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Shoulder pain among male industrial workers: Validation of a conceptual model in two independent French working populations

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ABSTRACT

This study aims to validate a conceptual model for shoulder pain risk factors in two independent samples of male industrial workers: the Cosali cohort (n = 334) and one pharmaceutical company (n = 487). Direct and indirect relationships between work organization factors (automatic speed of a machine or movement of a product and work pace dependent on customers' demand), psychosocial factors (Job strain model), biomechanical factors (working with abducted arms, working with arms at or above shoulder level, and perceived physical exertion), perceived stress, and shoulder pain were explored using structural equation models. Shoulder pain was positively associated with biomechanical exposure in both samples, and with perceived stress only in the pharmaceutical preparation manufacturer, while factors related to work organization and psychosocial factors had indirect impacts on the risk of chronic shoulder pain in both samples. The results provide a deeper understanding of the complex relationships between workplace risk factors and shoulder pain.

1. Introduction

Shoulder pain is a common musculoskeletal disorder that diminishes quality of life and causes difficulties in performing work-related tasks. Incidence rates of shoulder pain range from 7% to 43% according to the populations surveyed: French workers (Bodin et al., 2012; Cassou et al., 2002; Leclerc et al., 2004), American workers (Silverstein et al., 2006), Finnish workers (Miranda et al., 2001), new hires (Harkness et al., 2003), industry and service workers (Andersen et al., 2003), caregivers (Luime et al., 2005; Sadeghian et al., 2013; Smedley et al., 2003, p. 200) and clerical workers (Sadeghian et al., 2013). These rates also vary according to the reference period considered (last seven days, last month, last three months, last six months, etc.).

In France, shoulder compensation claims have increased since the 1980s (Aptel et al., 2011). At the same time, many companies have changed their organizational methods to increase their flexibility: autonomous work group, just-in-time, job rotation, etc. (Volkoff and Gollac, 1996). However, there is little epidemiological information available on the link between shoulder pain and the organizational factors regularly cited in the literature on ergonomics (Bourgeois, 2006; St-Vincent et al., 2014).

Some work-related biomechanical factors are known to be associated with shoulder pain (Larsson et al., 2007; Mayer et al., 2012; van Rijn et al., 2010), namely repetitive work, vibration, forceful exertion, postures of arms, especially work in which the arms are above the shoulders, and the combination of all of these factors. A recent meta-analysis focusing on shoulder disorders (clinical assessment) showed low-quality evidence for arm repetition, and moderate evidence for arm-hand elevation and shoulder load (van der Molen et al., 2017). Associations between work-related psychosocial factors and shoulder pain have also been identified (Hauke et al., 2011; Kraatz et al., 2013; Lamy et al., 2014), especially among the dimensions of the Job Content Questionnaire. However, the meta-analysis showed a low level of evidence for all of the psychosocial factors studied (van der Molen et al., 2017).

Several conceptual models (Carayon et al., 1999; Hagberg et al., 1995; Karsh, 2006; MacDonald et al., 2008; Punnett et al., 2009; Roquelaure, 2016; Sauter and Swanson, 1996; Stock et al., 2013) underline the major role of organizational factors in the occurrence of

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musculoskeletal disorders (MSDs) by determining the exposure to psychosocial and biomechanical risk factors. For example, the temporal (e.g., cycle time, etc.) and biomechanical (e.g., loads and force level required, etc.) characteristics of the work situation determine exposure to biomechanical factors. Similarly, organizational factors influence work-related psychosocial factors by determining the human resources allocated to the production activity and also the quality of work relationships and social support. Lamy et al. showed that the work-unit-level organizational characteristics may impact workers' musculoskeletal disorders by conditioning both work-task-related biomechanical exposure and individual perception of the working environment (Lamy et al., 2014). Several studies used structural equation models (SEM) to examine relationships between personal characteristics, workplace risk factors, and MSDs (Eatough et al., 2012; Larsman et al., 2006, 2011; 2013; Park et al., 2010; Sprigg et al., 2007). However, concurrent evaluations of the complex relationships between organizational, psychosocial and biomechanical risk factors, stress, and MSDs are still rare.

