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The Strain Index and ACGIH TLV for HAL: Risk of Trigger Digit in the WISTAH Prospective Cohort

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Objective: The objective of this study was to investigate the association between job physical exposure (JPE) and incidence of flexor tendon entrapment of the digits (FTED).

Background: FTED, commonly known as trigger digit, is associated with age, gender, and certain health disorders. Although JPE has been suggested as a risk factor for FTED, there are no prospective cohort studies.

Method: A cohort of 516 workers was enrolled from 10 diverse manufacturing facilities and followed monthly for 6 years. Worker demographics, medical history, and symptoms of FTED were assessed. JPE was individually measured using the Strain Index (SI) and American Conference of Governmental Industrial Hygienists (ACGIH) threshold limit value for hand activity level (TLV for HAL). Changes in JPE (assessed quarterly) and symptoms (assessed monthly) were recorded during follow-up. FTED was defined as demonstrated triggering on examination.

Results: Point prevalence of FTED at baseline was 3.6%. During follow-up there were 23 incident FTED cases (left and/or right hands). The incident rate for first occurrence of FTED from enrollment was 1.38 per 100 person-years. Risk factors were JPE, age, gender, diabetes mellitus, carpometacarpal osteoarthrosis, and rheumatoid arthritis. In multivariate models, the SI showed strong association with risk of FTED when treated as a continuous variable and marginal association when dichotomized (SI > 6.1). TLV for HAL showed a statistical trend of increasing risk of FTED using the ACGIH limits, but no association as a continuous variable.

Conclusions: Both JPE and personal risk factors are associated with FTED development. The SI and TLV for HAL are useful tools for estimating JPE.

Keywords: epidemiology, ergonomics, tenosynovitis, tendovaginitis, job analysis, musculoskeletal disorders

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INTRODUCTION

Trigger finger, trigger thumb, stenosing tenosynovitis, and stenosing tendovaginitis are terms used to describe flexor tendon entrapment of the digits (FTED; Moore, 2000). FTED is attributed to a pathologic, spatial disproportion between the diameter of the flexor tendon and the fibro-osseous canal formed by the first annular (A1) pulley (Akhtar, Bradley, Quinton, & Burke, 2005; Moore, 2000; Saldana, 2001; Weilby, 1970). This disproportion leads to localized pain, snapping, triggering, and/or locking of a digit when attempting to extend the digit following full flexion (Akhtar et al., 2005; Kameyama, Meguro, Funae, Atsumi, & Ikegami, 2009; Moore, 2000). Though localized digital pain is common (Saldana, 2001), triggering is not uniformly painful (Biundo, Mipro, & Fahey, 1997; Saldana, 2001). Based on data published in 1977, prevalence of FTED has been estimated at 2.6% in the general population (Strom, 1977); we were unable to identify more recent estimates. Estimates of FTED prevalence in broad working populations are not available.

Many demographic factors and diseases have been identified to be associated with FTED, including age, gender, diabetes mellitus (DM), rheumatoid arthritis (RA), Dupuytren's disease, thyroid disease, hand osteoarthrosis, hypertension, and carpal tunnel syndrome (CTS; Akhtar et al., 2005; Blyth & Ross, 1996; Chammas et al., 1995; Freiberg, Mulholland, & Levine, 1989; Hayashi et al., 2005; Kameyama et al., 2009; Kim, Edelman, & Kim, 2001; Makkouk, Oetgen, Swigart, & Dodds, 2008; Murphy, Failla, & Koniuch, 1995; Parker, 1979; Rhoades, Gelberman, & Manjarris, 1984; Saldana, 2001; Stahl, Kanter, & Karnielli, 1997; Stellbrink, 1971; Strom, 1977; Weilby, 1970).

Relationships between workplace biomechanical stressors and FTED are unclear. It has been speculated that biomechanical stressors play a role in the etiology of FTED (Akhtar et al., 2005; Bonnici & Spencer, 1988; Fahey & Bollinger, 1954; Hammer, 1934; Lapidus, 1953; Moore, 2000; Verdon, 1996); however, there have been few studies of FTED in occupational settings (Gorsche et al., 1998; Melhorn et al., 2011; Moore, 2000; Moore & Garg, 1994).

