paced work had an indirect impact on increasing CTS, either by raising biomechanical exposure (0.19, $P < 0.001$) or by lowering decision authority (−0.18, $P < 0.001$) and skill discretion (−0.20, $P < 0.001$), which in turn increased biomechanical exposure. Similar complex relationships were observed between risk factors and CTS defined by a more strict case definition. Biomechanical exposure had a direct impact on CTS, while organizational factors and psychosocial factors had an indirect impact on CTS. The findings support conceptual models linking work organization to CTS.

Keywords: Carpal tunnel syndrome, Musculoskeletal, Work, Occupational exposure, Structural equation modeling

1. Introduction

Carpal tunnel syndrome (CTS) is the most common entrapment neuropathy in the working population.[36] Certain personal characteristics (eg, age) and medical conditions (eg, obesity) increase the risk of CTS.[14,21,40,47–50] Workplace biomechanical stressors have been identified as risk factors for CTS, namely repetitive hand movements, hand–arm transmitted vibration, forceful manual exertion, bending/twisting of the wrist, and combinations of these factors.[5,28,41] The relationships between CTS and work-related psychological factors, such as job stain, are biologically plausible but less well established by epidemiological studies.[21,32,41] Recent coordinated prospective studies in US workers from various industries identified high job strain as a risk factor for CTS and social support as a protective factor, with psychosocial factors acting independently from the biomechanical factors.[22]

Conceptual causation models have linked work organization to musculoskeletal disorders of the upper extremity (UE-MSDs).[27,42,46,52] The pathway starts with the economic, social, and political environment (*macrolevel*) and workplace structures (*mesolevel*), such as the organization of production (eg, production on assembly lines with automatic machine vs activities of services to customer), work organization (eg, work pace dependent on the automatic rate), and management practices at the company or production unit level. These factors at the work organization level (*mesolevel*) influence in turn the exposure to biomechanical and psychosocial risk factors at the individual (or group of individuals) level (*microlevel*), eliciting the mechanical loading of the upper extremity and psychophysiological changes increasing the risk of CTS. For example, temporal (eg, cycle time and work/rest period) and biomechanical (eg, loads and force level required) characteristics of the work situation determine exposure to biomechanical factors. Similarly, work organization and management practices influence work-related psychosocial

Sponsorships or competing interests that may be relevant to content are disclosed at the end of this article.

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factors by determining the human resources allocated to the production activity and also the quality of work relationships and social support.[9] Some epidemiological findings suggest relationships between an increased risk of CTS and characteristics of the work production and work organization: "just-in-time" production processes, high-paced work depending on an automatic rate, and lack of change in activity or breaks during repetitive work.[31,39,44] Results describing the impact of job rotation on CTS are conflicting.[4,35,39,44] Independently from psychosocial and biomechanical risks, work organization may also increase the risk of CTS by influencing sleep and dietary habits (eg, shift work and obesity/metabolic syndrome).[54]

To improve the prevention of CTS in the working population, it is important to understand how work organization influences workers' biomechanical exposures, psychosocial factors, and the risk of CTS. In a previous prospective study (French Cosali cohort), we showed an association between CTS and factors related to work organization, namely machine-paced work and payment on a piecework basis.[39] The current study used structural equation modeling (SEM) to explore in more detail the complex relationships between organizational, psychosocial, biomechanical, and personal risk factors at baseline and CTS at follow-up in workers in this same cohort. Several studies have used SEM to study relationships between personal characteristics, workplace risk factors, and MSDs (see Bodin et al.,[10] for review). However, to the best of our knowledge, no study has simultaneously evaluated the complex relationships between organizational, psychosocial, and biomechanical risk factors and the risk of CTS.

2. Methods

2.1. Conceptual model

A conceptual model (**Fig. 1**) was defined on the basis of existing literature, field experience, and the expertise of the authors to test the following hypotheses of "causal relationships" between CTS and organizational, psychosocial, and biomechanical risk factors.

(1) According to *hypothesis 1*, the risk of CTS will be directly increased by biomechanical exposures[5,28,41] and, to a lesser extent, by exposure to psychosocial risk factors (direct link with CTS).[22]
(2) According to *hypothesis 2*, exposure to factors related to work organization, such as work pace dependent on machine rates or customers' demands, will influence the biomechanical and psychosocial risk factors[27,42,52].
(3) According to *hypothesis 3*, exposure to psychosocial risk factors, namely low decision latitude and high psychological demands, will indirectly influence CTS by increasing exposure to biomechanical risk factors (indirect link with CTS).[27,42,52] For example, workers with a low decision latitude may be limited in their way of organizing their workload, possibly resulting in higher biomechanical exposure.
(4) According to *hypothesis 4*, the relationships between social support and biomechanical exposure may be 2-fold: on the one hand, workers exposed to high biomechanical risk factors may require higher social support to increase cooperation between coworkers and reduce biomechanical exposure, and on the other hand, workers with low social support may be exposed to higher biomechanical risk factors.