We have previously designed a "causal model" of developing shoulder pain using SEM in a cohort of workers from the general working population covering various industry sectors in the French Pays de la Loire region (Bodin et al., 2018). The aim of the present study was to test if the model can be replicated in a large company from the industrial sector (Fig. 1). The direct and indirect relationships between workplace risk factors, perceived stress, and shoulder pain were explored. The following hypotheses were tested.

Hypothesis 1, the risk of shoulder pain is directly increased by biomechanical exposure (Hagberg et al., 1995; Kumar, 2001; Mayer et al., 2012; van Rijn et al., 2010) and perceived stress (Aptel and Cnockaert, 2002; Eijckelhof et al., 2013; Larsman et al., 2006; Lundberg, 2002; Lundberg et al., 2002; Miranda et al., 2001; Thiese et al., 2015). The abduction of the arm increases the mechanical load of the supraspinatus tendon (intrinsic mechanism) and can cause an extrinsic mechanical conflict between the supraspinatus tendon and adjacent anatomical structures when the arm is above the horizontal position (Hagberg et al., 1995; Kumar, 2001). The relationship between stress and shoulder pain is supported by several studies and involve three systems (Lundberg, 2002; Millar et al., 2017; Roquelaure, 2018): 1) Stress activates the central nervous system, which increases muscle tone and increases the "biomechanical load" of the muscles and tendons; 2) Stress activates the secretion of catecholamines (adrenaline and noradrenaline) which, through a variety of mechanisms, reduce microcirculation in the muscles and in the muscular tendons; 3) Stress activates the production/release of proinflammatory cytokines that promote the inflammation of tendons. An increase in muscle activity of the neck and shoulder has been demonstrated experimentally in response to exposure to occupational stressors (Eijckelhof et al., 2013).

Hypothesis 2, exposure to psychosocial factors, namely low decision latitude and high psychological demand, can indirectly influence shoulder pain by increasing exposure to biomechanical factors (Park et al., 2010; Thiese et al., 2015). Decision latitude offers more operational leeway to adjust working strategies and diminish biomechanical strain. Workers with low decision latitude may be limited in how they organize their workload, which may result in higher biomechanical strain. In addition, workers with high psychological demand (not having the time needed to do the job, having to work very fast, or intensely, etc.) may be more intensely exposed to biomechanical factors than those with low psychological demand, namely by increasing both muscle tension and the velocity of movements (Roquelaure, 2018).

Hypothesis 3, the relationships between social support and biomechanical exposure may be two-fold (Thiese et al., 2015). Exposure to high biomechanical loads may require more cooperation and social support between coworkers to cope with the task and reduce biomechanical exposure. Conversely, the lack of social support may give workers less opportunity to diminish biomechanical exposure.

Hypothesis 4, exposure to psychosocial factors can indirectly influence shoulder pain in increasing perceived stress (Edimansyah et al., 2008; Larsman et al., 2013, 2011; 2006; Lundberg, 2002). In other words, perceived stress would be a mediator in the relationship between psychosocial factors and shoulder pain (Inserm, 2011). A high level of social support is thought to protect the worker from stress and a strong psychological demand is thought to increase it. Strong decision-making autonomy can protect against stress but can also generate stress if the worker has too much autonomy and cannot cope with the demands of his/her work.

Hypothesis 5, exposure to factors related to work organization, namely the automatic speed of a machine or movement of a product, and a work pace dependent on customers' demand, can influence the biomechanical and psychosocial exposure. For example, workers responding to customers' demands may have more operational leeway to adjust their working strategies, enabling more decision latitude, or having to respond to customers may be associated with fast work, sometimes in "emergency mode" and thus to high psychological demands and biomechanical exposure. Several ergonomics studies support this hypothesis (Carayon et al., 1999; Hagberg et al., 1995; Karsh, 2006; MacDonald et al., 2008; Punnett et al., 2009; Roquelaure, 2016; Sauter and Swanson, 1996; Stock et al., 2013). However, few epidemiological studies have studied these associations (Bao et al., 2016).

