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Predicting Work-Related Incidence of Lateral and Medial Epicondylitis Using the Strain Index

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Background *The Strain Index (SI) has been developed to evaluate the risk for developing a distal upper extremity disorder. The objective of this study is to determine if the SI predicts incidence cases of work-related lateral, medial, or any epicondylities (LEPI, MEPI, and EPI).*
Methods *Six hundred seven workers were followed for up to 3.5 years, 70 developed EPI on the dominant side (44 LEPI, 13 MEPI, and 13 both). Survival analyses were conducted adjusting for demographic, psychosocial, and work organizational factors, with the SI as time-dependent variable.*
Results *High exposure (SI > 5), older age, and self-perceived poor general health were associated with incidence of LEPI and EPI, but not MEPI. There was a significant relationship between higher scores of SI and LEPI, hazard ratio (HR) 2.00 (95% CI 1.04–3.87) for SI 5.1–12, HR 2.12 (95% CI 1.11–4.05) for SI > 12.*
Conclusions *The SI can effectively identify jobs with increased risk of developing incidence of LEPI.* Am. J. Ind. Med. 57:1319–1330, 2014. © 2014 Wiley Periodicals, Inc.

KEY WORDS: strain index; occupation; epicondylitis; incidence; prospective study

INTRODUCTION

Epicondylitis (EPI) is a common upper-extremity musculoskeletal disorder. Lateral epicondylitis (LEPI) or "tennis elbow" is a musculotendonous disorder of the wrist extensor muscles at their origin along the lateral epicondyle of the humerus. LEPI is one of the major upper extremity musculoskeletal disorders (MSDs) in active workers [Ware et al., 1996; Silverstein and Adams, 2007]. Previous reports from different countries indicate that the prevalence of LEPI ranges from 2% to 14.5% in working populations [McCormack et al., 1990; Viikari-Juntura et al., 1991; Chiang et al., 1993; Ware et al., 1996; Ono et al., 1998; Shiri et al., 2006]. Medial epicondylitis (MEPI) or "golfer's elbow" is a musculotendonous disorder of the wrist flexor muscles along the medial epicondyle of the humerus. MEPI is less common than LEPI, with prevalence ranges from 0.2–3.8% in working populations [Ono et al., 1998; Descatha et al., 2003; Gold et al., 2009]. Most studies of EPI have not distinguished LEPI from MEPI [Hales and Bernard, 1996; Fredriksson et al., 1999; Nathan and Meadows, 2000]. In Washington State, non-traumatic epicondylitis had an annual compensable workers' compensation claims incidence rate of 4.7 per 10,000 full time employees, resulting in an average of 263 lost work days per claim and an average annual direct cost of more than $12 million [Silverstein and Adams, 2007].

The etiology of EPI is multi-factorial [Sluiter et al., 2001; Silverstein and Adams, 2007; Hegmann et al., 2013]. Various physical load factors, including repetitive, sustained, and forceful exertion, awkward postures, localized mechanical stress, and highly dynamic movements have been linked to increased risk of work-related LEPI [McCormack et al., 1990; Kurppa et al., 1991; Ritz, 1995; Ono et al., 1998; Leclerc et al., 2001; Werner et al., 2005; Shiri and Viikari-Juntura, 2011; Descatha et al., 2013; Fan et al., 2013; Herquelot et al., 2013] and MEPI [Descatha et al., 2003; Shiri et al., 2006; Descatha et al., 2013].

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There have been continuous challenges in obtaining the most accurate and precise assessments of physical workload. The major issues have been misclassification by self-reported exposure [Viikari-Juntura et al., 1996] and estimating exposure objectively at the group level [Ritz, 1995; Fallentin et al., 2001]. Therefore, physical workload estimates obtained objectively at the individual level are more desirable. Generally, direct measurements and video-based observation of exposures are assumed to have a higher level of accuracy than subjective assessment and self-reports of exposure [Winkel and Mathiassen, 1994; van der Beek and Frings-Dresen, 1998]. The key element in the ergonomic assessment process is in the selection of tools that are easy to use, take a minimal amount of time to complete, are low cost and applicable to a broad range of industries and occupations.

The Strain Index (SI) has been developed to evaluate the risk for developing a distal upper extremity (DUE) disorder [Moore and Garg, 1995]. The SI relies on the measurement or estimation of six task variables that describe the external demands or physical load of a job: intensity of exertion, duration of exertion, efforts per minute, hand/wrist posture, speed of work, and duration per day of the job. Each of the task variables is assigned a multiplier. The product of the six task variable multipliers produces the SI.

The SI was originally created as a method to assess musculoskeletal risk for single-task jobs in the pork processing industry [Moore and Garg, 1995]. The validity of the SI for single-task jobs was subsequently tested in a turkey processing plant [Knox and Moore, 2001; Moore et al., 2001] and in multiple manufacturing and health care services worksites in Washington State [Spielholz et al., 2008]. For evaluating complicated jobs with multiple forces/tasks, Bao et al. developed different data reduction methods to obtain SI scores that were used to quantify risk levels of different physical and mechanical hazards in the Washington State manufacturing and health care worksites [Bao et al., 2009]. These proposed methods, however, were not assessed using a health outcome.

This prospective study of 12 different manufacturing and service sector employers in Washington State involved a large variety of jobs, such as office work, assembly work, wood product manufacturing, and technical occupations in health care delivery. The objectives are to examine whether the SI predicts the incidence of work-related EPI and to assess meaningful SI cut-points to discriminate between low, medium, and high risk of developing EPI.