Gorsche et al. (1998) reported a FTED prevalence rate of 14% and incidence rate of 10.0 per 100 person-years in a short-term study (0.7 year) of a meat packing facility. They found that tool users as compared to non–tool users had a relative risk of 4.7 (95% CI: 1.5–23.9, $p < .02$). Moore and Garg (1994) conducted a retrospective cohort study of distal upper extremity disorders in a pork processing facility (37 job categories). They classified jobs as "safe" or "hazardous" and observed that all 15 FTED cases were on "hazardous" jobs.

The American Conference of Governmental Industrial Hygienists (ACGIH) threshold limit value (TLV) for hand activity level (HAL; ACGIH, 2002) and the Strain Index (SI; Moore & Garg, 1995) are widely used quantitative tools to measure distal upper extremity (DUE) job physical exposures (Dempsey, McGorry, & Maynard, 2005; Spielholz, Silverstein, Morgan, Checkoway, & Kaufman, 2001). These tools combine two or more job physical factors and offer summary measures of risk. The TLV for HAL includes two risk factors: normalized peak force (ACGIH, 2002) and HAL (Latko et al., 1997). The SI includes 6 putative risk factors (i.e., force, repetition, percentage duration of exertion, posture, speed of work, and shift duration; Moore & Garg, 1995).

The SI and TLV for HAL have been used to study risk of CTS, and other DUE musculoskeletal disorders (MSDs) either individually or in aggregate. These epidemiological studies have shown mixed results for the TLV for HAL (Bonfiglioli et al., 2012; Burt et al., 2011; Franzblau, Armstrong, Werner, & Ulin, 2005; Garg, Kapellusch, et al., 2012; Gell, Werner, Franzblau, Ulin, & Armstrong, 2005; Violante et al., 2007; Werner et al., 2005a, 2005b) and positive associations with the SI score (Garg, Kapellusch, et al., 2012; Knox & Moore, 2001; Moore & Garg, 1995; Moore, Rucker, & Knox, 2001; Moore, Vos, Stephens, Stevens, & Garg, 2006; Silverstein, Foley, & Polissar, 2006). There are no prospective studies for risk of FTED using either the TLV for HAL or SI.

This study's hypothesis is that there is an association between job physical factors, measured by the SI (Moore & Garg, 1995) and the TLV for HAL (ACGIH, 2002), and risk of developing FTED.

METHOD

The WISTAH study was a multicenter investigation of DUE MSDs conducted by the Center for Ergonomics at the University of Wisconsin–Milwaukee and the Rocky Mountain Center for Occupational and Environmental Medicine at the University of Utah with partial support from the National Institute of Occupational Safety and Health. The WISTAH study was approved by the University of Wisconsin–Milwaukee Institutional Review Board (#03.02.059). Details of the WISTAH study design and data collection methods are provided in Garg et al. (Garg, Hegmann, et al., 2012; Garg, Kapellusch, et al., 2012). The results reported in this article are for a subset of workers enrolled from 10 diverse manufacturing facilities located in the state of Wisconsin (USA).

Workers performed a variety of operations including (a) poultry processing, (b) manufacturing and assembly of animal laboratory testing equipment, (c) small engine manufacturing and assembly, (d) small electric motor manufacturing and assembly (<1.5 kW, starting weight < 0.1 kg, and finished weight ≤ 9 kg), (e) commercial lighting assembly and warehousing, (f) electrical generator manufacturing and assembly, (g) metal automotive engine parts manufacturing (three facilities), and (h) plastic and rubber automotive engine parts manufacturing and assembly.

Workers were enrolled during the first 12 months of the study. All production workers were eligible to participate in the study except those with unpredictable changes in job physical exposure or for whom it was not feasible to quantify physical exposure (e.g., third shift workers, temporary workers, supervisors and clerical workers in the plant, maintenance workers/mechanics, and fork truck drivers). Open meetings were arranged at each facility for the research team to explain the study to production workers. A total of 894 workers attended the meetings, and 672 of those (75.2%) voluntarily consented to participate in the study. The total number of production workers employed at the 10 facilities is not known because of high turnover of employees and frequent use of temporary workers. However, based on discussions with management at each facility, the total number of permanent production employees was between 1,000 and 1,100 during the study enrollment period. Thus, the overall participation rate is believed to be more than 50% of all permanent production employees.

Two different teams, blinded to one another, collected health outcomes and job physical exposure data at baseline and throughout the follow-up.