The aim of the current study was to test the five hypotheses using data from two independent samples of French workers from the industrial sector using structural equation modeling (SEM). We also hypothesized that psychosocial factors are correlated, that age and body mass index (BMI) are associated with shoulder pain and that age was associated with perceived stress. Several studies have used SEM to study relationships between personal characteristics, workplace risk factors and MSDs (Eatough et al., 2012; Larsman et al., 2013, 2011; 2006;

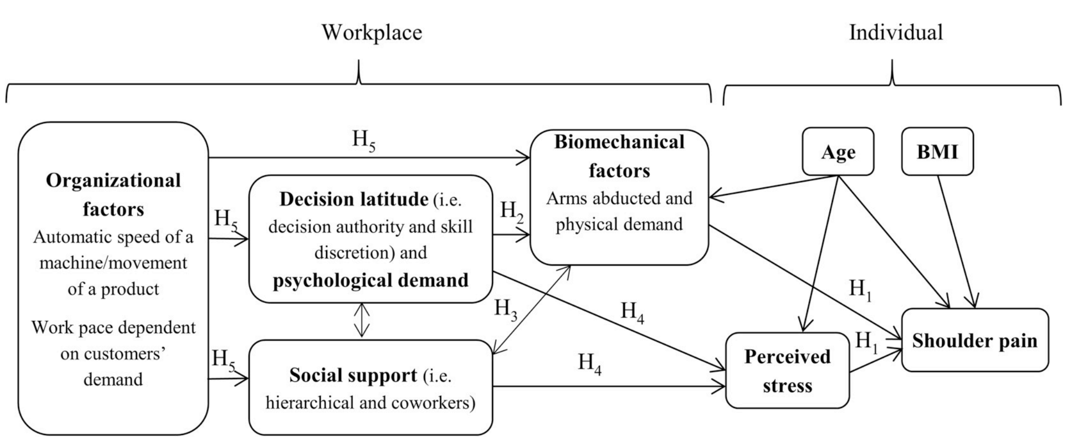

Fig. 1. Conceptual model linking work-related and personal factors to shoulder pain. H: Hypothesis tested.

Mehralizadeh et al., 2017; Park et al., 2010). However, to the best of our knowledge, no study has simultaneously evaluated the complex relationships between organizational, psychosocial and biomechanical risk factors and shoulder pain.

2. Materials and methods

2.1. Study populations

Data from two samples from the industrial sector were compared in this study: the Cosali cohort and one cross-sectional study conducted in an international pharmaceutical manufacturing site located in France.

The *Cosali study* was carried out in the Pays de la Loire region (Loire valley area, west central France) (Ha et al., 2009; Roquelaure et al., 2011). Between 2002 and 2005, a total of 3710 workers were selected at random by 83 occupational physicians (response rate of 90%). A self-administered questionnaire, about musculoskeletal symptoms, personal factors and working conditions (work organization, psychosocial factors, and biomechanical factors), was completed by workers at baseline and at follow-up in 2007. An extract from the questionnaire is available on Appendix A. The sample was characterized by a wide variety of activity sectors and occupations, and for the current study, only workers of the industrial sector were selected. In addition, only salaried workers not craftsmen, salesmen, or managers at baseline, still professionally active at follow-up and without shoulder pain at baseline were studied. Given that only 161 women met the above criteria, only men were studied (Appendix B).

A cross-sectional study was performed in 2009 in a pharmaceutical manufacturing site. All workers were invited to respond to a self-administered questionnaire during working hours, about musculoskeletal symptoms, personal factors and working conditions (Appendix A). A total of 1282 (~85%) workers responded (686 men and 590 women).

2.2. Risk factor assessment

In order to study risk factors of incident shoulder pain for the Cosali cohort, workplace factors at baseline, as well as age, BMI, perceived stress, and shoulder pain at follow-up, were studied (Bodin et al., 2018, 2011). Three types of workplace factors were self-assessed studied using the questionnaire (Table 1): factors related to work organization, psychosocial factors, and biomechanical factors. Two factors related to work organization were considered: the automatic speed of a machine or movement of a product, and work pace dependent on customers' demand. Psychosocial work factors were assessed using the French version of Karasek's Job Content Questionnaire (JCQ) with continuous dimensions studied (Niedhammer et al., 2006): decision latitude (i.e. decision authority (6 items) and skill discretion (3 items)), psychological demand (9 items), and social support (i.e. supervisor social support (4 items) and co-worker social support (4 items)). Biomechanical factors were selected according to Sluiter et al. (2001): working with abducted arms, working with arms at or above shoulder level, and perceived physical exertion. For posture, the response categories were presented on a 4-level Likert-type scale, as follows: "never or practically never", "rarely (<2 h/day)", "often (2–4 h/day)" and "always (>4 h/day)". The latter two categories were merged due to a low number of workers exposed to the last category. Perceived physical exertion was assessed using the Rating Perceived Exertion (RPE) Borg scale graded from 6 ("no exertion at all") to 20 ("maximum exertion") (Borg, 1990) and it was