METHODS

Subjects

We conducted a prospective cohort study of work-related musculoskeletal disorders among full-time employees in 12 different manufacturing and health care facilities in the state of Washington from 2001 to 2004. Detailed health data collection methods, physical exposure data collection, and processing of physical exposure data have been presented in previously publications [Bao et al., 2006a; Fan et al., 2009; Silverstein et al., 2009]. Among 733 subjects enrolled in the study, we excluded the 42 prevalent dominant side EPI cases at baseline (27 LEPI, 4 MEPI, and 11 both LEPI and MEPI) and 84 subjects who were lost to follow-up (Fig. 1). Of the

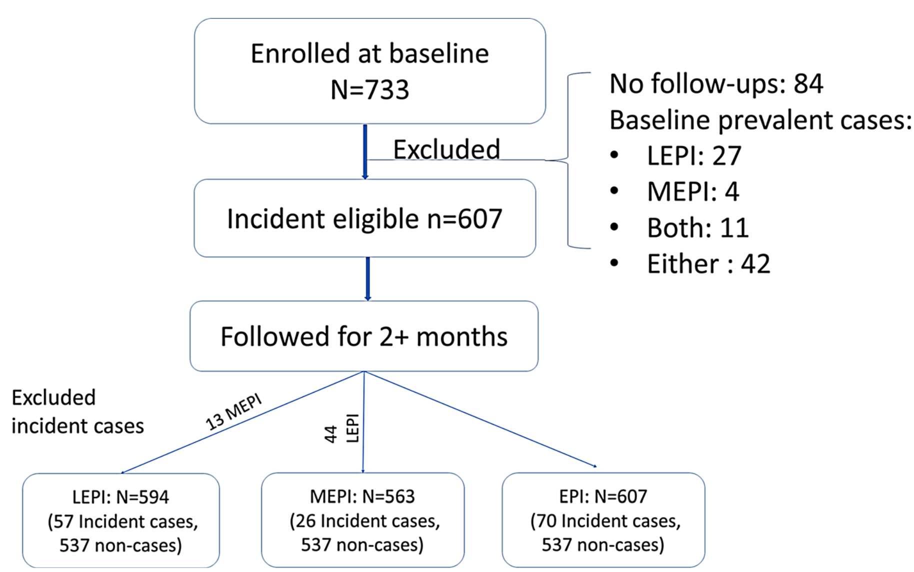

FIGURE 1. Study subjects. LEPI: dominant side lateral epicondylitis. MEPI: dominant side medial epicondylitis. EPI: dominant side epicondylitis.

607 remaining subjects who were eligible and were followed for up to 3.5 years, 70 subjects became EPI incident cases on the dominant side (44 LEPI, 13 MEPI, and 13 both LEPI and MEPI). The remaining 537 subjects were non-cases. We conducted analyses separately for the 57 LEPI incident cases (including 13 concurrent MEPI cases), 26 MEPI incident cases (including 13 concurrent LEPI cases), and 70 EPI incident cases (44 LEPI only, 13 MEPI only, 13 LEPI and MEPI, Fig. 1), using 537 non-cases as the reference group. Due to job changes during the follow-ups, the total number of jobs held for the 57 workers who became LEPI incident cases was 72. The correspondent number of jobs held for the 26 MEPI and 70 EPI incident cases were 31 and 88, respectively, and the 537 non-cases were 685 (Table I).

Health Data collection

Briefly, we collected information about each participating worker's health and work using detailed structured interviews (interviewers were blinded to workplace physical exposures and physical examination information), and physical examinations (examiners were blinded to work, including job title, health history, symptoms reported to interviewers, and physical load factors of the job). Health information included personal factors (age, gender, race/ethnicity, education, and high hand force or repetitive sports and hobbies), relevant health history (diabetes, rheumatoid or degenerative arthritis, gout, hypertension, acute traumatic injuries, smoking, medications, and treatment for MSDs), and work history (duration of employment with the company, job, and similar work prior to current job).

The subjects were screened for symptoms of any pain or discomfort in the previous 12 months and in the past seven days by structured interviews using the standardized Nordic Questionnaire. A specific body map was used to ascertain a more precise location of symptoms. Information was obtained on symptom onset, duration, frequency, and severity, and whether symptoms interfered with the pace or quality of work, or had resulted in lost workdays. Subjects were evaluated on whether symptoms resulted from traumatic injuries. An occupational physician, a registered nurse, or a physical therapist blinded to self-reported health status completed a brief physical examination of the neck and upper extremities for all subjects. The physical examinations were conducted bilaterally. All study participants signed written informed consent. Human subjects' approval was given for both the original study and the analysis of the data in this study by the Washington State Institutional Review Board.

Case Definition

Positive elbow or forearm symptoms were defined as: 1) any pain, aching, stiffness, burning, numbness, or tingling in the elbow or forearm region in the past seven days; and 2) symptoms that lasted more than one week or occurred more

TABLE I. Study Population by Case Status, Dominant Side

	Incidence lateral epicondylitis (LEPI)	Incidence medial epicondylitis (MEPI)	Incidence lateral or medial epicondylitis (EPI)	Non-cases
Number of subjects	57	26	70	537
Follow-up time				
Range (days)	77–1288	77–1288	77–1288	84–1288
Median (days)	413	496.5	416.5	461
Sum (person yrs)	78.9	39.4	97.3	1042.5
Incidence rate (/100 person yrs)	5.1	2.4	7.9	
Number of jobs held				
1	47	22	58	439
2	8	3	9	62
3	0	1	1	27
4	1	0	1	5
5	1	0	1	3
6	0	0	0	1
Total jobs	72	31	88	685

than three times in the previous 12 months; and 3) no previous accident or sudden injury at the elbow/forearm area at the time of the onset of symptoms. Positive physical exams for LEPI included: pain in the lateral humeral epicondylar region on resisted wrist extension [Sluiter et al., 2001] or tenderness on palpation of the lateral epicondyle. Positive physical exams for MEPI include: pain at the medial epicondylar region on resisted wrist flexion [Sluiter et al., 2001] or tenderness on palpation of the medial epicondyle. A positive clinical case was defined as positive symptoms at the elbow or forearm from the structured interview plus a corresponding positive physical exam on the symptomatic side. Only those who were not clinical cases of LEPI or MEPI on the same elbow at baseline were considered in this prospective study (Fig. 1). Only dominant side incident cases were considered in these analyses.