Health Outcomes and Demographic Data Collection

At baseline, workers completed a questionnaire and were given a structured interview and a physical examination. These were administered by trained occupational therapists using standardized methods (Garg, Hegmann, et al., 2012). Together these three instruments provided information on (a) workers' demographics (e.g., age, gender, handedness, etc.), (b) medical history (e.g., DM, thyroid disorders, high blood pressure, RA, carpometacarpal osteoarthrosis [CMC OA, defined as a positive CMC grind test], Dupuytren's disease, thyroid disease, history of DUE MSDs, and other relevant diseases), (c) pain rating on a 10-point scale for each digit, (d) palpation of every digital flexor tendon for nodules thought to be consistent with stenosis at the A1 pulley, (e) focal tenderness over the A1 pulley, and (f) evidence of triggering/locking in each digit. Symptoms, physical examination findings, and history of disorders were collected bilaterally.

Each worker in the cohort was followed monthly to ascertain new and/or changed symptoms of finger pain and/or triggering during the past month. A focused physical examination was performed on those workers experiencing new pain and/or complaining of triggering during the preceding month (Garg, Hegmann, et al., 2012).

Flexor Tendon Entrapment of the Digits Case Definition

The FTED case definition for this study required demonstrated triggering, on physical examination, of one or more digits in either hand. Those workers that met the case definition at baseline were excluded from becoming an incident case. During follow-up, eligible workers who met the FTED case definition became incident cases on the day of their monthly physical examination and, for the purpose of these analyses, ceased to contribute additional person-time to the study (i.e., workers could become an incident case only once). Workers who developed triggering or digit pain, as the result of an acute injury, were censored as a nonevent 1 day before reporting the symptoms.

Job Physical Exposure Data Collection

Baseline job physical exposure data were collected for each individual worker and for each hand separately by trained ergonomics analysts using standardized methods (Garg, Kapellusch, et al., 2012). Workers and their supervisors were asked how many different tasks each worker performed (job rotation) and the duration of each task. Tasks were video-recorded for later laboratory analyses.

Tasks with cycle time ≤2 min were video recorded for at least 10 cycles and tasks with cycle time >2 min were recorded for 20 to 45 min, ensuring that at least one complete task cycle was recorded (Garg, Hegmann, et al., 2012; Garg, Kapellusch, et al., 2012). Videos were recorded from three different camera angles using a single camera. For each of the three camera angles, a minimum of three cycles was recorded for tasks with cycle time ≤2 min, and a minimum 5 min was recorded for tasks with cycle times >2 min.

Videos were analyzed frame by frame in a laboratory to determine analyst overall force rating, temporal exertion requirements, hand/wrist postures, and speed of work (Garg, Hegmann, et al., 2012; Garg, Kapellusch, et al., 2012). An expert ergonomist estimated overall force ratings for each hand/wrist to assign an overall intensity of exertion (force) rating for the SI score calculations (Moore & Garg, 1995). Three different temporal exertion requirements were measured: (a) HAL rating using a verbal anchor scale (ACGIH, 2002; Latko et al., 1997), (b) number of efforts per minute, and (c) percentage duration of exertion (Moore & Garg, 1995). Efforts per minute, percentage duration of exertion, speed of work, and hand/wrist posture were assessed according to the SI methodology (Moore & Garg, 1995).

Trained ergonomics analysts queried each worker every 3 months to assess job physical exposure changes. If either a worker or a supervisor reported a change in the job, physical exposures were re-collected using the same methods as at baseline (Garg, Hegmann, et al., 2012; Garg, Kapellusch, et al., 2012).

Classifications of the SI and ACGIH TLV for HAL

SI and TLV for HAL were computed for each task that a worker performed at baseline as well as for those tasks that changed during the follow-up period. SI scores were calculated using the analyst's overall force rating, efforts/min, percentage duration of exertion, hand/wrist posture, speed of work, and duration of task (Moore & Garg, 1995). First, SI was treated as a continuous variable. Then, SI score was categorized into low risk (SI ≤ 6.1) and high risk (SI > 6.1) using the most recent recommendations (Garg, Kapellusch, et al., 2012; Moore et al., 2006).

TLV for HAL scores were calculated according to the ACGIH (2002) methodology using the equation: TLV for HAL Score = (Analyst Peak Force Rating of Borg CR-10 Scale ÷ [10 – HAL Rating]) (Garg, Kapellusch, et al., 2012). First, we treated TLV for HAL score as a continuous variable. Then, using the ACGIH prescribed cut points, TLV for HAL scores were classified into one of the three categories: below the action limit (AL; score < 0.56), between the AL and TLV (0.56 ≤ score ≤ 0.78), and above the TLV (score > 0.78).

