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Running title: Selected questions on biomechanical exposures for surveillance

ABSTRACT (293 WORDS)

Objective. Questionnaires for assessment of biomechanical exposure are frequently used in surveillance programs, though few studies have evaluated which key questions are needed. We sought to reduce the number of variables on a surveillance questionnaire by identifying which variables best summarized biomechanical exposure in a survey of the French working population.

Methods. We used data from the 2002-2003 French experimental network of Upper-limb work-related musculoskeletal disorders (UWMSD), performed on 2685 subjects in which 37 variables assessing biomechanical exposures were available (divided into four ordinal categories, according to the task frequency or duration). Principal Component Analysis (PCA) with orthogonal rotation was performed on these variables. Variables closely associated with factors issued from PCA were retained, except those highly correlated to another variable (rho>0.70). In order to study the relevance of the final list of variables, correlations between a score based on retained variables (PCA score) and the exposure score suggested by the SALTSA group were calculated. The associations between the PCA score and the prevalence of UWMSD were also studied. In a final step, we added back to the list a few variables not retained by PCA, because of their established recognition as risk factors.

Results. According to the results of the PCA, seven interpretable factors were identified: posture exposures, repetitiveness, handling of heavy loads, distal biomechanical exposures, computer use, forklift operator specific task, and recovery time. Twenty variables strongly correlated with the factors obtained from PCA were retained. The PCA score was strongly correlated both with the SALTSA score and with UWMSD prevalence ($p<0.0001$). In the final step, six variables were reintegrated.

Conclusion. Twenty-six variables out of 37 were efficiently selected according to their ability to summarize major biomechanical constraints in a working population, with an approach combining statistical analyses and existing knowledge.

Keywords: occupational physical exposure, musculoskeletal diseases, upper extremity, questionnaire, principal component analysis.

INTRODUCTION.

Upper-limb work-related musculoskeletal disorders (UWMSD) are an important problem in industrial countries. There is strong evidence for association between biomechanical exposures and these disorders (Hagberg et al. 1997; Roquelaure et al. 2002; Bernard BP 1997). Various assessment methods of biomechanical exposure are available, especially ergonomic analyses and questionnaires (Stock et al. 2005). Questionnaires are frequently used in surveillance programs since they are considered in many contexts as simple and valid tools for biomechanical exposure assessment (Leclerc 2005; Balogh et al. 2001; Hansson et al. 2001; Chen et al. 2002). For instance, Hagberg et al. had proposed a two level surveillance method for work exposure, with a first level based on questionnaire and check-list.

However, there are few recommendations about which variables should be included in an exposure questionnaire (Leijon et al. 2002). In 2000, the European consensus on UWMSD organised by the "SALTSA" group proposed a general score on work exposure, based on published literature on risk factors (Sluiter et al. 2001). However, comparisons between this list of variables and other questionnaires had not been performed, especially for the purpose of surveillance in general work settings.

We sought to identify which variables in a questionnaire best summarized biomechanical exposures in the context of a surveillance system. To fulfill this purpose, we analyzed data based on a surveillance survey of the French working population, and reduced the number of variables in the physical exposure questionnaire by using a principal component analysis (PCA).

POPULATION AND METHODS

Subjects

The French National Institute for Public Health Surveillance (InVS) implemented an experimental epidemiological surveillance system for UWMSD in the Pays de la Loire region (Loire Valley district, West-Central France) in 2002 and 2003 (Roquelaure et al. 2006; Melchior et al. 2006). This region in the West of France represents about 5% of the French working population and is characterized by a large industrial sector. Eighty occupational physicians working in the Pays de la Loire region (out of 460) volunteered to participate in the sentinel network in 2002 and/or 2003. They included a sample of workers under their surveillance, following a two-stage sampling with a randomized procedure: first, 15 to 30 half-days of consultation for each physician were sampled with the help of the investigators. Next, each physician was asked to randomly include 1 out of 10 workers per half-day of consultation. The sample of workers represented 24.1 workers per 10,000 workers in the Pays de la Loire region (26.3/10,000 men and 21.6/10,000 women). Less than 10% of selected workers failed to participate (no shows, refusals) and overall, almost all economic sectors and occupations of the salaried workforce in the Pays de la Loire region were represented.