Exposure Assessment and Strain Index Computation

Briefly, during the worksite visits, each worker were videotaped performing his/her job. The video tapes taken from the worksite visits were digitized and processed in the laboratory by the analysts who were blinded to the health status of the worker. Detailed time studies were conducted for each forceful hand exertion and posture using the Multimedia Video Task Analysis (MVTA) software [Yen and Radwin, 1995]. Forceful exertions [Bao et al., 2006b] involved during typical tasks observed were estimated by the ergonomists. Types of forceful exertion included lifting/lowering (object weights $\geq$4.5 kg), pushing/pulling ($\geq$4.5 kg force), power gripping ($\geq$4.5 kg of object weight or with 4.5 kg power grip), pinch gripping ($\geq$0.9 kg of object weight or with 1.8 kg pinch grip force), and other types of forceful hand exertions (e.g., thumb press, one handed pull etc.). Different computation methods were used to deal with multiple forceful exertions [Bao et al., 2009]. A data reduction method was developed for the SI scores computation in multiple force jobs [Bao et al., 2006a]. In this study, the SI parameter of intensity of exertion is an estimate of the hand force required of a task and is calculated based on the “most frequently occurring forceful exertion” in a job. Duration of exertion and efforts per minutes were calculated based on the frequency and duty cycle of the detailed time-study results of repetitive muscle activity analysis. Hand/wrist posture and speed of work were estimated at task level and selected from the common force task. Duration per day was the duration of the tasks in a job and obtained from interviews of workers or supervisors.

All subjects were evaluated at baseline for their initial job physical exposure. Those who reported a job change by the ergonomists in a follow-up visit were re-evaluated for their job physical exposure. Consequently, those who changed jobs had more than one set of SI parameters and SI scores. The information on the duration for each job held was critical in the statistical analyses.

Job Risk Classification Using SI Scores

The SI scores were used to categorize job risk classifications based on various cut points. First we used the cut points of three and seven for job risk classification of Safe vs. Hazardous as proposed by Moore and Garg [Moore and Garg, 1995]: an SI ≤ 3 is almost surely Safe and an SI > 7 almost surely Hazardous. Another cut point of five, originally proposed by Moore and Garg [Moore and Garg, 1995] and tested by Moore [Moore et al., 2001], was found to provide good discrimination between Low exposure (SI ≤ 5) and High exposure (SI > 5) jobs. A third set of cut points, five and 12, was generated based on the distribution of our study population, aiming for equal numbers of jobs within each category, with a slightly higher proportion in the reference group of Low exposure jobs.

Psychosocial and Work Organization Factors

A self-administered psychosocial questionnaire was completed to assess job demands, decision latitude, job security [Karasek and Theorell, 1990], job satisfaction, and social support [Bigos et al., 1991]. Medians of the current sample were used as cut points for categorizing the psychosocial variables. Work organizational factors were assessed at the department level by fielder ergonomists using an observational tool [Howard et al., 2009]. Work organization factors included pacing, job rotation, social aspects of the work (team coordination), and structural job constraints of task activities.

Statistical Analyses

For the SI parameters that were used to assess job level tasks and to compute the SI scores, one-way non-parametric analyses were performed. The differences between the incident cases and non-cases were compared using Wilcoxon rank sum test for the SI scores and Fisher’s exact test for the SI parameters. Since the SI scores were positively skewed, we carried out further analyses using the job risk classifications.

Survival analyses were conducted to examine how well the SI predicted incidence of LEPI, MEPI, and EPI. Demographic characteristics, psychosocial, and work organizational factors were considered as time independent variables and were collected at baseline and annually. Exposure variables were treated as time-dependent variables, depending on the number of jobs that each individual worker held during the follow-up visits. Specifically, each subject was followed until he/she became an incident case or by the study ended. The incident cases and non-cases may have held multiple jobs before becoming a case and at the end of the study, respectively. SI parameters and scores were available for each subject at each new job held. Therefore, the number of records represented the number of jobs held by each subject. To determine whether or not to include the covariates in the final model, the Kaplan–Meier survival curves and the log-rank test of equality across strata were computed for each variable of demographic characteristics, psychosocial, and work organizational factors. All those variables that had a *P*-value of 0.2 or less were considered for the multivariable Cox proportional hazard models. We used the counting process style of input (the PHREG procedure in SAS) by modeling the marginal distribution of the time until an incident case was identified (an event). This procedure allows for more than one record per subject and each record represents a time interval where the value of the time-dependent exposure variable is assumed constant. The final models included age, gender, and other significant covariates and were built for each job risk classifications based on the SI scores.

All statistical analyses were performed using the SAS statistical program (v9.3, SAS Institute Inc., Cary, NC).

RESULTS

Study Subjects and Number of Jobs Held

Of the 607 subjects who were at risk of becoming incident cases during the 3.5 years of follow-up period, 57 (5.1 per 100 person-years) met case definition criteria for EPI on the dominant side. The corresponding incident cases (rates) of MEPI and EPI were 26 (2.4 per 100 person-years) and 70 (7.9 per 100 person-years), respectively (Table I). About 82% of the study participants held only one job during the follow-up period while a few subjects held up to six jobs (Table I).