Table 1
Workers characteristics according to the population study

	Cosali study (n=334)				Manufacturer of pharmaceutical preparations (n=487)				p-value
	n	%	Mean	SD	n	%	Mean	SD	
Factors related to work organization[c]									
Automatic speed of a machine or movement of a product	83	24.9			144	29.6			0.14[a]
Work pace dependent on customers' demand	106	31.7			165	33.9			0.52[a]
Biomechanical factors[c]									
Arms above shoulder level									0.07[a]
Never or almost never	203	60.8			307	63.1			
Rarely (less than 2 hours a day)	101	30.2			118	24.2			
Often (2 to 4 hours a day) / Most of the time (more than 4 hours a day)	30	9.0			62	12.7			
Arms abducted									**0.02**[a]
Never or almost never	207	62.0			260	53.4			
Rarely (less than 2 hours a day)	81	24.2			127	26.1			
Often (2 to 4 hours a day) / Most of the time (more than 4 hours a day)	46	13.8			100	20.5			
Perceived physical demand (Borg's RPE)			12.5	2.8			11.6	3.2	**<0.001**[b]
Psychosocial factors[c]									
Decision authority			36.7	7.0			34.3	7.8	**<0.001**[b]
Skill discretion			34.6	6.6			34.3	6.6	0.47[b]
Psychological demand			21.4	3.6			22.7	4.5	**<0.001**[b]
Supervisor social support			11.5	2.0			11.3	2.8	0.46[b]
Coworker social support			12.5	1.8			12.7	2.0	0.14[b]
Personal factors[d]									
Shoulder pain									<0.01[a]
No shoulder pain	293	87.7			394	80.9			
Shoulder pain in the last 7 days with VAS ≥2 and no chronic shoulder pain	14	4.2			15	3.1			
Chronic shoulder pain	27	8.1			78	16.0			
Age ≥ 45	138	41.3			67	13.8			**<0.001**[a]
Body mass index									0.36[a]
Underweight-Normal	173	51.8			269	55.2			
Overweight	140	41.9			181	37.2			
Obesity	21	6.3			37	7.6			
Perceived stress (0-10)			3.3	2.3			3.8	2.7	**0.01**[b]

SD: Standard deviation; RPE: Rating of perceived exertion.
[a] Chi-squared test, in bold, p-value<0.05.
[b] Student's t-test, in bold, p-value<0.05.
[c] Baseline characteristics for Cosali.
[d] Follow-up characteristics for the Cosali study.

continuously studied. Perceived stress was assessed on a visual analog scale (VAS) ranging from 0 to 10 and continuously studied. Using a Nordic-style questionnaire (Kuorinka et al., 1987), workers were asked if they had experienced any aching, discomfort, pain, or numbness in the shoulders in the preceding 12 months and in the preceding 7 days. The duration of symptoms during the preceding 12 months and the pain intensity at the time of the questionnaire (on a VAS ranging from 0 to 10) were collected. An ordinal variable in three modalities was created: (i) no shoulder pain, (ii) shoulder pain during the preceding 7 days with intensity of pain greater than or equal to 2 without shoulder pain lasting more than 1 month during the preceding 12 months, and (iii) shoulder pain lasting more than 1 month during the preceding 12 months (regardless of the presence or absence of shoulder pain during the preceding 7 days with pain intensity greater than or equal to 2). Age was dichotomized at 45 years (Djade et al., 2020; Leong et al., 2019) and BMI was divided into three categories, using the World Health Organization criteria (Weir and Jan 2019): underweight or normal weight (<25 kg/m^2), overweight (25–30 kg/m^2), and obese (≥30 kg/m^2).

2.3. Statistical analyses

Only participants with complete data were included in the analyses: 334 men for the Cosali study and 487 men for the cross-sectional study performed in a pharmaceutical manufacturing site.