Methods

The study included a self-administered questionnaire about work exposure followed by a standardized physical examination performed by the occupational physician. The physician strictly applied the methodology and clinical tests described in the "Criteria document" for UWMSD developed by SALTSA group (Sluiter et al. 2001). All sentinel physicians were trained by the investigators to perform a standardized physical examination based on this document for the evaluation of UWMSD. The presence of non-specific UWMSD during the last twelve months or the last seven days was also identified using the "Nordic" questionnaire (Kuorinka et al. 1987).

Analyses of study data were performed in four steps: in the first step, we set up a PCA from the work exposure questionnaire. Thirty seven variables dealing with physical exposures were included in a PCA followed by orthogonal rotation. PCA is often used to convert large sets of variables to smaller, more informative linear combinations of the original variables with minimum loss of original information. Technically speaking, PCA is a linear transformation that transforms the data to a new coordinate system such that the greatest variance by any projection of the data comes to lie on the first coordinate (called the first principal component), the second greatest variance on the second coordinate, and so on. A scree plot was used to determine the number of meaningful factors to be retained for rotation. We used the criterion proposed by Kaiser in 1960, which retains only factors with Eigenvalues greater than 1, and the graphical method proposed by Cattell in 1966 called the *scree* test based on the smooth decrease of Eigenvalues, and the explained variance (Fallissard B. 1998). In interpreting the rotated factor pattern, an item was said to load on a given factor if the factor loading was 0.40 or greater for that factor (Niedhammer 2002).

In the second step, we reduced the number of variables, in order to keep around twenty variables. The goal of 20 questions was determined before the study, considering the balance between efficacy and feasibility. Twenty variables that loaded more than 57% on the principal factors of the PCA after rotation were thus retained. If two variables were strongly correlated (Pearson's correlation coefficient >0.70), only the most strongly correlated with the principal factor was kept.

The third step aimed at confirming the relevance of the retained variables in the second step, by comparison with the exposure score developed by the SALTSA group, and by their association with the prevalence of UWMSD. First, all the retained variables were summed in a score called the "PCA score". Pearson's correlations between this score and SALTSA's upper limb global score were calculated. Since the SALTSA group also proposed regional upper limb scores for the neck, shoulder, elbow, and hand/wrist, we also examined correlations between these regional scores and the factors identified by PCA with orthogonal rotation (Sluiter et al. 2001). Second, means of "PCA" scores between subjects with UWMSD and subjects without UWMSD were compared using the Student's t test. Presence of UWMSD was defined in two ways: through reported symptoms only, and through a physical examination in combination with symptoms.

In the fourth step, we reintegrated important variables, since PCA could have failed to identify a few known risk factors. We thus decided to examine variables not favored in PCA, which corresponded to variables loaded on more than one factor or on none of them (at a threshold of 40%). These variables were reconsidered according to correlations to SALTSA scores and knowledge from international consensus (Bernard BP 1997; Buckle and Devereux 1999; Sluiter et al. 2001). The variables close to those not included in the PCA were also reconsidered. In order to complete this approach and to have a better description of the links between these variables and those kept in the second step, additional PCA were performed with subsets of variables.

We used Statistical Analysis Software for all analyses (SAS v8.2, SAS institute Inc, Cary, NC, USA). The Pays de la Loire study received the approval of France's national committee for data protection (CNIL: Commission Nationale Informatique et Liberté).

RESULTS

The questionnaire included 37 questions on biomechanical exposure. The categories of the thirty five variables were based on task frequency, such as proposed in SALTSA consensus (Sluiter et al. 2001): never **(=1**); uncommonly (defined by less than 2 hours by day when appropriate, =**2**); frequently (defined by 2 to 4 hours by day when appropriate, =**3**); all the time (defined by more than 4 hours by day when appropriate, =**4**). Two variables corresponding to a numeric scale ranging from 0 to 9 (subjective evaluation of repetitiveness and subjective evaluation of force). Vehicle driving (except fork-lift truck) and working on a slippery ground were not included, since these variables were not considered as UWMSD risk factors.

PCA was performed on 2514 subjects (6.3% had missing data). Using the scree plot of Eigenvalues (figure 1), we decided to keep seven factors. The proportion of variance explained by these seven factors was 55%, with at least two variables loaded on each factor after rotation.