SI Scores and SI Parameters

The differences in median SI scores between incident cases and non-cases were not significant for LEPI, MEPI, and EPI (Table II). For SI parameters, the only statistical difference existed in speed of work for MEPI ($P = 0.0480$, data not shown) and EPI ($P = 0.0227$, Table II).

Job Risk Classifications

The job risk classification using cut points of three and seven divided the subjects at the job level into Safe ($SI \leq 3$, 22%), Action (SI 3.1–7, 30%), and Hazardous ($SI > 7$, 48%) jobs for LEPI (Table III). With a relatively smaller proportion of jobs in the Safe job category and larger in the Hazardous job category, there was no statistically significant difference in survival functions by this job risk classification ($P > 0.05$). Similar proportions of job risk classification and results on survival functions were observed for MEPI and EPI (Table III). Using the cut point of five which divided subjects at the job level into about 40% Low exposure and the rest High exposure, LEPI incident cases ($n = 40$) were3% points higher in the proportion High exposure compared with non-cases ($n = 17$) ($P = 0.02$). The same cut point of $SI = 5$ however, resulted in similar proportions of MEPI incidence cases and non-cases, 3.5% vs. 3.7%, respectively ($P = 0.55$). There was a marginally significant result ($P = 0.06$) for EPI by this job risk classification, which was likely due to the effect of LEPI incident cases. The new set of cut points of five and 12 further divided the High exposure into two groups of close to 30% each. The crude estimate on the survival function was marginally significant ($P = 0.05$) for LEPI incident cases, but not significant for MEPI and EPI incident cases.

Personal, Psychosocial, and Work Organization Factors

Age was a significant covariate for all three health outcomes based on survival function estimation ($P < 0.01$, Table IV). Female had a higher proportion of LEPI and EPI cases than that of male ($P < 0.1$). Subjects with high job satisfaction was statistically significant for all three outcomes, and resulted in marginally higher proportions of incident cases ($P < 0.1$), while a marginally significant result was observed among workers having better health for LEPI ($P < 0.1$). Working as an individual versus working in a team with any degree of coordination (minimal to high) was significant for EPI ($P < 0.05$) while marginal for LEPI ($P < 0.1$). MEPI cases had more job rotation ($P < 0.1$).

The Association Between Incidence of LEPI, MEPI, and EPI and the SI

Table V presents the crude and adjusted hazard ratio estimates for the three outcomes. The association between job risk classification of Safe, Action, and Hazardous jobs ($SI <= 3$, SI 3.1–7, and $SI > 7$, respectively) and LEPI, MEPI, or EPI was not statistically significant (Table V). The job risk classification of High exposure vs. Low exposure ($SI > 5$ vs. $<= 5$), which was associated with adjusted hazard ratio (HR) for LEPI and MEPI 2.06 (95% CI 1.16–3.64) and 1.69 (95% CI 1.03–2.78), respectively. The job risk classification which divided High exposure further into two groups ($SI > 12$ and SI 5.1–12 vs. $SI <= 5$) indicated

TABLE II. Strain Index and Six Parameters, at Job Level*

	Lateral epicondylitis (N = 757 jobs)			Medial epicondylitis (N = 716 jobs)			Lateral and/or medial epicondylitis (N = 773 jobs)		
	Total	Incident cases	Non-cases	Total	Incident cases	Non-cases	Total	Incident cases	Non-cases
Strain index (SI)									
n		57	700		26	690		70	703
Range		0.8–108	0.3–243		1.5–60.8	0.3–243		0.8–108	0.3–243
Median (quartiles1–3)		8 (4.5–18)	6.8 (3.4–18)		6.8 (3.0–18)	6.8 (3.4–18)		6.8 (3.4–18)	6.8 (3.4–18)
SI parameters, n (%)									
Intensity of exertion (IE)									
Light	471	36 (7.2)	435 (92.4)	444	15 (3.4)	429 (96.6)	482	46 (9.5)	436 (90.5)
Somewhat hard	199	12 (6.0)	187 (94.0)	191	7 (3.7)	184 (96.3)	203	14 (6.9)	189 (93.1)
Hard	58	7 (12.1)	51 (87.9)	53	3 (5.7)	50 (94.3)	59	8 (13.6)	51 (86.4)
Very hard	28	2 (7.1)	26 (92.9)	27	1 (3.7)	26 (96.3)	28	2 (7.1)	26 (92.9)
Near max	1	0 (0)	1 (100)	1	0 (0)	1 (100)	1	0 (0)	1 (100)
Duration of exertion (DE, proportion of the exertion cycle), n(%)									
<10	21	1 (4.8)	20 (95.2)	20	0 (0)	20 (100)	21	1 (4.8)	20 (95.2)
10–29.9	82	7 (8.5)	75 (91.5)	74	1 (1.4)	73 (98.6)	83	8 (9.6)	75 (90.4)
30–49.9	151	10 (6.6)	141 (93.4)	147	7 (4.8)	140 (95.2)	153	11 (7.2)	142 (92.8)
50–79.9	348	23 (6.6)	325 (93.4)	329	10 (3.0)	319 (97.0)	356	30 (8.4)	326 (91.6)
≥ 80	155	16 (10.3)	139 (89.7)	146	8 (5.5)	138 (94.5)	160	20 (12.5)	140 (87.5)
Efforts per minute (EM), n(%)									
<4	138	9 (6.5)	129 (93.5)	135	4 (3.0)	131 (94.0)	143	12 (8.4)	131 (91.6)
4–8.9	136	15 (11.0)	121 (89.0)	125	7 (5.6)	118 (94.4)	139	17 (12.2)	122 (87.8)
9–14.9	238	18 (7.6)	220 (92.4)	224	10 (4.5)	214 (95.5)	245	25 (10.2)	220 (89.8)
15–19.9	112	9 (8.0)	103 (92.0)	104	3 (2.9)	101 (97.1)	112	9 (8.0)	103 (92.0)
≥ 20	133	6 (4.5)	127 (95.5)	128	2 (1.6)	126 (98.4)	134	7 (5.2)	127 (94.8)
Hand/wrist posture (HWP), n(%)									
Very Good	14	0 (0)	14 (100)	14	0 (0)	14 (100)	14	0 (0)	14 (100)
Good	134	7 (5.2)	127 (94.8)	132	5 (3.8)	127 (96.2)	139	11 (7.9)	128 (92.1)
Fair	330	25 (7.6)	305 (92.4)	308	8 (2.6)	300 (97.4)	335	28 (8.4)	307 (91.6)
Bad	275	25 (9.1)	250 (90.9)	258	13 (5.0)	245 (95.0)	281	31 (11.0)	250 (89.0)
Very Bad	4	0 (0)	4 (100)	4	0 (0)	4 (100)	4	0 (0)	4 (100)
Speed of work (SW), n(%)									
Very Slow	18	4 (22.2)	14 (77.8)	14	0 (0)	14 (100)	18	4 (22.2)	14 (77.8)
Slow	128	5 (3.9)	123 (96.1)	125	0 (0)	125 (100)	131	5 (3.9)	126 (96.2)
Fair	437	37 (8.5)	400 (91.5)	410	20 (4.9)	390 (95.1)	447	47 (10.5)	400 (89.5)
Fast	160	10 (6.3)	150 (93.8)	153	5 (3.3)	148 (96.7)	162	12 (7.4)	150 (92.6)
Very Fast	14	1 (7.1)	13 (92.9)	14	1 (7.1)	13 (92.9)	15	2 (13.3)	13 (86.7)
Duration per day (hours, DD), n(%)									
4–8	502	37 (7.4)	465 (92.6)	476	18 (3.8)	458 (96.2)	514	48 (9.3)	466 (90.7)
≥ 8	255	20 (7.8)	235 (92.2)	240	8 (3.3)	232 (96.7)	259	22 (8.5)	237 (91.5)