In addition, we postulated that psychosocial risk factors are correlated, that age increases the risk of CTS and reduces exposure to biomechanical risk factors, that high body mass index (BMI) increases the risk of CTS, and that female gender is associated with higher exposure to psychosocial and lower exposure to biomechanical risk factors and CTS relative to men.

2.2. Study population

This prospective study was based on a large sample of workers in the French Pays de la Loire region, who received a health surveillance examination between 2002 and 2005, and was again examined between 2007 and 2010. The region contains 5.6% of the French working population, and its diversified socioeconomic structure resembles that of France as a whole.[20]

Between 2002 and 2005, 83 occupational physicians (OPs) volunteered to take part in the study (18% of OPs in the region). They selected 3710 workers at random before routinely scheduled surveillance examinations (of 184,600 workers under surveillance by the 83 OPs, 2.0%). Fewer than 10% of the selected workers were not included (no shows, refusals, and duplications). Women were slightly underrepresented in the sample (42% of participants vs 47% of workers in the region, $P < 0.001$). Overall, the distribution of occupations in the sample was close to that of the regional workforce, except for the occupations not receiving surveillance from OPs (eg, farmers, shopkeepers, and self-employed workers).

The workers included between 2002 and 2005 were reassessed between 2007 and 2010 (n = 1611). We excluded subjects with the following characteristics: (1) workers with CTS at baseline, (2) craftsmen, salesmen, and managers and workers in the agriculture sector at baseline because of the low number of subjects in these occupations and economic sector, (3) workers lost from follow-up, and (4) workers with missing data for at least one of the variables studied. Finally, 1367 workers (804 men and 563 women) free from CTS at baseline were included in this study (Supplementary Fig. 1, available at http://links.lww.com/PAIN/A924).

2.3. Measurements at baseline

At baseline, workers completed a self-administered questionnaire about their sociodemographic characteristics, musculoskeletal symptoms, and their working conditions during a typical working day over the 12 preceding months.

Age and BMI were studied as continuous variables. Three types of work-related factors were studied: work organization, psychosocial, and biomechanical risk factors.

(1) Factors related to work organization considered were (yes/no) "work pace dependent on customers' demands" (*During a typical day, is your work pace imposed by external demand [public, customer]?*) and "work pace dependent on an automatic rate". The latter was established by 2 questions: "*During a typical day, is your work pace imposed by the automatic rate of a machine?*" and "*During a typical day, is your work pace imposed by the automatic movement of a product or item?*".
(2) Psychosocial risk factors were assessed according to the validated French version of the Karasek Job Content Questionnaire.[34] The different dimensions were studied as continuous: decision latitude (including decision authority and skill discretion), psychological demand, supervisor support, and coworker support.
(3) Biomechanical risk factors were selected according to existing literature and previous studies using the same database[39,43]: sustained or repeated wrist bending posture, holding tools/objects in a pinch grip (only for women due to the low number of men with CTS exposed), working with hand-held vibrating