These seven factors identified by PCA were closely related with UWMSD risk factors identified by other studies. Taking into account variables loaded on each factor, the following factors were identified: posture exposures, repetitiveness, handling of heavy loads, distal biomechanical exposures; a fifth factor specific for "computer use"; a sixth for "forklift operator task", and a seventh for "recovery time" (table 1). Among the 37 variables, 34 were loaded with one and only one factor (table 1). However two variables were loaded on two factors (subjective evaluation of force and "wrist bending"), and one variable on none of them ("holding an unsupported arm away from the body"). These three variables were considered for inclusion in step four. All variables were positively loaded on PCA factors, except "wearing gloves" and subjective evaluation of force in "computer use".

Two pairs of variables were highly correlated: "working with a computer screen" with "working with a keyboard and/or a computer mouse", and repetition of similar actions (defined as actions performed more than two to four times a minute) with subjective evaluation of repetitiveness (0.95 and 0.72 respectively). "Working with a computer screen" and repetition of similar actions were excluded since they were less correlated with the factors. After examining the correlation between exposure variables and PCA factors (Table 1), 20 variables were retained using a threshold of 57% for loading.

The PCA score, calculated as a sum of the twenty variables, was closely correlated with the global SALTSA score (rho=0.59 p<0.0001). The correlations between the seven factors from PCA and various SALTSA scores are given in table 2. The global SALTSA score was correlated with all factors, especially with the repetitiveness factor and the distal biomechanical exposures factor, but not with the "forklift operator" factor. However, specific neck/shoulder postures seemed to be poorly identified: shoulder SALTSA score was correlated with posture exposures only with a correlation coefficient of 0.30 and weakly correlated with "forklift operator" (rho=0.04); neck SALTSA score was associated only with "computer use". The mean of PCA score among all subjects was 37.1 with a minimum of 21.3 and a maximum of 66.7 (standard deviation at 6.0). The PCA score was closely associated with the presence of UWMSD: the mean PCA score was 37.5 in the group with at least one positive answer to Nordic-style questionnaire (68.2% of workers, n=1831), versus 36.2 in the group without reported symptoms (p<0.0001). Workers with at least one positive UWMSD test at physical examination (12.8% of workers, n=345), had a mean PCA score of 38.5, versus 36.9 in the group without any positive test at physical examination ($p<0.0001$).

The three remaining variables corresponding to three different exposures loaded on two factors or on none of them, were examined more carefully based on existing knowledge of risk factors and correlation between PCA factors and the regional SALTSA scores. The subjective evaluation of force was the only variable for force, which is a risk factor usually taken into account, and was reintegrated into the list of exposures. The variable "holding an unsupported arm away from the body" represented neck/shoulder specific postures. Although they are important posture risk factors, they had low loading in the PCA and low correlation with the neck SALTSA score. For that reason, "holding an unsupported arm away from the body", "extreme neck extension" and "holding arms above the shoulders" were reintegrated. In the same way, "wrist bending" corresponds to pronation and supination and can be considered among wrist/forearm/elbow exposures (Sluiter et al. 2001). Although correlations between the elbow SALTSA score and distal biomechanical exposures factors were fair, no specific risk factor for the elbow region was retained by PCA. For that reason, "wrist bending" and "repeated flexion of the elbow" were also reintegrated.

The more widely used four point ordinal variable "repetition of similar actions" was retained over the 10 point variable "subjective evaluation of repetitiveness", even though the correlation with the corresponding factor was slightly lower (0.79 versus 0.81).

Finally, twenty-six variables were selected (in grey in table 1), which corresponded to 30% reduction in the number of variables.

In order to complete this approach and analyse the links between the retained variables and the other variables, specific PCAs were performed, except for subjective evaluation of force which was considered as a factor by itself. A specific PCA for distal biomechanical exposures in the list above was performed. Two factors were identified: the first one corresponded to hand/wrist exposures only, with "using tools with force", "using vibrating tools", "turning over the hand such as using a screwdriver", "pressing with palm of the hand"; the second one corresponded to wrist/forearm/elbow exposures with "pinching tight between thumb and index", "wrist bending", and "repeated flexion of the elbow".

In the same way, a specific PCA for posture exposures variables was performed (in the list above). Two factors were identified: the first one corresponded to lower body posture exposures with "kneeling", "bending down", and "bending in the side"; the second one corresponded to upper body posture exposures with "carrying cumbersome objects", "extreme neck extension", "holding arms above the shoulders" and "holding an unsupported arm away from the body".