*Incidence cases held up to five jobs and non-cases held up to six jobs per subject during the course of follow-ups. The three cohorts of LEPI, MEPI, and EPI included 594, 563, and 607 subjects, with correspondent total number of jobs of 757, 716, and 773, respectively.

significant relationships for LEPI, HR 2.00 (95% CI 1.04–3.87, $P = 0.0383$) for SI 5.1–12, HR 2.12 (95% CI 1.11–4.05, $P = 0.0238$) for SI > 12. The association between this job risk classification and EPI was marginally significant ($P < 0.1$), with no exposure–response relationship. There was no statistically significant association between this job risk classification and MEPI.

DISCUSSION

In this prospective study of workers in the manufacturing and service industries, we found that job risk classification for High exposure (SI > 5), older age, and self-perceived poor general health were related to the incidence of LEPI and EPI (Table V). Regarding job physical exposures, the higher SI

TABLE III. Estimating the Survival Functions of Strain Index, at Job Level*

		Lateral epicondylitis (N = 757 jobs)				Medial epicondylitis (N = 716 jobs)				Lateral and/or medial epicondylitis (N = 773 jobs)			
Job classification	**SI**	**Total**	**Cases**	**% Cases**	***P*********	**Total**	**Cases**	**% Cases**	***P*********	**Total**	**Cases**	**% Cases**	***P*********
Safe	≤ 3	168	10	6.0	0.23	166	7	4.2	0.97	175	16	9.1	0.71
Action	3.1–7	229	18	7.9		215	8	3.7		235	23	9.8	
Hazard	> 7	360	29	8.1		335	11	3.3		363	31	8.5	
Low exposure	≤ 5	299	17	5.8	0.02	286	10	3.5	0.55	304	24	7.9	0.06
High exposure	> 5	458	40	8.7		430	16	3.7		469	46	9.8	
Low exposure	≤ 5	295	17	5.8	0.05	286	10	3.5	0.83	304	24	7.9	0.14
Medium exposure	5.1–12	209	19	9.1		190	6	3.2		213	23	10.8	
High exposure	> 12	253	21	8.3		240	10	4.2		256	23	9.0	

scores in High exposure revealed a higher risk of developing LEPI. The observed associations were stronger for job physical exposures, i.e., the SI, than for any covariates. Neither High exposure (the SI cut points five and 12) nor Hazardous jobs (the SI cut points three and seven), however, were associated with the incidence of MEPI.

It is important to note that only the association between the SI and LEPI was statistically significant (Table V), even though the job risk classification of higher SI scores (> 12) in High exposure were associated with both LEPI and EPI. For a few studies conducted for MEPI, forceful work was reported as a risk factor for incident cases of MEPI (odds ratio [OR 1.95, 95% CI 1.15–3.32]) [Descatha et al., 2003] and prevalent cases of MEPI among male workers (OR 2.2, 95% CI 1.0–4.7) [Shiri et al., 2006]. It's speculated that the lack of association between SI and MEPI in this study could be due to fewer incident cases of MEPI.

Occupational exposure of force and combined exposure of force, repetition, posture and/or vibration have been related moderately to the prevalence of epicondylitis [Palmer et al., 2007; van Rijn et al., 2009; Shiri and Viikari-Juntura, 2011]. Thus far, there have been a few large longitudinal studies conducted in the US and European the incidence of LEPI. These studies suggest strong evidence of a relationship between LEPI and occupational exposure of high hand force [Leclerc et al., 2001] and the combination of high force and awkward hand and wrist postures [Descatha et al., 2013; Fan et al., 2013; Herquelot et al., 2013]. However, past studies have used different methods to estimate physical workload of force, posture and used different case definitions [van Rijn et al., 2009; Shiri and Viikari-Juntura, 2011], which make it harder to compare the results from different study designs.