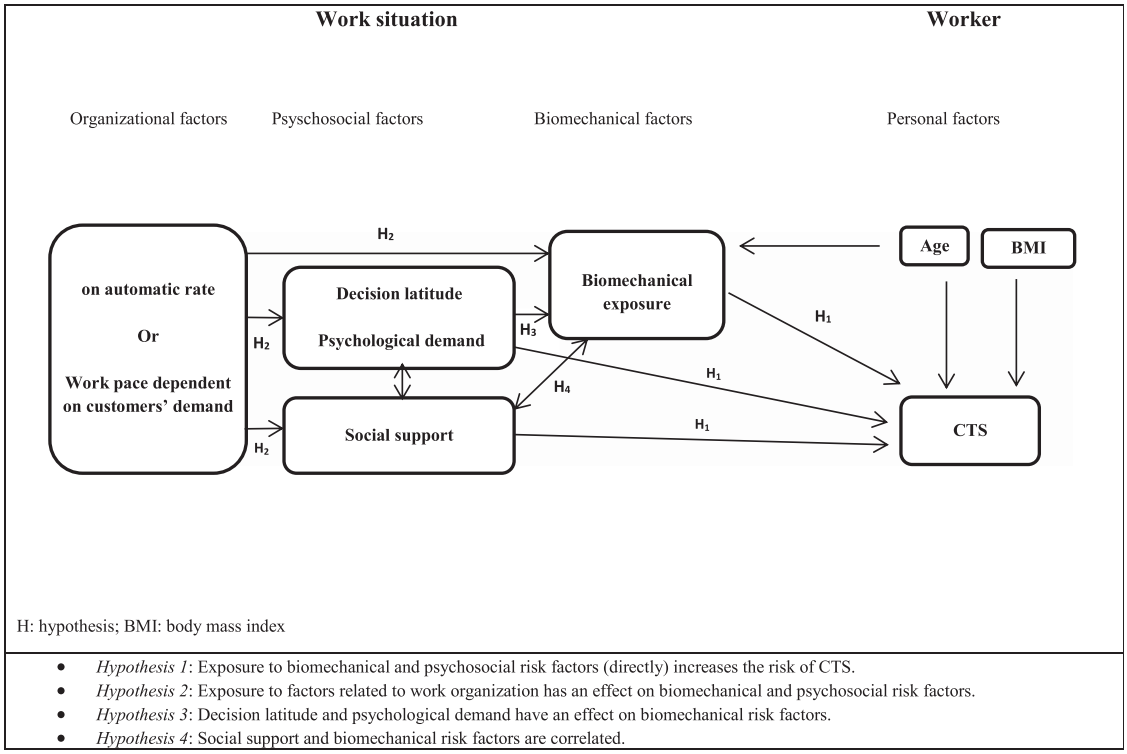

Figure 1. Conceptual model of the relationships between organizational, psychosocial, biomechanical, and personal factors and carpal tunnel syndrome (CTS).

tools (only for men due to the low number of women with CTS exposed), and perceived physical exertion. Durations of exposure are as "never or practically never," "rarely" (<2 hours/day), "often" (2-4 hours/day), and "always" (>4 hours/day). For men, due to the low number of men with CTS, durations of exposure to these factors were defined according to the criteria document for evaluating the work-relatedness of upper-extremity musculoskeletal disorders ("Criteria document").[51] These risk factors were assessed using pictures to facilitate the workers' understanding. Perceived physical exertion was assessed using the Rating Perceived Exertion Borg scale graduated from 6 ("very, very light") to 20 ("maximum exertion").

2.4. Carpal tunnel syndrome assessment at baseline and follow-up

Carpal tunnel syndrome was assessed in the same way at baseline and follow-up. All workers reporting upper-limb symptoms occurring during the preceding 12 months were examined by the OP using a standardized clinical procedure that strictly applied the methodology and clinical tests of the "Criteria document" to diagnose MSD.[39,51] Each OP received guidelines describing the clinical procedure (including diagnostic criteria charts and photographs of clinical tests) and underwent a 3-hour training program to standardize physical examinations.

Two case definitions of CTS were used in this study[39,51]: (1) "symptomatic CTS" based on the presence of positive symptom criteria only, whether physical examination signs were positive or not, and (2) "CTS based on symptoms and signs" requiring the presence of both symptom and physical examination criteria. Symptom criteria for CTS were the presence of symptoms on the day of the medical examination (or for at least 4 days during the preceding 7 days) including intermittent paresthesia or pain in at least 2 of the first 3 digits, either of these also being present at night (causing pain in the palm, wrist, or radiating proximal to the wrist). The physical examination criteria were positivity of at least one of the following tests during the physical examination: flexion and compression test, carpal compression test, Phalen test, and Tinel test.

2.5. Statistical analysis

Chi^2 and Fisher tests for binary variables and Student *t*-tests for continuous variables were used to compare characteristics of the sample according to the presence or absence of CTS.

Structural equation modelings were implemented to test the conceptual model of symptomatic CTS (**Fig. 1**) in the whole sample of workers.[7,11,13] One latent variable was considered (ie, biomechanical factors according to the variables describe above). Standardized beta parameters were presented with statistical significance defined as a *P*-value lower than 0.05. Structural equation modelings were performed with the Lavaan package of R software (version 3.2.0; The R Foundation for Statistical Computing, Vienna, Austria) using the WLSMV estimator (weighted least-squares estimation with robust standard errors and a mean and variance adjusted test statistic) adapted for categorical variables.[18,45] Model fit was assessed using mean square error of approximation (RMSEA), comparative fit index (CFI), Tucker–Lewis index (TLI), and standardized root mean square residual (SRMR). The following cutoff values were applied to interpret the quality of the fit[12,24]: value lower than 0.07 for RMSEA, values greater than 0.95 for CFI and TLI, and value lower than 0.08 for SRMR. The χ^2 is sensitive to sample size, Hoe suggested to examine the ratio of χ^2 to the degrees of freedom.[23] A ratio of 3 or less is a reasonably good indicator of model fit.