DISCUSSION

In this study, variables were selected according to their ability to summarize major biomechanical exposures in a working population, using methods combining statistical analysis by PCA and existing knowledge. Our study has some potential limitations related to the population, the method and the retained variables.

The random selection of workers during their compulsory annual occupational health examination resulted in a broadly representative sample of region's workforce. However, women were slightly under-represented, and skilled and unskilled manual workers somewhat over-represented in our sample (Roquelaure et al. 2006).

PCA with orthogonal rotation is widely used for description and data reduction in many fields (Murray et al. 2005; Lin and Altman 2004; Heberger et al. 1999; Gangopadhyay et al. 2001; Cleall et al. 1979; Niedhammer et al. 2000; Niedhammer 2002). Similar methods are available, such as oblique rotation (Varclus procedure in SAS (Nakache and Confais 2005)), although they are less commonly used. The use of PCA has some limits, including the importance of the initial selection of variables and the limitations of this methodology if used alone.

The results of PCA strongly depend on the initial list of variables. The list of variables in the questionnaire came from surveys (Roquelaure et al. 2002; Leclerc et al. 2001) and were based on the SALTSA consensus criteria (Sluiter et al. 2001). The choice of variables was as exhaustive as possible, making it difficult to use this questionnaire in a large surveillance system. Some risk factors were not included in the present analysis, because they were less specific for UWMSD: psychosocial factors, vehicle driving (except fork-lift truck) and working on a slippery ground. Possible answers were based on task frequency, which is quite usual. For instance, Viikari-Juntura et al. assessed the validity of self-reported physical workloads by ordinal scale questionnaire and a logbook compared to a task analysis and observation for neck and back pain (Viikari-Juntura et al. 1996). In another study among office workers, the constraints variables about repetitiveness or break possibility were based on frequency of the task with 5 categories on an ordinal scale, from "never" to "always" (Juul-Kristensen and Jensen 2005). PCA could not be used as an exclusive method, considering the risk of eliminating important ergonomic or medical dimensions. Variables could be excluded if they were not strongly correlated to others, or conversely if they were correlated with a variety of unspecific tasks. That is why PCA should be used as a decision support tool, in conjunction with an expert analysis approach.

Some choices were made in the PCA and should be discussed. The loading threshold for factors interpretation was high, given our purpose of data reduction. The number of factors in the analyses was based on most widely used criteria (Fallissard B. 1998). The strong correlations between the PCA score and the SALTSA general score, such as those between PCA score and the presence of at least one UWMSD assessed in the questionnaire and/or physical examination, were also important arguments for the final list of variables.

Factors from PCA corresponded to known UWMSD risk factors (Bernard BP 1997; Colombini et al. 2001; Spielholz et al. 1999; Lagerstrom et al. 1995). Vibrations were not isolated as a factor, although they are a known risk factor of UWMSD (Bernard BP 1997; Spielholz et al. 1999; Lagerstrom et al. 1995; Sluiter et al. 2001). However, vibrations include body vibrations and hand vibrations, and both of them are represented in the final list (driving a fork-lift truck and using a vibrating tool respectively). Three unexpected factors have been isolated: "computer use", "forklift operator" and "recovery time". "Recovery time" is a risk factor intermediate between biomechanical and psychosocial risk factors. "Computer use" is a traditional UWMSD risk factor, which must be distinguished from repetitiveness and distal biomechanical exposures (Stock et al. 2005; Juul-Kristensen and Jensen 2005).

The variables were reintegrated in the fourth step using both statistical (remaining variables) and non-statistical criteria. The evaluation of force was positively loaded with posture exposures and negatively with "computer use". This variable was also loaded on handling of heavy loads and repetitiveness (loading at 0.37 and 0.32 respectively). Forcefulness is an important biomechanical factor of UWMSD, which could be associated with others risk factors (Bernard BP 1997; Sluiter et al. 2001). "Holding arms above the shoulders", which has low loading with factors from PCA, was also reintegrated. In fact, our method poorly identified neck/shoulder postures, which is confirmed by the quite poor correlation between PCA score and neck/shoulder SALTSA score. However, the specific PCA on posture variables efficiently differentiated low back from upper back posture exposures. Studies about neck and shoulder disorders show associations between neck and shoulder uncomfortable posture and these disorders (van der Windt et al. 2000; Sluiter et al. 2001). In the same way, variables usually associated with elbow diseases were poorly identified by our method, even though correlations between "distal biomechanical exposures" and SALTSA factors of the elbow and of the wrist were acceptable. "Wrist bending" was associated with more than one factor ("repetitiveness" and "distal biomechanical exposures"), and "repeated flexion of the elbow" was associated with the factor of repetitiveness but not with "distal biomechanical exposures". These variables were reintegrated because they are considered as important factors of wrist/forearm/elbow exposures (Sluiter et al. 2001). Furthermore, specific PCA on upper-limb biomechanical variables efficiently differentiated hand/wrist exposures from wrist/forearm/elbow exposures.