In practice, researchers and practitioners try to obtain the most accurate exposure assessment measurements within time and money constraints to quantify potential risk factors for work-related MSDs. The SI is a well-established method and is widely used by researchers and ergonomists in quantifying job physical exposures [Dempsey et al., 2005].

The original SI article reported that a criterion of SI score for Safe and Hazardous jobs (the SI cut points of three and seven) is especially sensitive to the parameter of intensity of exertion as this criterion was based on a relatively small number of mono-task jobs (n = 25) in the pork industry, it was recommended that users interpret the SI scores in the 3–7 range cautiously [Moore and Garg, 1995]. Our current analyses of a prospective study design with multiple tasks indicated no statistically significant difference in intensity of exertion between the incident cases and non-cases for any of the three health outcomes considered (Table III). Furthermore, even though the cut-points for each of the SI parameters and their corresponding multipliers were later validated in some industries [Knox and Moore, 2001; Moore et al., 2001; Rucker and Moore, 2002; Spielholz et al., 2008]. The original SI was developed for a mono-task job, with only one type of forceful exertion. In practice, there are usually multiple tasks involved and researchers, therefore, have tried different ways to generate one force value for jobs with several forceful exertions. In the present study, the most common forceful exertion approach is used. Repetitive muscle activity included not only forceful hand exertions but also all other hand muscle activities, even those with very low force exertions [Bao et al., 2009]. The methods using the most common-muscle forceful exertion and repetitive muscle activity (the "common-muscle" approach) tend to produce higher SI scores [Bao et al., 2009]. About 20% of the jobs were Safe jobs with an SI < = 3 for the three health outcomes examined (Table III). According to previous work on estimating the frequency and duty cycle of the repetitive muscle activities [Bao et al., 2009], the SI scores calculated with "common-muscle" approach is higher. The cut-points for job risk classification may need to be established differently for the different computation methods.

Our study has certain limitations. Longer durations of employment in strenuous job are associated with the prevalence [Ritz, 1995; Haahr and Andersen, 2003a] and incidence of LEPI [Ritz, 1995; Leclerc et al., 2001; Haahr and

TABLE IV. Distribution of Personal, Psychosocial and Work Organizational Factors, at Individual Worker Level*

	Lateral epicondylitis (N = 594 subjects)				Medial epicondylitis (N = 563 subjects)				Lateral and/or medial epicondylitis (N = 607 subjects)			
	Total	**Cases**	**% Cases**	**HR****	**Total**	**Cases**	**% Cases**	**HR****	**Total**	**Cases**	**% Cases**	**HR****
Overall	594	57	9.6		563	26	4.6		607	70	11.5	
Personal factors												
Age group, 51 +	117	17	14.5	1	111	11	9.9	1	123	23	18.7	1
36–50	262	35	13.4	1.00	239	12	5.0	0.52	268	41	15.3	0.86
18–35	215	5	2.3	0.22**	213	3	1.4	0.20**	216	6	2.8	0.23**
BMI group, obese	149	17	11.4	1	140	8	5.7	1	153	21	13.7	1
Overweight	199	15	7.5	1.04	191	7	3.7	1.10	202	18	8.9	1.06
Lean	246	25	10.2	0.69	232	11	4.7	0.71	252	31	12.3	0.69
Years in current job (years), > 5	158	21	13.3	1	146	9	6.2	1	160	23	14.4	1
1–5	251	24	9.6	0.66	235	8	3.4	1.12	256	29	11.3	0.87
<= 1	185	12	6.5	0.74	182	9	4.9	0.58	191	18	9.4	0.79
Gender, male	306	21	6.9	1	296	11	3.7	1	312	27	8.7	1
Female	288	36	12.5	1.68*	267	15	5.6	1.40*	295	43	14.6	1.52*
Race, White	251	23	9.2	1	242	14	5.8	1	257	29	11.3	1
Other	343	34	9.9	0.86	321	12	3.7	1.45	350	41	11.7	0.88
Education, high school or above	100	8	8.0	1	97	5	5.2	1	100	8	8.0	1
Less than high school graduate	494	49	9.9	0.79	466	21	4.5	1.09	507	62	12.2	0.63
Smoking status, current	173	18	10.4	1	165	10	6.1	1	176	21	11.9	1
past	122	16	13.1	1.33	109	3	2.8	1.31	123	17	13.8	1.20
Never	299	23	7.7	1.55	289	13	4.5	0.53	308	32	10.4	1.23
With medical disorders (HBP, DM, Gout, or Thyroid)	118	10	8.5	1	114	6	5.3	1	121	13	10.7	1
No	476	47	9.9	0.73	449	20	4.5	1.01	486	57	11.7	0.79
Hobbies or sports requiring high hand force	234	24	10.3	1	219	9	4.1	1	239	29	12.1	1
No	360	33	9.2	1.11	344	17	4.9	0.81	368	41	11.1	1.10
Hobbies or sports requiring high repetitive hand activities	198	19	9.6	1	186	7	3.8	1	202	23	11.4	1
No	396	38	9.6	0.99	377	19	5.0	0.75	405	47	11.6	0.99
Psychosocial												
High job demands	354	33	9.3	1	337	16	4.7	1	360	39	10.8	1
No	211	23	10.9	1.01	194	6	3.1	1.15	215	27	12.6	0.91
High decision latitude	275	27	9.8	1	260	12	4.6	1	281	33	11.7	1
No	290	29	10.0	1.22	271	10	3.7	0.74	294	33	11.2	1.02
High job satisfaction	394	34	8.6	1	372	12	3.2	1	400	40	10.0	1
No	171	22	12.9	1.68*	159	10	6.3	1.74*	175	26	14.9	1.52*
High social support	292	30	10.3	1	271	9	3.3	1	296	34	11.5	1
No	273	26	9.5	1.10	260	13	5.0	1.29	279	32	11.5	1.05
High job security	393	38	9.7	1	369	14	3.8	1	399	44	11.0	1
No	172	18	10.5	1.27	162	8	4.9	1.24	176	22	12.5	1.25
Better general health	310	23	7.4	1	295	8	2.7	1	314	27	8.6	1
No	255	33	12.9	1.90	236	14	5.9	1.66	261	39	14.9	1.69
Work organization												
Social contents												
Work team, min. to high coordination	330	34	10.3	1	312	16	5.1	1	338	42	12.4	1
Individual	258	23	8.9	0.58*	244	9	3.7	0.52	262	27	10.3	0.58**