A first sensitivity analysis was conducted using only cases of CTS based on both symptoms and signs (n = 32 cases) in the whole sample of workers. A second sensitivity analysis was

conducted to test the model for symptomatic CTS separately in men and women to take into account the differences in exposure to work-related risk factors between genders[34] and potential differential effects of these factors according to gender.

The study received approval from France's National Committee for Data Protection (Commission Nationale de l'Informatique et des Libertés). Each subject provided informed written consent to participate in this study.

3. Results

The study sample comprised 1367 workers (804 men and 563 women) (**Table 1** and Supplementary Fig. 1, available at http://links.lww.com/PAIN/A924). When compared with the workers not included in the analyses, there were no sex differences between the workers included or not in the analyses (41.2% and 42.2% of women, respectively, $P = 0.553$) and no age differences (38.6 years (SD = 8.8) vs 38.7 years (SD = 11.2), $P = 0.939$). There was no statistically significant difference between occupational categories ($P = 0.334$). However, there was a difference for the industry sector ($P < 0.01$): the included subjects worked more in the industrial sector than workers not included in this study (38.5% vs 32.0% respectively) and less in the construction (4.9% vs 6.4% respectively) and services sectors (56.6% vs 61.7% respectively).

A total of 51 symptomatic cases of CTS were diagnosed at follow-up (18 in men and 33 in women, prevalence: 2.2% and 5.9%, $P < 0.001$), including 32 cases based on both symptoms and signs (10 in men and 22 in women, prevalence: 1.2% and 3.9%, $P = 0.001$).

The model fit of the SEM of symptomatic CTS regarding the 1367 workers was good (ratio X^2/degrees of freedom = 3.1, RMSEA = 0.039 (95% CI 0.031, 0.048), CFI = 0.963, TLI = 0.928, SRMR = 0.036). As shown in **Figure 2** and Supplementary Table 1 (available at http://links.lww.com/PAIN/A924), complex relationships were observed between biomechanical, psychosocial, organizational, and personal risk factors for CTS. The risk of symptomatic CTS was directly increased by biomechanical exposure (standardized coefficient = 0.19, $P = 0.011$). None of the psychosocial factors had a direct impact on symptomatic CTS, whereas the 2 dimensions of decision latitude, ie, decision authority (−0.13, $P < 0.001$) and skill discretion (−0.11, $P = 0.003$), decreased the risk of symptomatic CTS by reducing biomechanical exposure. Considering organizational factors, exposure to work pace dependent on an automatic rate indirectly increased the risk of symptomatic CTS, either by increasing biomechanical exposure (0.19, $P < 0.001$) or by lowering decision authority (−0.18, $P < 0.001$) and skill discretion (−0.20, $P < 0.001$), which in turn increased biomechanical exposure. Machine-paced working rates were also associated

Table 1

Characteristics of the study population according to carpal tunnel syndrome (CTS) and gender.