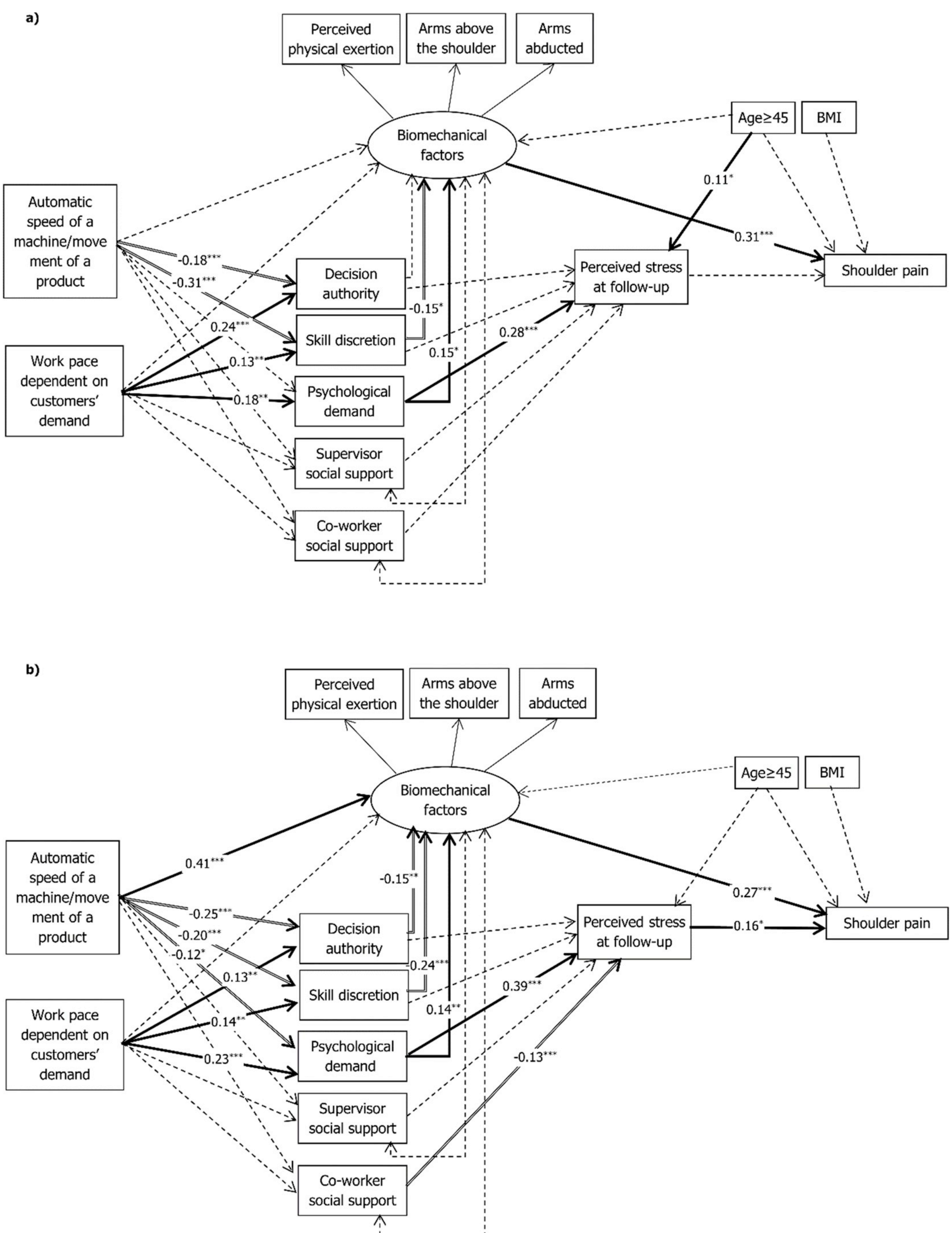

Fig. 2. Structural equation model for a) Cosali survey (n = 334), b) Manufacturer of pharmaceutical preparations (n = 487). Ellipses = latent variables; boxes = observed variables. Significant ($P < 0.05$) positive direct paths are depicted as solid lines. Significant ($p < 0.05$) negative direct paths are depicted as double solid lines. Non-significant paths are depicted as dotted lines. *$p < 0.05$;**$p < 0.01$;***$p < 0.001$. Correlations between psychosocial factors are not represented.