(*Continued*)

TABLE IV. (*Continued.*)

	Lateral epicondylitis (N = 594 subjects)				Medial epicondylitis (N = 563 subjects)				Lateral and/or medial epicondylitis (N = 607 subjects)			
	Total	Cases	% Cases	HR**	Total	Cases	% Cases	HR**	Total	Cases	% Cases	HR**
Job contents												
Very strong structural restraints	316	28	8.9	1	302	14	4.6	1	322	34	10.6	1
Very minor to strong structural restraints	272	29	10.7	1.12	254	11	4.3	1.29	278	35	12.6	1.08
Pace												
Self or social/peer	465	41	8.8	1	444	20	4.5	1	476	52	10.9	1
Piece rate or quota, machine or line	123	16	13.0	1.07	112	5	4.5	1.35	124	17	13.7	1.18
Rotation, yes	180	16	8.9	1	174	10	5.7	1	184	20	10.9	1
No	408	41	10.0	1.31	382	15	3.9	1.99*	416	49	11.8	1.27

*Time constant covariates collected at baseline. Missing for psychosocial (LEPI: one case and 29 non-cases, MEPI: four cases and 32 non-cases) and work organization variables (LEPI: six non-cases, MEPI: one case and seven non-cases).
**Hazard ratios (HR) from survival analyses: ** indicating $P < 0.05$; * indicating $P < 0.10$.

Andersen, 2003b]. In particular, we didn't find job tenure at current work to be an independent predictor; this could be due to the assumption we made on job physical exposures. We assumed that job physical exposure started at the beginning of the study because we could not accurately quantify the physical exposures prior to the baseline visit. This would be particularly important for those who held the same job for a longer time, i.e., the 27% of participating workers who held the same job for more than five years (Table IV) and would also be important for those who had similar exposure although they had changed their jobs. Consequently, we are not sure of the lag time between the beginning of exposure and onset time of an incident case, especially for those incident cases with shorter follow-up time. A second area of difficulty lies in the assumption that the physical exposure remained unchanged until a job change was confirmed by a study ergonomist. This is the basis for the counting process Cox regression model where each exposure affects the next for the same individual. We've attempted to alleviate this by considering outside job hobbies as covariates. However, hobbies were collected at baseline and treated as a time-independent variable. Even though the changes in self-reported hobbies were not considered in the analyses, the potential bias would not be pointed in one direction and therefore would not result in an overestimate of the overall HRs.

The strengths of this study includes 1) its prospective study design; 2) the large and varied cohort of workers in multiple industries of manufacturing and health services; 3) the health outcomes considered both LEPI and MEPI, and the incident case definition considered both symptoms and physical signs; 4) job physical exposure was assessed by video-taping and job analyses at the subject level, with job analysts blinded to morbidity data; and 5) the SI score was calculated for each subject considering multiple forces/tasks and re-evaluated with corresponding changes in exposure when a job change occurred.

This study assessed not only the role of the factors measured in the SI on developing new cases of LEPI, MEPI, and EPI, it also considered personal attributes, medical history, demographics, and outside work activities. We found an increase in risk of LEPI, MEPI, and EPI with an increase in age. Older age categories (>40 years) have been reported with higher prevalence of LEPI [Leclerc et al., 2001; Shiri et al., 2006; Fan et al., 2009], higher incidence of LEPI [Descatha et al., 2013; Fan et al., 2013; Herquelot et al., 2013], and the association between female gender and the prevalence of LEPI [Viikari-Juntura et al., 1991; Ono et al., 1998; Fan et al., 2009]. In these analyses, female had a marginally higher proportion of incident cases than that of male workers ($P < 0.1$, Table IV). However, there was no statistically significant association between gender and incidence of LEPI in the multivariable Cox regression models (Table V). This finding is consistent with previously reports of longitudinal studies [Leclerc et al., 2001; Descatha et al., 2013; Fan et al., 2013]. Gender differences in types of jobs and physical exposure are well known in studies of work-related MSDs [Messing et al., 2009; Silverstein et al., 2009]. In our data, it appeared that the effect of job risk classifications, i.e., the SI scores, were more prominent than that of female gender for the incident cases of LEPI and EPI. We did not find an association between gender and incident of MEPI. This result is also consistent with a previous report [Descatha et al., 2003]. Similarly, while the association between smoking and the prevalence of LEPI has been reported [Shiri et al., 2006; Fan et al., 2009], our findings of

TABLE V. Multivariable Analyses on Incidence of Lateral and/or Medial Epicondylitis, Dominant Side