	Men (n = 804)			Women (n = 563)			Together (n = 1367)		
	No CTS (n = 786)	CTS (n = 18)	*P*	No CTS (n = 530)	CTS (n = 33)	*P*	No CTS (n = 1316)	CTS (n = 51)	*P*
Work pace dependent on automatic rate, no. (%)	131 (16.7)	5 (27.8)	0.208*	51 (9.6)	5 (15.2)	0.361*	182 (13.8)	10 (19.6)	0.244*
Work pace dependent on demand of customers, no. (%)	353 (44.9)	10 (55.6)	0.370†	256 (48.3)	13 (39.4)	0.320†	609 (46.3)	23 (45.1)	0.868*
Wrist bending posture (≥2 hours/day), no. (%)	263 (33.5)	10 (55.6)	0.050†						
Wrist bending posture, no. (%)						0.590*			0.489*
Never or almost never				291 (54.9)	15 (45.5)		658 (50.0)	20 (39.2)	
Rarely (less than 2 h a day)				76 (14.3)	7 (21.2)		232 (17.6)	10 (19.6)	
Often (2-4 h a day)				90 (17.0)	6 (18.2)		265 (20.1)	13 (25.5)	
Most of the time (more than 4 h a day)				73 (13.8)	5 (15.2)		161 (12.2)	8 (15.7)	
Holding tools/objects in a pinch grip, no. (%)						**0.015***			0.186*
Never or almost never				409 (77.2)	18 (54.6)		927 (70.4)	31 (60.8)	
Rarely (less than 2 h a day)				34 (6.4)	5 (15.2)		148 (11.3)	6 (11.8)	
Often (2-4 h a day)				41 (7.7)	4 (12.1)		141 (10.7)	6 (11.8)	
Most of the time (more than 4 h a day)				46 (8.7)	6 (18.2)		100 (7.6)	8 (15.7)	
Hand-held vibrating tools (≥2 hours/day), no. (%)	145 (18.5)	9 (50.0)	**0.003***				165 (12.5)	9 (17.7)	0.283*
Perceived physical demand, mean (SD)	11.9 (3.0)	12.7 (2.1)	0.258‡	11.1 (3.2)	11.2 (2.9)	0.739‡	11.6 (3.1)	11.8 (2.7)	0.651‡
Decision authority, mean (SD)	37.0 (6.8)	34.2 (6.0)	0.084‡	35.2 (7.4)	35.4 (8.0)	0.889‡	36.3 (7.1)	35.0 (7.3)	0.196‡
Skill discretion, mean (SD)	35.0 (6.2)	33.1 (5.3)	0.198‡	33.2 (6.4)	32.8 (6.6)	0.705‡	34.3 (6.4)	32.9 (6.1)	0.125‡
Psychological demand, mean (SD)	21.4 (3.6)	21.9 (5.1)	0.662‡	21.6 (3.4)	21.5 (3.3)	0.878‡	21.5 (3.6)	21.6 (4.0)	0.738‡
Supervisor social support, mean (SD)	11.5 (2.3)	10.7 (2.2)	0.122‡	11.7 (2.1)	11.5 (2.3)	0.679‡	11.6 (2.2)	11.2 (2.3)	0.266‡
Coworker social support, mean (SD)	12.6 (1.7)	12.6 (1.9)	0.940‡	12.7 (1.8)	12.3 (1.6)	0.317‡	12.6 (1.8)	12.4 (1.7)	0.415‡
Age, mean (SD)	38.3 (9.0)	39.5 (8.0)	0.567‡	38.9 (8.7)	41.5 (8.2)	0.093‡	38.5 (8.9)	40.8 (8.1)	0.071‡
Body mass index, mean (SD)	24.8 (3.5)	23.7 (2.4)	0.188‡	23.3 (4.1)	24.4 (3.8)	0.117‡	24.2 (3.8)	24.2 (3.4)	0.995‡

In bold, *P* value < 0.05.

* Fisher exact test comparing baseline characteristics according to the presence or not of CTS.

† Chi^2 test comparing baseline characteristics according to the presence or not of CTS.

‡ Student *t* test comparing baseline characteristics according to the presence or not of CTS.