Pearson's chi-squared test for nominal variables and Student's t-test for continuous variables were used to compare the men's characteristics in the two samples.

SEMs were used to test the conceptual model (Fig. 1) (Beran and Violato, 2010; Buhi et al., 2007). The aim of the SEM is to test the relevance of a conceptual model, usually represented by a path diagram, in which assumptions about direct and indirect relationships between variables are presupposed. It follows a confirmatory approach where the conceptual model is built *a priori*, in accordance with the available scientific knowledge (Bodin et al., 2018). SEMs were performed with the Lavaan package of R software v3.0.3 using the WLSMV estimator (weighted least squares estimation with robust standard errors and a mean and variance adjusted test statistic) (Rosseel, 2012). The model fit was assessed using cut-off value recommendations (Hooper et al., 2008): greater than 0.95 for the Tucker-Lewis index (TLI) and the comparative fit index (CFI), and 0.07 or below for the root mean square error of approximation (RMSEA). The χ^2 test is sensitive to sample size, and Hoe suggested examining the ratio of χ^2 to the degree of freedom (Hoe, 2008). A ratio of 3 or less is a reasonably good indicator of model fit.

3. Results

3.1. Comparison of the two study populations

Workers in the Cosali study were employed in 181 companies (18 missing values), mainly in manufacturers of food products (19.8%), office machinery and equipment (12.9%), metal work (11.4%), and rubber and plastic products (11.4%). None worked in a manufacture of pharmaceutical products/preparations. A comparison of the two study populations is shown in Table 1 In the Cosali study, 8.1% of workers declared chronic shoulder pain vs 16.0% in the pharmaceutical manufacturing site ($p < 0.01$).

3.2. Structural equation models

The results of the SEM are shown in Fig. 2: a) Cosali study and b) pharmaceutical manufacturing site and Appendix C. Fit indices of the SEM are acceptable for the Cosali study (ratio of χ^2/degrees of freedom = 0.9, TLI = 1.008, CFI = 1.000, RMSEA = 0.000 [95% CI 0.000–0.041]) and the pharmaceutical manufacturing site (ratio of χ^2/degrees of freedom = 1.3, TLI = 0.978, CFI = 0.989, RMSEA = 0.025 [95% CI 0.000–0.044]).

In both samples, shoulder pain was positively associated with biomechanical factors (standardized coefficient = 0.31, $p < 0.001$ in the Cosali study and 0.27, $p < 0.001$ in the pharmaceutical manufacturing site). Biomechanical factors were associated with lower skill discretion (−0.15, $p = 0.049$ in the Cosali study and −0.24, $p < 0.001$ in the pharmaceutical manufacturing site) and higher psychological demand (0.15, $p = 0.02$ and 0.14, $p < 0.01$, respectively). No correlations were statistically significant between social support and biomechanical exposure. Psychological demand was positively associated with perceived stress (0.28 and 0.39, $p < 0.001$ in the Cosali study and the pharmaceutical manufacturing site respectively). Considering organizational factors, the automatic speed of a machine/movement of a product was associated with higher biomechanical factors (0.41, $p < 0.001$) in the pharmaceutical manufacturing site, although the association was of borderline significance in the Cosali study (0.10, $p = 0.11$). In addition, in both samples, the automatic speed of a machine/movement of a product was negatively associated with decision authority (−0.18 and −0.25, $p < 0.001$) and skill discretion (−0.31 and −0.20, $p < 0.001$), while a work pace dependent on customers' demands was positively associated with psychosocial factors: decision authority (0.24, $p < 0.001$ in the Cosali study and 0.13, $p < 0.01$ in the pharmaceutical manufacturing site), skill discretion (0.13 and 0.14, $p < 0.01$), and psychological demand (0.18, $p < 0.01$ in the Cosali study and 0.23, $p < 0.001$ in the pharmaceutical manufacturing site). There were some differences between the samples, however. More associations were significant in the pharmaceutical manufacturing site. For the latter, shoulder pain was positively associated with perceived stress (0.16, $p = 0.01$). Biomechanical factors were associated with lower decision authority (−0.15, $p < 0.01$) and perceived stress was associated with lower levels of co-worker social support (−0.13, $p < 0.001$). Finally, the automatic speed of a machine/movement of a product was associated with lower psychological demand (−0.12, $p = 0.01$).