Assigning Exposure at the Worker Level

About half of workers performed more than one task during their workday (i.e., had job rotation). We used "typical exposure" to assign exposure at the worker level as there is no consensus method to quantify job exposures for a worker with job rotation (Garg & Kapellusch, 2009a, 2009b). Typical exposure was defined as exposure from the task the worker performed for the largest percentage of a work shift (i.e., quasi mode). Details of job physical exposure variables collected for this study are described in Garg et al. (Garg, Hegmann, et al., 2012; Garg, Kapellusch, et al., 2012).

Statistical Analyses

Time to first event of FTED among incident eligible workers was modeled using Cox proportional hazard (PH) regression (Cox, 1972). To account for changes in job physical exposure during follow-up, both the SI score and TLV for HAL were treated as time-varying covariates (Garg, Kapellusch, et al., 2012). All other covariates such as age, gender, body mass index (BMI), and medical history were treated as time-independent covariates. Analyses were performed using the coxph() function in R-64 version 2.13.1 for Macintosh (R Development Core Team, 2011).

The functional form of each continuous variable (age, BMI, SI score, and TLV for HAL) was examined using Martingale residual plots (Therneau, Grambsch, & Fleming, 1990). The null PH model was fit and the resulting Martingale residuals were plotted against each of the four continuous variables. Smoothed plots of the residuals provided approximate shapes of the association between the log hazard ratio and a given covariate (Therneau et al., 1990). As different smoothing methods may suggest different functional forms (Lin, Wei, & Ying, 1993), we examined loess and cubic smoothing splines as flexible means for estimating the shape (Ruppert, Wand, & Carroll, 2003). Results were consistent between smoothing methods, and no transformations were suggested for age, BMI, SI, or TLV for HAL.

Multivariate models were built to test whether the SI and TLV for HAL were associated with increased risk of FTED after controlling for medical history and demographic confounders (covariates). A single initial multivariate model was built using covariates (i.e., non-physical-exposure factors) that (a) were not collinear and (b) had a univariate p value ≤ .15. With these covariates, a best subsets variable selection procedure using the Akaike information criterion was used to select a final covariate model (Collett, 2003). The SI and TLV for HAL were then separately forced into the final covariate model, and their associations with FTED were assessed

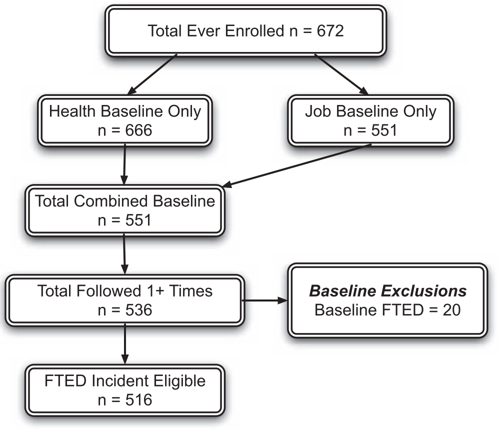

Figure 1. Subject enrolment and exclusion statistics.

using the likelihood ratio test. Because of the small number of FTED cases and relatively large number of qualified covariates, DM, CMC OA, and RA—all believed to be strong risk factors for FTED (Kameyama et al., 2009; Makkouk, et al., 2008; Moore, 2000)—were considered both individually and as a combined single variable, though not in the same candidate covariate models.

Separate multivariate models were fit for the SI and TLV for HAL as continuous variables. Subsequently, the categorical forms of the SI (Moore et al., 2006) and TLV for HAL (ACGIH, 2002) were separately forced into the covariate model. For categorical analyses, we used the low exposure group as the reference for the SI and TLV for HAL. However, in those situations where there were not sufficient cases in the low exposure group, we used the highest exposure group as the reference.

RESULTS

Out of 672 workers initially enrolled at baseline, 551 workers (82.0%) completed baseline data collection (Figure 1). Out of 551 workers, 536 had at least 1 month of follow-up data. Out of those 536 workers, 4 workers had bilateral and 16 had unilateral FTED at baseline based on this study's case definition. Excluding those 20 workers, the cohort for this article included 516 workers who were eligible to develop an incident case of FTED. The cohort was followed for an average of 38.7 ± 20.2 (range = 1.9–71.3) months. Over the 6-year follow-up period, participation decreased, primarily because of plant closings and layoffs.