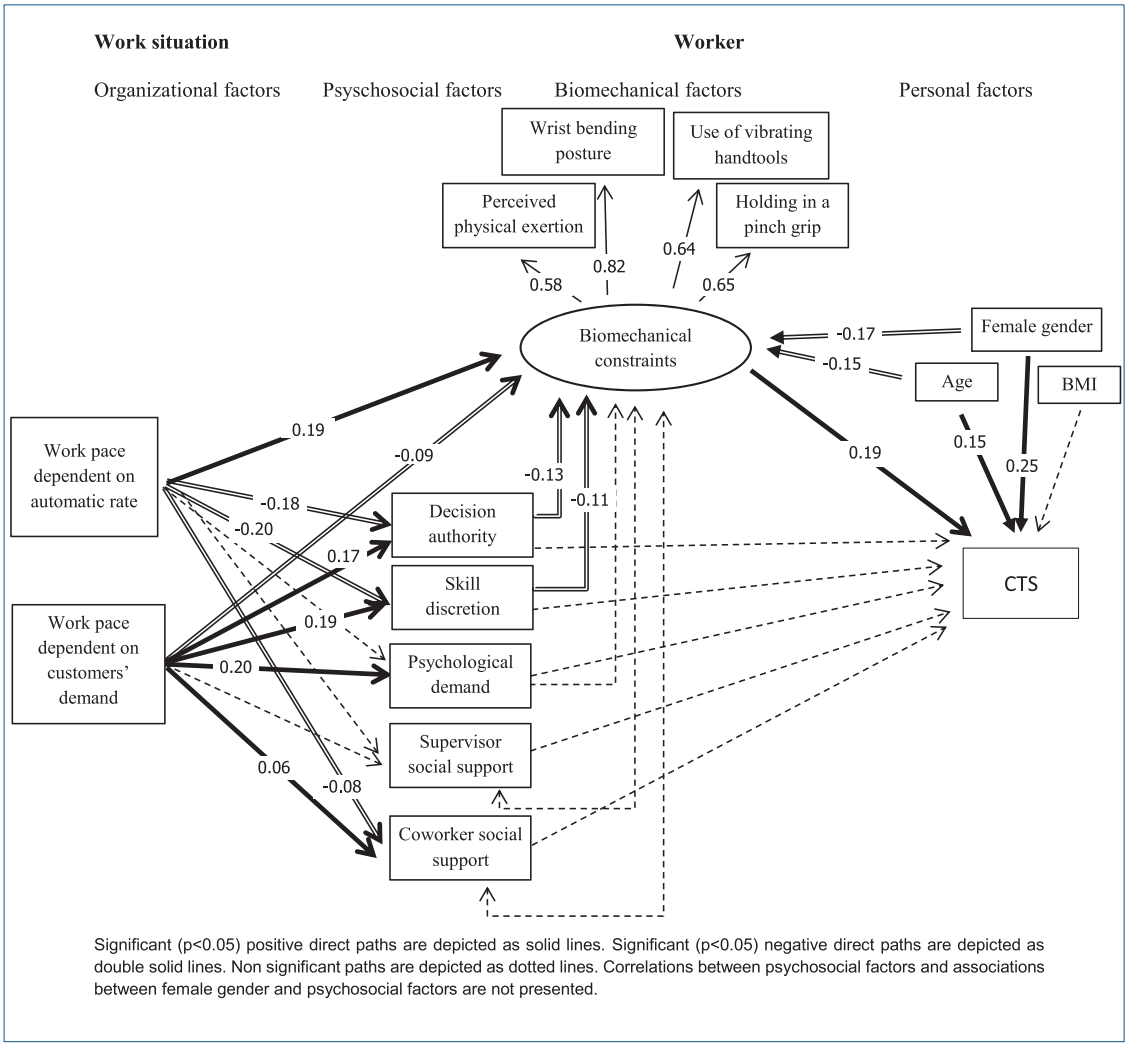

Figure 2. Structural equation model of the relationships between organizational, psychosocial, biomechanical, and personal factors and symptomatic carpal tunnel syndrome (CTS) in French workers, Cosali (COhorte des SAlariés Ligériens) survey (n = 1367).

with a decrease in coworkers' social support (−0.08, $P = 0.002$). Exposure to work pace dependent on customers' demands had the opposite effect, by decreasing biomechanical exposure (−0.09, $P = 0.006$) and increasing decision authority (0.17, $P < 0.001$), skill discretion (0.19, $P < 0.001$), psychological demand (0.20, $P < 0.001$), and coworkers' social support (0.06, $P = 0.041$). Considering personal factors, ageing and female gender had dual effects on the risk of symptomatic CTS, both directly increasing the risk (0.15, $P = 0.042$ and 0.25, $P < 0.001$, respectively) and indirectly decreasing the risk by reducing biomechanical exposure (−0.15, $P < 0.001$ and −0.17, $P < 0.001$, respectively). No relationships were observed between CTS and BMI.

Analyses using the case definition of CTS based on symptoms and signs: Using the more restrictive case definition, similar relationships were observed between CTS (n = 32) and the 4 classes of risk factors (Supplementary Table 1 and Supplementary Fig. 2, available at http://links.lww.com/PAIN/A924): (1) direct increase in the risk of developing CTS after biomechanical exposure (0.28, $P = 0.001$); (2) indirect effect of psychosocial factors, such as decision authority (−0,13, $P < 0.001$) and skill discretion (−0,11, $P = 0.003$) on the risk of developing CTS through a decrease in biomechanical exposure, (3) indirect effect of work pace dependent on automatic rate, through an increase in biomechanical exposure (0.19, $P < 0.001$) or a decrease in decision authority (−0.18, $P < 0.001$) and skill discretion (−0.20, $P < 0.001$), (4) indirect impact of work pace dependent on customers' demand, either by reducing biomechanical exposure (−0.09, $P = 0.006$) or by increasing decision authority (0.17, $P < 0.001$) and skill discretion (0.19, $P < 0.001$), (5) indirect effect of ageing and female gender by reducing biomechanical exposure (−0.15, $P < 0.001$ and −0.17, $P < 0.001$, respectively), (6) direct increasing impact of female gender on CTS (0.28, $P < 0.001$), and (7) lack of direct impact of ageing and increasing BMI.

Analyses using the symptomatic case definition of CTS according to gender: The SEMs of symptomatic CTS were similar in men (n = 804, 18 symptomatic CTS) and women (n = 563, 33 symptomatic CTS) concerning the work-related factors (Supplementary Table 2, available at http://links.lww.com/PAIN/A924) for (1) the direct effect of biomechanical exposure on the risk of CTS, (2) the lack of direct effect of psychosocial factors, (3) the indirect effect of work pace dependent on an automatic rate, either by increasing biomechanical exposure or by lowering decision authority and skill discretion, (4) indirect impact of work pace dependent on customers' demand, either by increasing decision authority and skill discretion, (5) indirect effect of ageing by reducing biomechanical exposure, and (6) lack of direct effect of ageing and BMI. However, the indirect impact of decision

authority and skill discretion resulting in reduced biomechanical exposure was only observed in women, while the indirect impact of work pace dependent on customers' demand by decreasing biomechanical exposure was only statistically significant in men. The positive effect of work pace dependent on an automatic rate on the supervisor and coworkers' social support was only statistically significant in women, and the positive effect of work pace dependent on customers' demand on the coworkers' social support was only statistically significant in men. The two-way relationship between social support and biomechanical exposure was only statistically significant in women.