A total of 26 variables could still appear to be high, but it deals with a relatively large number of different UWMSD and with their different risk factors. The number of variables was initially decided based on this expected heterogeneity and the possibility to reintegrate variables. PCA was performed on both genders without any distinction. However, PCA based on men only and on women only found quite similar results. PCA allowed grouping of variables into factors, which could help for later reduction, depending on the objectives of a future study. Furthermore, "computer use" and "forklift operator" factors could be documented by other sources than these questions (job title for instance).

In conclusion, this combined approach, based on statistical analysis (PCA) and existing knowledge, allowed us to efficiently select 26 variables out of 37 according to their ability to summarize major biomechanical exposures in a working population. A shorter questionnaire on biomechanical exposures would be useful in some contexts, especially for surveillance. The validity and test characteristics of this questionnaire should be now be evaluated in a prospective study, in order to test its usefulness in surveillance systems and other settings.

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REFERENCES

Balogh, I., Orbaek, P., Winkel, J., Nordander, C., Ohlsson, K., and Ektor-Andersen, J. (2001) Questionnaire-based mechanical exposure indices for large population studies--reliability, internal consistency and predictive validity. Scand. J. Work Environ. Health 27: 41-48.

Bernard B.P. Musculoskeletal disorders and workplace factors: a critical review of epidemiologic evidence for work-related musculoskeletal disorders of the neck, the upper-limb, and low back. National Institute of Occupational Safety and Health. 97-141. 1997. Cincinnati.

Buckle, P. and Devereux, J. J. (1999) Work-related neck and upper limb musculoskeletal disorders. European Agency for Safety and Health at Work.

Chen, Y., Meyer, J. D., Song, J., McDonald, J. C., and Cherry, N. (2002) Reliability assessment of a coding scheme for the physical risk factors of work-related musculoskeletal disorders. Scand. J. Work Environ. Health 28: 232-237.

Cleall, J. F., BeGole, E. A., and Chebib, F. S. (1979) Craniofacial morphology: a principal component analysis. Am. J. Orthod. 75: 650-666.

Colombini, D., Occhipinti, E., Delleman, N., Fallentin, N., Kilbom, A., and Grieco, A. (2001) Exposure assessment of upper limb repetitive movements: a consensus document developed by the Technical Committee on Musculoskeletal Disorders of International Ergonomics Association (IEA) endorsed by International Commission on Occupational Health (ICOH). G. Ital. Med. Lav. Ergon. 23: 129-142.

Fallissard B. (1998) Comprendre et utiliser les statistiques dans les sciences de la vie. Masson, Paris.

Gangopadhyay, S., Gupta, A., and Nachabe, M. H. (2001) Evaluation of ground water monitoring network by principal component analysis. Ground. Water 39: 181-191.

Hagberg, M., Silverstein, B. A., Wells, R., Smith M.J., Herbert, R., Hendrick H.W., Carayon P., and Pérusse M. (1997) Work related musculoskeletal disorders (WMSDs). A reference book for prevention. Taylor and Francis, Bristol.

Hansson, G. A., Balogh, I., Bystrom, J. U., Ohlsson, K., Nordander, C., Asterland, P., Sjolander, S., Rylander, L., Winkel, J., and Skerfving, S. (2001) Questionnaire versus direct technical measurements in assessing postures and movements of the head, upper back, arms and hands. Scand. J. Work Environ. Health 27: 30-40.

Heberger, K., Keszler, A., and Gude, M. (1999) Principal component analysis of measured quantities during degradation of hydroperoxides in oxidized vegetable oils. Lipids 34: 83-92.

Juul-Kristensen, B. and Jensen, C. (2005) Self-reported workplace related ergonomic conditions as prognostic factors for musculoskeletal symptoms: the "BIT" follow up study on office workers. Occup. Environ. Med. 62: 188-194.