Demographics of the incident eligible cohort (N = 516) are summarized in Table 1. The mean age of the cohort was 41.9 ± 11.5 (range = 18.7–68.1) years. Most of the cohort was female (66.9%), and 69.0% were overweight (BMI = 25–29.9 kg/m^2) or obese (BMI ≥ 30.0 kg/m^2). Regarding medical history at baseline, 81 workers (15.7%) had high blood pressure, 74 (14.3%) high cholesterol, 54 (10.5%) CTS, 49 (9.5%) CMC OA, 22 (6.2%) thyroid problems, 21 (4.1%) DM, 7 (1.4%) RA, and 4 (0.8%) Dupyutren's disease (Table 1). Those workers with high blood pressure, CMC OA, DM, and RA at baseline had subsequent FTED incidence rates per 100 person-years of 2.42, 2.75, 3.09, and 6.05, respectively. There was only one incident case of FTED among those reporting thyroid problems at baseline, and none among those with Dupyutren's disease. Thus, these two factors were not considered in univariate analyses.

Point prevalence of FTED at baseline was 3.6%. During follow-up (average: 38.7 months) there were 23 new FTED cases (n = 21, 6.1% of females and n = 2, 1.2% of males) resulting in an incident rate of 1.38 cases per 100 person-years. Females had a higher FTED incidence rate than males, 1.85 versus 0.38 per 100 person-years, respectively. Three workers developed bilateral FTED and 20 workers unilateral (11 in the right hand and 9 in the left). Nearly all workers (n = 21) had only one digit affected. The thumb was most commonly affected (29.4%), followed by the long finger (26.5%), ring finger (17.6%), index finger (14.7%), and small finger (11.8%).

The case definition required all cases to have locking. Regarding other symptoms, 15 (71.4%) incident cases had a palpable nodule, 12 (57.1%) had focal tenderness over the A1 pulley, and 14 (66.7%) had pain. The mean pain rating among those 14 workers was 5.2 ± 2.3 (range = 2–9) on a 10-point scale.

Descriptive statistics for job physical exposure variables reported in Table 1 were calculated from physical exposures in the first period of observation (baseline). However, univariate analyses reported for job physical exposure

TABLE 1: Descriptive Statistics for TLV for HAL, SI, and Covariates (N = 516)

Category	Variable	Category	$M \pm SD$ (Range) or %
Demographic	Age (years)	—	41.9 ± 11.5 (18.7–68.1)
	Gender	Male	33.1%
		Female	66.9%
Anthropometric	Body mass index kg/m^2	—	29.0 ± 6.8 (16.5–58.6)
Medical history	CMC OA	Yes	9.5%
	CTS	Yes	10.5%
	DM	Yes	4.1%
	High blood pressure	Yes	15.7%
	High cholesterol	Yes	14.3%
	RA	Yes	1.4%
	Thyroid problem	Yes	6.2%
	DM/CMC OA/RA	Yes	13.8%
Job physical factors[a]	TLV for HAL (ACGIH limits)	< AL (< 0.56)	24.2%
		≥ AL to ≤ TLV	33.7%
		> TLV (> 0.78)	42.1%
	TLV for HAL score[b]	—	0.86 ± 0.61 (0.07–6.00)
	SI categories (Moore et al., 2006)	≤ 6.1	28.1%
		> 6.1	71.9%
	SI score	—	15.2 ± 13.8 (0.8–108)

Note. ACGIH = American Conference of Governmental Industrial Hygienists; AL = action limit; CMC = carpometacarpal; CTS = carpal tunnel syndrome; DM = diabetes mellitus; HAL = hand activity level; OA = osteoarthrosis; RA = rheumatoid arthritis; SI = Strain Index; TLV = threshold limit value.
[a]Descriptive statistics are for first observation period (baseline) only, and these statistics do not include changes in exposure during the follow-up period.
[b]TLV for HAL Score = (Analyst Peak Force Rating on Borg CR-10 Scale ÷ [10 – HAL Rating]).

variables in Table 2 included data from all observation periods (time-varying covariates). Distributions of the constituent variables (e.g., peak force, overall force, HAL, frequency of exertion) used to calculate the TLV for HAL and the SI scores were previously reported by Garg, Kapellusch, et al. (2012).