4. Discussion

This study showed that biomechanical exposure had a direct impact on CTS, whereas organizational factors and psychosocial factors had indirect impacts on the risk of CTS in a cohort of workers representative of a region's workforce. These same relationships were observed using not only the symptomatic definition of CTS, but also the more restrictive definition requiring both symptoms and physical examination signs. This study allows a better understanding of the chain of determinants of CTS than our previous study of risk factors for CTS related to work organization using logistic regression models.[39] The use of a SEM model with the same data set in this study highlighted how the characteristics of work organization (ie, work pace) at the level of the plant or workshop influenced the exposure to psychosocial and biomechanical factors at the level of the work situation and indirectly influenced the risk of CTS.

Comparison with the literature is difficult since these results are innovative among the few studies that used SEM to analyze the complex relationships between workplace risk factors and CTS or, more generally, UE-MSDs.[1,4,15,17,19,22,29,30,33,38] To the best of our knowledge, none had studied associations of CTS with work-related organizational factors.

The study confirms our first hypothesis by showing that exposure to biomechanical risk factors, such as high perceived workload, hand-transmitted vibration, and repetitive/sustained wrist bending and pinching directly increased the risk of CTS. This finding agrees with several systematic reviews and meta-analyses on CTS[5,28,41] and the recent coordinated prospective studies in US workers.[21,22] Contrary to an analysis of the US study which showed independent effects of some workplace psychosocial exposures on CTS,[19] our study found no direct link between CTS and any psychosocial factors under study. Nevertheless, we observed an indirect impact of psychosocial factors on CTS, since increases in both dimensions of decision latitude in the job strain model (decision authority and skill discretion)[26] were associated with decreased biomechanical exposure. This agrees with our third hypothesis and ergonomic knowledge that having more decision latitude offers more operational leeway to adjust working strategies, possibly resulting in lower biomechanical exposure.[53]

Our results showed that exposure to factors related to work organization such as work pace dependent on automatic rate had a direct impact on biomechanical exposure, confirming the second hypothesis of the study, and leading to an indirect increase in CTS risk. This agrees with a recent study demonstrating that machine-paced jobs increased biomechanical exposure.[3] Exposure to work pace dependent on an automatic rate also had a direct impact on psychosocial factors by decreasing both decision authority and skill discretion, the 2 dimensions of decision latitude in the job strain model. Since lower decision latitude is associated with higher biomechanical exposure, automatic work pace results in another indirect increase of CTS risk. Hypothesis 4 was partially confirmed since two-way relationships between social support and biomechanical exposure were only observed in women. As suggested by ergonomic studies, exposure to high biomechanical loads may require more cooperation and social support between coworkers to cope with work tasks and reduce biomechanical exposure. Conversely, the lack of social support may give workers less possibility to diminish biomechanical exposure.[53]

In contrast to machine-paced jobs, exposure to work pace dependent on customers' demands decreased biomechanical exposure, increased decision latitude and psychological demand, and improved social support from coworkers. Few epidemiological studies have studied these associations, but workers responding to customers' demands may have more operational leeway to adjust their working strategies, enabling more decision latitude and cooperation between coworkers.[53] Exposure to customers' demands increased overall psychological demand. Having to respond to customers may be associated with more complex tasks and a higher variety of work tasks than industrial work and may also lead to work with more perceived urgency, and thus to high psychological demands.

Concerning the personal factors, the study showed that ageing and female gender directly increased the occurrence of CTS, in agreement with other medical and epidemiologic literature.[2,6,21,44] According to our results, this direct increasing effects of ageing and female gender may be at least partially counterbalanced by indirect effects of ageing and female gender in reducing the risk of CTS by decreasing biomechanical exposures. The impact of ageing and gender on biomechanical exposures possibly reflected a differential distribution of the physical work between older/younger workers and men/women in companies. Moreover, ageing workers may develop skills and knowledge to improve their working strategies and decrease biomechanical exposure.[53] Contrary to our hypothesis and some epidemiological findings,[14,50] no association was observed between higher BMI and CTS. It must be noted that there were no obese men with symptomatic CTS in the study cohort, and among women, the rate of obesity was higher in those with CTS vs those without, though the difference was not statistically meaningful.