4. Discussion

We have previously designed a "causal model" linking factors related to work organization, biomechanical factors, psychosocial factors, perceived stress, and incidence rates of shoulder pain in the Cosali cohort, a French cohort of workers from the general working population covering various industry sectors in the Pays de la Loire region (Bodin et al., 2018). Using a subsample of males from the industrial sector of the Cosali cohort and a sample of males from an industrial company, our results showed that shoulder pain was directly associated with biomechanical exposure in both samples and with perceived stress only in the manufacturer of pharmaceutical preparations, while factors related to work organization and psychosocial factors had indirect impacts on the risk of chronic shoulder pain in both samples.

Comparison with the literature is difficult because there are few studies which have used SEM to study the complex relationships between workplace risk factors, stress and shoulder pain, and to our knowledge, none had studied associations with work organization. This study confirms the first hypothesis. Shoulder pain was positively associated with biomechanical factors in the Cosali study and the pharmaceutical manufacturing site. This is consistent with the biomechanical model of MSDs (Hagberg et al., 1995; Kumar, 2001) and epidemiological literature (Mayer et al., 2012; van Rijn et al., 2010). In addition, shoulder pain was positively associated with perceived stress only in the pharmaceutical manufacturing site. In the sample of male Cosali workers of all industry sectors, shoulder pain was also associated with perceived stress (Bodin et al., 2018). Male Cosali workers from the industrial sector were less stressed than male Cosali workers of other industry sectors, and this could explain the lack of effect of perceived stress on shoulder pain in the current study. Lack of power could also explain this non-significant association. Lundberg et al. showed that mental stress may induce muscle tension and contribute to the incidence of shoulder pain, although the effect of mental stress on muscle activity is small compared to the effect of manual tasks on blue-collar workers (Lundberg et al., 2002). In addition, previous epidemiological studies among assembly workers (Kjellberg and Wadman, 2007), forestry workers (Miranda et al., 2001), and elderly female computer users (Larsman et al., 2006) showed that perceived stress was associated with shoulder pain.

In both samples, the results showed that psychosocial factors influence shoulder pain through their association with biomechanical factors. Biomechanical factors were negatively associated with skill discretion, positively associated with psychological demand and negatively associated with decision authority only in the pharmaceutical manufacturing site (hypothesis 2). This agrees with the SEM of Park et al. which shows that job-related stress factors (i.e., physical burden and job control) have a direct effect on biomechanical factors (Park et al., 2010). The lack of association between decision authority and biomechanical factors in the Cosali study may be explained by lower exposure to awkward arm postures and higher decision authority compared to the pharmaceutical manufacturing site. Contrary to what was suggested by ergonomics studies (St-Vincent et al., 2014), this study did not show correlations between biomechanical factors and social support (hypothesis 3). Thiese et al. found that supervisor social support was associated with forceful exertion and hand activity level, and that getting along with co-workers was associated with forceful exertion, overall force, peak force, and threshold limit value for hand activity level (Thiese et al., 2015).

The results showed also that psychosocial factors influence shoulder pain through their association with perceived stress. Psychological demand was positively associated with perceived stress in both study populations and co-worker social support was negatively associated with perceived stress only in the pharmaceutical manufacturing site (hypothesis 4). These results were in line with previous studies using SEM (Larsman et al., 2006, 2011, 2013) and linear regression (Edimansyah et al., 2008).

The study showed that the automatic speed of a machine/movement of a product was associated with higher biomechanical exposure in the company sample, although the association was of borderline significance in the Cosali study (hypothesis 5). This is in line with ergonomics literature, which has shown that an industrial process increases biomechanical constraints (St-Vincent et al., 2014; Westgaard and Winkel, 2011), and a recent cross-sectional study that showed an association between work pace and all biomechanical stressors at the task and job levels (Bao et al., 2016). In our study, the automatic speed of a machine/movement of a product was associated with a lower decision latitude in both samples. This is consistent with results obtained by Melin et al., which showed that workers in the assembly line reported less variation, independence, and abilities to learn new skills compared to the workers in the flexible work organization (Melin et al., 1999).