In Tables 3 to 6, an overall p value is provided for each variable in the multivariate model. This p value represents the significance of each variable in the final multivariate model using the likelihood ratio test.

Univariate and Multivariate Results

Table 2 summarizes the results from unadjusted univariate analyses for relevant covariates. The factors statistically associated ($p \leq .05$) with FTED were age, gender, DM, high blood pressure, CMC OA, RA, and the combined DM/CMC OA/RA variable. High cholesterol was marginally associated ($p = .09$), BMI showed a weak association ($p = .15$), and CTS showed no statistical association ($p = .93$) with FTED.

When treating the biomechanical measures of job physical exposures as linear variables in univariate analyses, the SI was statistically associated with incidence of FTED (HR = 1.04 per unit, $p < .001$) and the TLV for HAL was not (HR = 1.2 per unit, $p = .44$). Both the SI and the TLV for HAL were statistically associated with incidence of FTED as categorical variables, using their recommended limits. The categorical SI (Moore et al., 2006) had an HR = 3.1 (95% CI: 1.0–9.2, $p = .04$; Table 2). The categorical

TABLE 2: Univariate Hazard Ratios for TLV for HAL, SI, and Covariates ($N = 516$)

Category	Variable (overall *p* value)	Category	*n* (cases)	HR (95% CI)[a]	*p* Value
Demographic	Age (years)	Continuous—linear (per unit increase)	516 (23)	1.07 (1.03–1.12)	< .01
	Gender	Male	171 (2)	1.0	—
		Female	345 (21)	5.0 (1.16–21.12)	.03
Anthropometric	Body mass index (kg/m^2)	Continuous—linear (per unit increase)	516 (23)	1.04 (0.99–1.09)	.15
Medical history	CMC OA	No	467 (17)	1.0	—
		Yes	49 (6)	3.2 (1.3–8.1)	.01
	CTS	No	462 (21)	1.0	—
		Yes	54 (2)	1.1 (0.2–4.6)	.93
	DM	No	495 (20)	1.0	—
		Yes	21 (3)	4.7 (1.4–16.0)	.01
	High blood pressure	No	435 (14)	1.0	—
		Yes	81 (9)	3.3 (1.4–7.6)	< .01
	High cholesterol	No	442 (17)	1.0	—
		Yes	74 (6)	2.2 (0.9–5.7)	.09
	RA	No	509 (21)	1.0	—
		Yes	7 (2)	8.8 (2.0–38.8)	< .01
	DM/CMC OA/ RA	No	445 (13)	1.0	—
		Yes	71 (10)	5.0 (2.2–11.4)	< .001
Biomechanical stressors	TLV for HAL (ACGIH limits; $p < .01$)	< AL (< 0.56)	125 (2)[b]	0.17 (0.04–0.74)	.02
		≥AL to ≤ TLV	174 (6)[b]	0.35 (0.13–0.91)	.03
		> TLV (> 0.78)	217 (15)[b]	1.0	—
	TLV for HAL score[c]	Continuous—linear (per unit increase)	516(23)	1.2 (0.8–2.0)	.44
	Strain Index (Moore et al., 2006, limit)	SI ≤ 6.1	145 (4)[b]	1.0	—
		SI > 6.1	371 (19)[b]	3.1 (1.0–9.2)	.04
	Strain Index	Continuous—linear (per unit increase)	516 (23)	1.04 (1.02–1.06)	< .001

Note. ACGIH = American Conference of Governmental Industrial Hygienists; AL = action limit; CI = confidence interval; CMC = carpometacarpal; CTS = carpal tunnel syndrome; DM = diabetes mellitus; HAL = hand activity level; HR = hazard ratio; OA = osteoarthrosis; RA = rheumatoid arthritis; SI = Strain Index; TLV = threshold limit value.
[a]Hazard ratio of 1.0 with no confidence interval indicates reference category for the variable.
[b]For cases, *n* is based on exposure at the time a worker became a case. For noncases, *n* is based on exposure at baseline.
[c]TLV for HAL Score = (Analyst Peak Force Rating on Borg CR-10 Scale ÷ [10 – HAL Rating]).