Kuorinka, I., Jonsson, B., Kilbom, A., Vinterberg, H., Biering-Sorensen, F., Andersson, G., and Jorgensen, K. (1987) Standardised Nordic questionnaires for the analysis of musculoskeletal symptoms. Appl. Ergon. 18: 233-237.

Lagerstrom, M., Wenemark, M., Hagberg, M., and Hjelm, E. W. (1995) Occupational and individual factors related to musculoskeletal symptoms in five body regions among Swedish nursing personnel. Int. Arch. Occup. Environ. Health 68: 27-35.

Leclerc, A. (2005) Exposure assessment in ergonomic epidemiology: is there something specific to the assessment of biomechanical exposures? Occup. Environ. Med. 62: 143-144.

Leclerc, A., Landre, M. F., Chastang, J. F., Niedhammer, I., and Roquelaure, Y. (2001) Upper-limb disorders in repetitive work. Scand. J. Work Environ. Health 27: 268-278.

Leijon, O., Wiktorin, C., Harenstam, A., and Karlqvist, L. (2002) Validity of a self-administered questionnaire for assessing physical work loads in a general population. J. Occup. Environ. Med. 44: 724-735.

Lin, Z. and Altman, R. B. (2004) Finding haplotype tagging SNPs by use of principal components analysis. Am. J. Hum. Genet. 75: 850-861.

Melchior, M., Roquelaure, Y., Evanoff, B., Chastang, J. F., Ha, C., Imbernon, H., Goldberg, J. F., Leclerc, A., and Pays de la Loire Study Group . Why are manual workers at high risk of upper limb disorders? The role of physical work factors in a random sample of workers in France (the Pays de la Loire study). Occup Environ Med . 2006. In press.

Murray, V., McKee, I., Miller, P. M., Young, D., Muir, W. J., Pelosi, A. J., and Blackwood, D. H. (2005) Dimensions and classes of psychosis in a population cohort: a four-class, four-dimension model of schizophrenia and affective psychoses. Psychol. Med. 35: 499-510.

Nakache, J. P. and Confais, J. (2005). Approche pragmatique de la classification. Technip, Paris.

Niedhammer, I. (2002) Psychometric properties of the French version of the Karasek Job Content Questionnaire: a study of the scales of decision latitude, psychological demands, social support, and physical demands in the GAZEL cohort. Int. Arch. Occup. Environ. Health 75: 129-144.

Niedhammer, I., Siegrist, J., Landre, M. F., Goldberg, M., and Leclerc, A. (2000) [Psychometric properties of the French version of the Effort-Reward Imbalance model]. Rev. Epidemiol. Sante Publique 48: 419-437.

Roquelaure, Y., Ha, C., Leclerc, A., Touranchet, A., Sauteron, M., Melchior, M., Imbernon, E., Goldberg, J. F., and and 80 occupational physicians of the Pays de la Loire Region . Epidemiological Surveillance of Upper Extremity Musculoskeletal Disorders in the working Population: the French Pays de la Loire Study. Arthritis Rheum. 2006. In Press.

Roquelaure, Y., Mariel, J., Fanello, S., Boissiere, J. C., Chiron, H., Dano, C., Bureau, D., and Penneau-Fontbonne, D. (2002) Active epidemiological surveillance of musculoskeletal disorders in a shoe factory. Occup. Environ. Med. 59: 452-458.

Sluiter, B. J., Rest, K. M., and Frings-Dresen, M. H. (2001) Criteria document for evaluating the work-relatedness of upper-extremity musculoskeletal disorders. Scand. J Work Environ. Health 27 Suppl 1: 1-102.

Spielholz, P., Silverstein, B., and Stuart, M. (1999) Reproducibility of a self-report questionnaire for upper extremity musculoskeletal disorder risk factors. Appl. Ergon. 30: 429-433.

Stock, S. R., Fernandes, R., Delisle, A., and Vezina, N. (2005) Reproducibility and validity of workers' self-reports of physical work demands. Scand. J. Work Environ. Health 31: 409-437.

van der Windt, D. A., Thomas, E., Pope, D. P., de Winter, A. F., Macfarlane, G. J., Bouter, L. M., and Silman, A. J. (2000) Occupational risk factors for shoulder pain: a systematic review. Occup Environ Med 57: 433-442.