	Lateral epicondylitis*		Medial epicondylitis*		Lateral and/or medial epicondylitis*	
	HR	(95% CI)	HR	95% CI	HR	95% CI
Job classification: Safe, Action, and Hazard						
Crude						
Safe (SI ≤ 3)	1		1		1	
Action (SI 3.1–7)	1.56	(0.72–3.40)	1.03	(0.37–2.85)	1.25	(0.66–2.38)
Hazard (SI > 7)	1.90	(0.92–3.92)	1.10	(0.42–2.83)	1.30	(0.71–2.40)
Adjusted						
Age	1.05	(1.02–1.07)	1.07	(1.02–1.11)	1.05	(1.03–1.08)
Gender, F vs. M	1.46	(0.84–2.54)	1.19	(0.54–2.64)	1.35	(0.83–2.21)
Poor general health	1.85	(1.08–3.15)	1.80	(0.82–3.97)	1.75	(1.08–2.82)
Safe (SI ≤ 3)	1		1		1	
Action (SI 3.1–7)	1.47	(0.67–3.22)	1.00	(0.36–2.81)	1.21	(0.63–2.30)
Hazard (SI > 7)	1.88	(0.91–3.90)	1.09	(0.42–2.83)	1.31	(0.71–2.42)
Job classification: Low and High exposure, 2 categories						
Crude						
Low exposure (SI ≤ 5)	1		1		1	
High exposure (SI > 5)	2.00	(1.13–3.54)	1.42	(0.64–3.13)	1.65	(1.00–2.71)
Adjusted						
Age	1.05	(1.02–1.07)	1.07	(1.02–1.11)	1.05	(1.03–1.08)
Gender, F vs. M	1.49	(0.86–2.58)	1.20	(0.55–2.65)	1.38	(0.85–2.25)
Poor general health	1.89	(1.11–3.22)	1.78	(0.81–3.90)	1.76	(1.09–2.83)
Low exposure (SI ≤ 5)	1		1		1	
High exposure (SI > 5)	2.06	(1.16–3.65)	1.41	(0.64–3.12)	1.69	(1.03–2.78)
Job classification: Low to High exposure, 3 categories						
Crude						
Low exposure (SI ≤ 5)	1		1		1	
Medium exposure (SI 5.1–12)	2.01	(1.04–3.88)	1.14	(0.41–3.13)	1.73	(0.98–3.08)
High exposure (SI > 12)	1.98	(1.04–3.78)	1.67	(0.69–4.04)	1.57	(0.88–2.79)
Adjusted						
Age	1.04	(1.02–1.07)	1.06	(1.02–1.11)	1.05	(1.03–1.08)
Gender, F vs. M	1.50	(0.86–2.61)	1.27	(0.57–2.81)	1.37	(0.84–2.25)
Poor general health	1.89	(1.11–3.22)	1.80	(0.82–3.94)	1.75	(1.09–2.83)
Low exposure (SI ≤ 5)	1		1		1	
Medium exposure (SI 5.1–12)	2.00	(1.04–3.87)	1.11	(0.40–3.07)	1.73	(0.97–3.07)
High exposure (SI > 12)	2.12	(1.11–4.05)	1.69	(0.69–4.13)	1.65	(0.92–2.95)

*During the course of study: 537 non-cases held 685 jobs; 57 LEPI incident cases held 72 jobs; 26 MEPI 31, 70 EPI 88. Hazard ratios (HR) were generated from multivariable survival analyses.

no statistically significant association with incidence of LEPI are consistent with another report [Leclerc et al., 2001].

Workers with LEPI and MEPI have a significantly higher prevalence of other work-related upper limb MSDs [Descatha et al., 2003; Herquelot et al., 2013]. We considered shoulder or hand symptoms on the dominant side but these variables did not make it into the final model; nor did they change the HRs of SI results when these two variables were forced in the adjusted models (Data not shown).

Limited and inconsistent results have been reported on work-related psychosocial factors, such as low social support at work [Haahr and Andersen, 2003a; Fan et al., 2009] and low job control [Haahr and Andersen, 2003a], and the association with the prevalence of LEPI. In this prospective study, even though high job satisfaction showed a marginally lower proportion of incident cases for the three health outcomes in the results of tests on survival function ($P < 0.1$), it was not statistically significant in the multivariable Cox models (data not shown). Little is known from the existing literature of the association between work organizational factors and the three health outcomes in this study. In the survival function test, social content (working as a team with minimum to highest coordination vs. individual) was related to incident cases of EPI (Table IV, $P < 0.05$), LEPI ($P < 0.1$), and MEPI ($P < 0.1$); however, it became insignificant in the multivariable Cox regression models (data not shown). More studies are needed to further evaluate the effects of psychosocial and work organizational factors.

In their updated treatment guidelines for the Elbow Disorders, the American College of Occupational and Environmental Medicine recommend that modified work duties, which preclude high-force exertions for workers with LEPI [Hegmann et al., 2013]. In the occupational setting, modification of job physical factors could reduce the risk or improve the prognosis of EPI [Punnett and Wegman, 2004; Martimo et al., 2010]. This study provides new insights and evidence for a relationship between LEPI and occupational exposure to high intensity and longer duration of hand forces with non-neutral hand/wrist postures, as measured by the SI. Practitioners should consider using the SI when evaluating work activities to determine if those activities increase the risk of workers developing LEPI. Clinicians from primary to secondary care should pay attention to strenuous job physical exposures for patients with LEPI. This finding should also be considered when developing work-related injury prevention and management policies. Future studies are needed to confirm the findings of this study and to focus on the effectiveness of task modifications to prevent work-related EPI.

This prospective study includes individual job physical exposure and health outcome measures and demonstrates that the SI method can effectively identify jobs with increased risk of developing LEPI incident cases. These analyses also indicated that work-related LEPI and MEPI incidence were multifactorial. However, given the results observed in this study, the role of other etiological factors would not alter the conclusion that the SI appears to be a useful tool in predicting the incident of work-related LEPI.

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