A work pace dependent on customers' demands was associated with higher decision latitude and psychological demand in both samples. Few epidemiological studies have focused on these associations. Firstly, a work pace dependent on customers' demands may increase the complexity of the tasks compared to industrial work. Secondly, customer pressure can lead to faster performance, sometimes in "emergency mode", and to feelings of insufficient time to ensure high-quality work (i.e., high psychological demand). Compared to paced work, workers exposed to customer demand may have more operational leeway to adjust their working strategies, thereby allowing for more decision latitude. Moreover, a flexible work organization may be perceived as more varied, providing the opportunity to learn new skills compared to assembly line work (Melin et al., 1999).

The main strength of this study lies in its ability to validate a conceptual model in two independent samples of male workers from industrial French working populations. However, our model was designed to study incidence rates of shoulder pain and the company survey was cross-sectional, due to the difficulty to obtain a large longitudinal sample in a company.

Data on the pharmaceutical manufacturing site refers to all male workers employed at the time of the survey and the response rate was high. The percentage of subjects lost to follow-up in the Cosali study was high. This was due to the difficulties of a longitudinal design in occupational medicine in France, related to the high mobility of both the occupational physicians and the workers in a period of economic crisis (Sérazin et al., 2014). However, no differences in terms of employment contract, age, BMI, and work-related factors have been found between included and non-included workers. A selection bias linked to the "healthy worker effect" cannot be excluded in the two samples. Only workers without shoulder pain at baseline were selected for the Cosali study, which makes it possible to avoid misclassification bias of exposure due to pain. However, these "healthy" workers could represent a selected group, since they are free from shoulder pain despite exposure to work-related factors. Silverstein et al. recommend stratifying analyses according to gender for the purposes of assessing risk factors of MSDs (Silverstein et al., 2009). Due to the low number of women working in the industry sector in the Cosali cohort, analyses were performed only on men.

Shoulder pain and workplace risk factors were assessed by self-administered questionnaires, according to the protocol of the Cosali study which has been published (Ha and Roquelaure, 2007). However, the self-reporting of shoulder pain and exposure may have biased risk estimates. Shoulder pain was assessed by means of the Nordic questionnaire; Descatha et al. (2007) showed the validity of this questionnaire for monitoring upper-limb work-related musculoskeletal disorders. Due to cost and time limitations, direct exposure measurements by observation or biomechanical measurements were not possible. Self-reported measures offer the possibility of surveying a large sample of workers, including a wide variety of job titles and thus occupational tasks as well. The variables were selected according to literature and standardized questionnaires were used. Shoulder postures were requested for a typical workday in the preceding 12-month period and were based on the recommendations of the European consensus criteria document for the evaluation of upper extremity MSDs (Sluiter et al., 2001). Meyer et al. published a French version of the conclusions of the consensus, including the work-related risk factors (Meyer et al., 2002). The questions regarding industrial work rate constraints and work pace dependent on customers' demands were taken from large repeated French studies (SUMER [SUrveillance Médicale des Expositions aux Risques professionals - Medical surveillance of exposure to occupational hazards] and French Working Conditions Survey) (Dares, 2015). Psychosocial factors were assessed by the French version of the JCQ (Niedhammer et al., 2006), as is the case with most longitudinal studies on neck and shoulder disorders (Kraatz et al., 2013). However, new models have emerged to evaluate psychosocial workplace factors, such as organizational justice (Ndjaboué et al., 2012). Due to the length of the self-administered questionnaire, no questions were asked about personal psychosocial factors (such as anxiety or low mood), perceived muscle tension, physical capacity, individual working techniques, family status, sports or life events.

SEM helps explore inter-relationships between different risk factors and identify their respective direct and indirect roles. However, our causal hypotheses are based on literature and other paths may also be possible. Furthermore, because of the cross-sectional nature of the company survey, conclusions about causality must be interpreted with caution, assuming that we could not exclude reverse causation.

A deeper understanding of the complex relationships between occupational factors and shoulder pain could improve prevention. This study showed the importance of work organization in the occurrence of shoulder pain for determining both the biomechanical and psychosocial features of the work situations that workers face, and indirectly the risk of chronic shoulder pain. The "causal model" of shoulder pain obtained in a cohort of workers from the general working population can be globally replicated in a specific industry. Further research is needed to explore the underlying mechanism of sickness absence following shoulder pain.

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Declaration of competing interest

The authors declare no conflict of interest.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.apergo.2020.103075.

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