Viikari-Juntura, E., Rauas, S., Martikainen, R., Kuosma, E., Riihimaki, H., Takala, E. P., and Saarenmaa, K. (1996) Validity of self-reported physical work load in epidemiologic studies on musculoskeletal disorders. Scand. J. Work Environ. Health 22: 251-259.

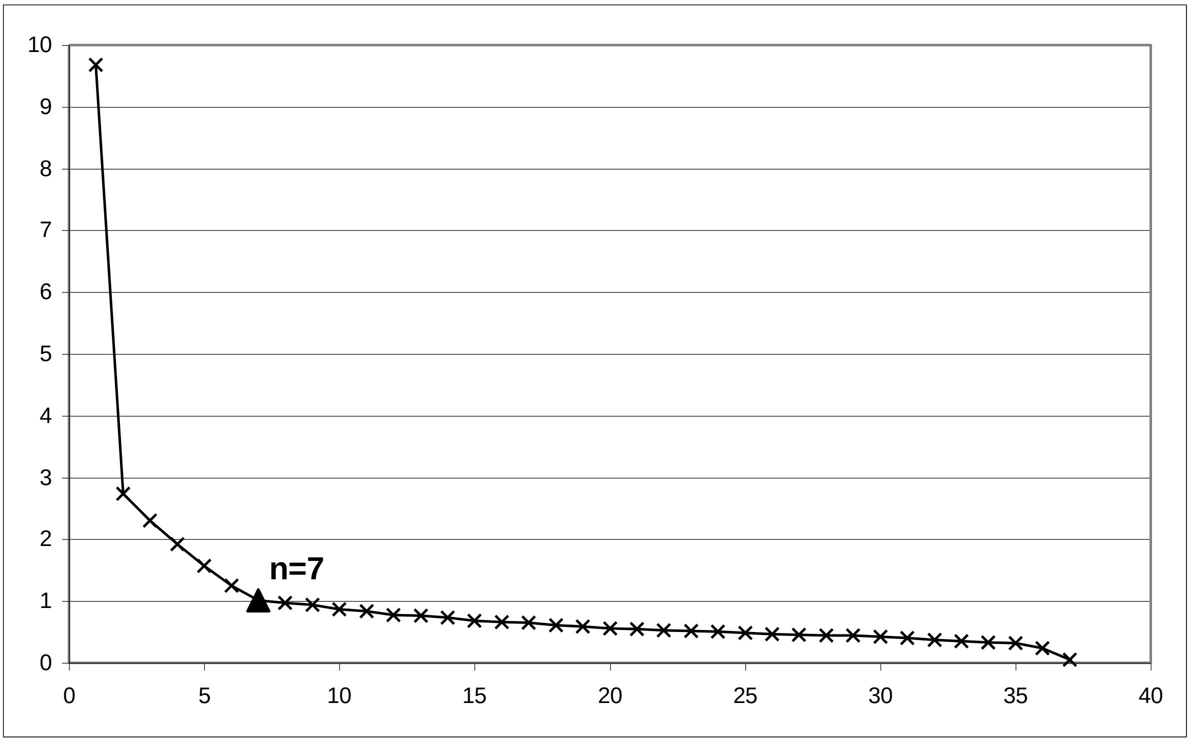

Figure 1: Scree plot of Eigenvalues from principal component analysis based on the 37 biomechanical variables.

The threshold was based on the Kaiser's criterion (Eigenvalues greater than 1), and the scree test (smooth decrease of Eigenvalues).