Sensitivity analyses were stratified by gender to take into account the observed differences in the prevalence of CTS and exposure to workplace risk factors between men and women.[34,52] As for the SEM models for shoulder pain in the same cohort,[10] the SEM models for CTS (Supplementary Table 2, available at http://links.lww.com/PAIN/A924) were globally comparable in men and women considering the direct relationships between biomechanical exposure and CTS, and the lack of direct influence of psychosocial factors. The impacts of machine-paced work on biomechanical exposure and on the 2 dimensions of decision latitude were globally similar. Among the noticeable differences, no impact on social support was observed in men. The influence of work pace dependent on customers' demands was comparable in men and women for decision latitude and psychological demands, but not for biomechanical exposure and social support (effect observed only in men). The interrelationship between social (supervisor) support and biomechanical exposure was only observed in women. These differences may reflect a differential distribution of the organizational and psychosocial factors between men and women, but also the lack of statistical power of the SEM models when stratified by sex.

4.1. Strengths and limitations of the study

The prospective design was a major strength of this study, and the random selection of workers during a health examination at baseline

was designed to ensure a sample representative of the region's workforce. Structural equation modeling was used in this study offering the possibility of studying several outcomes simultaneously and enabling exploration of interrelationships between different risk factors and identifying their respective direct and indirect roles in the prediction of outcomes, a major advantage over conventional logistic regression. In our conceptual model based on the literature, some associations are assumed to be causal.

The study presents several limitations. A total of 56.6% of the baseline cohort could not be followed up for physical examination. Of these, 58.5% were no longer being monitored by any OP of the network because they had left their baseline job without informing their OP. In some cases, their OP had refused to participate. The follow-up period coincided with a major economic crisis in France between 2008 and 2009, during which the regional salaried workforce decreased by 3.4% and that of temporary employment agencies by 33.7% according to the French Economic Institute.[25]

The lowest participation rates were among young workers, workers in temporary employment at baseline, and those with a short length of service at baseline. This was to be expected because of the difficulty of following up young workers in insecure employment. This was amplified by the economic crisis, which strongly affected temporary employment and younger workers. On the whole, workers with a risk factor for UE-MSD at baseline were less often available for the second physical examination, although workers in the industrial sector in France have more frequent mandatory physical examinations. We suspect that the economic crisis may have excluded from work (and from follow-up) and workers most exposed to the risk of UE-MSDs, including workers in the manufacturing industry. A study on the impact of loss to follow-up in epidemiological studies on UE-MSDs[8] found that the differences in the characteristics between participants and those lost to follow-up did not influence the risk ratios for associations between exposure factors for UE-MSDs and UE-MSD status. Beside a lack of statistical power, we therefore believe that the impact from loss to follow-up on the results was probably low.

This study was nested in a surveillance program for UE-MSDs, and CTS was assessed clinically by trained OPs using a rigorous standardized medical examination without a nerve conduction study.[51] Because of the small number of incident cases, the case definition used in this study was enlarged to include symptomatic cases of CTS without positive examination. This was useful from an epidemiological surveillance point of view,[37] but some workers with CTS symptoms probably had no actual slowing of the median nerve. Nevertheless, the comparison of different case definitions of CTS in a large US cohort, including the one we used in this study (Sluiter et al. 2001), and definition including a nerve conduction study (Rempel et al. 1998), showed a fairly good agreement between different case definitions, even those which only included symptoms. This, in addition to sensitivity analysis, suggests that the results can be compared across different research studies of risk factors for CTS.[16]

Because of cost and time limitations, direct exposure measurements by observation were not possible in this surveillance program. We used a self-administrated questionnaire to assess the work-related factors, which is a common surveillance technique. Work postures and actions were illustrated through pictures to increase the validity of self-assessed exposures. As far as possible, standardized and validated instruments, such as the Karasek Job Content Questionnaire for psychosocial factors, were used. The questions regarding machine-paced work and work pace dependent on customer demand came from previous large French studies conducted by of DARES (Directorate for Research, Studies, and Statistics).

Implications for practice and future research may be drawn from this study. Work organization is an important, but complex target for strategies aimed at preventing CTS in the working population.[53] By identifying the complex relationships between the direct and indirect determinants of CTS, this study helps to propose preventive measures adapted to these determinants (organizational measures increasing decision latitude combined with technical measures decreasing the physical workload). Further interventional research needs to bring together various disciplines (ergonomics, work psychology, epidemiology, etc.) with different stakeholders in the workplace to determine whether such measures are effective in preventing CTS and other work-related musculoskeletal disorders.

Conflict of interest statement

The authors have no conflicts of interest to declare.

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Appendix A. Supplemental digital content

Supplemental digital content associated with this article can be found online at http://links.lww.com/PAIN/A924.

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