	Posture exposures (Factor 1)	Repetitiveness (Factor 2)	Handling of heavy loads (Factor 3)	Distal biomechanical exposures (Factor 4)	"Computer use" (Factor 5)	"Forklift operator" (Factor 6)	"Recovery time" (Factor 7)	C.
Repetition of similar actions	7	79*	12	0	-5	8	-17	68
High rhythm of working (same action or cycle <30")	30	57*	-30	-9	-4	13	-13	55
Subjective evaluation of repetitiveness	8	81*	11	-1	-7	6	-23	74
Possibility of more than 10' break	-1	-34	-4	-2	17	3	68*	60
Ability to shift the gaze away from work	-10	-21	0	-5	10	-7	76*	65
Making precise gesture	9	57*	10	30	-15	8	-21	50
Working seated	-34	-14	-27	-22	65*	5	-2	69
Kneeling	64*	-2	5	23	-28	7	7	56
Bending down	65*	26	8	15	-35	-5	3	64
Bending to the side	67*	25	-1	20	-7	0	-2	56
Carrying load less than 10 kg	11	9	78*	11	-12	-5	5	66
Carrying load from 10 to 20 kg	17	4	75*	9	-6	11	-6	62
Carrying load more than 20 kg	18	-9	57*	11	-7	22	-10	44
Carrying cumbersome objects	60*	13	27	1	-5	7	-10	46
Carrying objects hard to catch	57*	-1	28	16	-9	21	-11	50
Pushing load	52*	14	34	8	-9	10	-6	44
Driving a fork-lift truck	7	3	15	5	1	74*	-5	58
Manipulating load from 1 to 4 kg	8	19	70*	16	-17	-4	8	60
Manipulating load more than 4 kg	21	9	74*	7	-16	12	-4	65
Subjective evaluation of force	41*	31	37	17	-42*	22	-12	67
Using tools with force	8	24	7	59*	-22	15	23	55
Using vibrating tools	13	4	11	62*	-17	27	6	53
Wearing gloves	13	19	14	23	-49*	35	-7	50
Cold work environment	19	15	4	9	-29	49*	-1	39
Using a computer screen	-17	-14	-13	-21	81*	-6	13	78
Using a keyboard and/or a computer mouse	-16	-12	-14	-22	81*	-6	13	79
Extreme neck flexion	18	51*	2	22	16	-27	25	50
Extreme neck extension	37	6	14	30	7	41*	8	43
Holding arms above the shoulders	50*	16	23	27	-14	13	3	44
Holding arm behind the trunk	40*	0	5	32	32	5	-5	38
Holding an unsupported arm away from the body	27	30	18	37	-4	0	-14	35
Having an armrest	-1	11	-9	12	62*	-3	6	43
Repeated flexion of the elbow	12	51*	17	35	-9	8	-6	44
Turning over the hand such as using a screwdriver	19	2	9	74*	-13	6	0	61
Wrist bending	18	48*	14	45*	-20	2	0	53
Pressing with palm of the hand	25	-2	12	68*	1	7	-9	55
Pinching tight between thumb and index	9	19	13	59*	1	-27	-18	51

Table 1: Result of principal component analysis (PCA) and factors loading (expressed as percent):

Variables retained in the second step are underlined (57% threshold, without a correlation with another variable higher than 0.70). In grey, final variables retained including those reintegrated in the fourth step.

C.= Communalities;*=at least 40% loading with the corresponding factor.

	SALTSA neck	SALTSA shoulder	SALTSA elbow	SALTSA hand/wrist	SALTSA global
Posture exposures	rho=0.01 p=0.64	**rho=0.30 p<0.0001**	**rho=0.19 p<0.0001**	**rho=0.14 p<0.0001**	**rho=0.22 p<0.0001**
Repetitiveness	**rho=0.56 p<0.0001**	**rho=0.46 p<0.0001**	**rho=0.51 p<0.0001**	**rho=0.52 p<0.0001**	**rho=0.57 p<0.0001**
Handling of heavy loads	rho=-0.02 p=0.26	***rho=0.33 p<0.0001***	**rho=0.30 p<0.0001**	**rho=0.27 p<0.0001**	**rho=0.22 p<0.0001**
Distal biomechanical exposures	rho=0.03 p=0.15	**rho=0.21 p<0.0001**	***rho=0.32 p<0.0001***	***rho=0.31 p<0.0001***	**rho=0.45 p<0.0001**
"Computer use"	***rho=0.38 p<0.0001***	rho=0.01 p=0.62	**rho=-0.06 p=0.003**	**rho=0.14 p<0.0001**	**rho=0.23 p<0.0001**
"Forklift operator"	**rho=-0.09 p<0.0001**	**rho=0.06 p<0.01**	**rho=0.06 p=0.002**	**rho=0.04 p=0.04**	rho=0.01 p=0.72
"Recovery time"	**rho=-0.08 p<0.0001**	**rho=-0.18 p<0.0001**	**rho=-0.16 p<0.0001**	**rho=-0.12 p<0.0001**	**rho=-0.06 p=0.002**

Table 2: Correlation results between SALTSA scores and factors retained by principal component analysis with orthogonal rotation (Sluiter et al. 2001).

- In bold character, significant correlation, p<0.05,
- italic = rho> 0.30,
- underligned = rho> 0.40.