TABLE 3: Multivariate Model for Risk of FTED With the Strain Index as Continuous Variable

Variable (overall *p* value)[a]	Category/ Function	*n* (cases)	HR	95% CI	*p* Value
SI score ($p < .01$)[a]	Continuous (per unit increase)	516 (23)	1.04	1.02–1.06	< .01
Covariates					
Age (years; $p < .01$)[a]	Continuous (per unit increase)	516 (23)	1.06	1.01–1.11	.01
Gender (p =0.07)[a]	Male	171 (2)	1.0	—	—
	Female	345 (21)	3.2	0.8–14.3	.12
DM/CMC OA/RA ($p < .01$)[a]	No	445 (13)	1.0	—	—
	Yes	71 (10)	3.3	1.4–7.7	< .01

Note. CI = confidence interval; CMC = carpometacarpal; DM = diabetes mellitus; FTED = flexor tendon entrapment of the digits; HR = hazard ratio; OA = osteoarthrosis; RA = rheumatoid arthritis; SI = Strain Index.
[a]Overall significance associated with including each variable in the model using the likelihood ratio test.

TLV for HAL showed a significant trend of increasing risk ($p < .01$). There were only two cases below the AL, and 15 cases above the TLV. Therefore, because of insufficient number of cases below AL, above TLV was used as reference. The hazard ratios were 0.17 (95% CI: 0.04–0.74, $p = .02$) and 0.35 (95% CI: 0.13–0.91, $p = .03$) for < AL and ≥ AL to ≤ TLV, respectively.

The multivariate PH regression model for covariates included age, gender, and the combined diabetes/CMC OA/RA variable. When introduced into the multivariate model of covariates as a linear variable, the SI showed a strong statistical association with increased risk of FTED (HR = 1.04 per unit, 95% CI: 1.02–1.06, $p < .01$; Table 3). When treated as a categorical variable the SI showed marginal association with increased risk of FTED (HR = 2.6, 95% CI: 0.8–8.0, $p = .07$; Table 4).

When treated as a linear variable, the TLV for HAL was not statistically associated (HR = 1.18 per unit, $p = .56$) with FTED (Table 5). As a categorical variable using its prescribed limits (ACGIH, 2002), TLV for HAL showed a statistically significant trend of increased risk of FTED ($p = .02$). Using > TLV as reference, the HRs were 0.18 (95% CI: 0.04–0.79, $p = .02$) and 0.45 (95% CI: 0.17–1.17, $p = .10$) for < AL and ≥ AL to ≤ TLV, respectively (Table 6).

DISCUSSION

This appears to be the first study reporting relationships between measured biomechanical stressors and increased risk of FTED in manufacturing environments. Our results suggest that both individual factors (age, gender, and medical history) and biomechanical stressors (measured using the SI and TLV for HAL) are associated with increased risk of FTED.

The SI

As a continuous variable, the SI showed a strong association with higher risk of FTED with an increase in SI score (Table 3). The results of this study suggest that risk for developing FTED is particularly high at very high levels of physical exposure. For example, compared to unexposed, the HRs were 2.0, 3.0, and 5.0 at SI scores of 18, 28, and 41, respectively. This observation is consistent with studies that have suggested increased risk of FTED on repetitive and/or physically stressful jobs (Akhtar et al., 2005; Bonnici & Spencer, 1988; Fahey & Bollinger, 1954; Gorsche et al., 1998; Hueston & Wilson, 1972; Moore, 2000; Verdon, 1996). For example, Moore (2000) noted that Moore and Garg (1994) found nearly all their FTED cases on a job with SI = 54. However, it is important to note that only 25% of workers in

TABLE 4: Multivariate Model for Risk of FTED With the Strain Index as Categorical Variable Using the Recommended Limit of SI = 6.1 (Moore et al., 2006)

Variable (overall *p* value)[a]	Category/Function	*n* (cases)	HR	95% CI	*p* Value
SI score ($p = .07$)[a]	SI ≤ 6.1	145 (4)[b]	1.0	—	—
	SI > 6.1	371 (19)[b]	2.6	0.8–8.0	.09
Covariates					
Age (years; $p < .01$)[a]	Continuous (per unit increase)	516 (23)	1.06	1.01–1.11	< .01
Gender ($p = .08$)[a]	Male	171 (2)	1.0	—	—
	Female	345 (21)	3.1	0.7–14.3	.13
DM/CMC OA/RA	No	445 (13)	1.0	—	—
($p < .01$)[a]	Yes	71 (10)	3.8	1.6–8.8	< .01

Note. CI = confidence interval; CMC = carpometacarpal; DM = diabetes mellitus; FTED = flexor tendon entrapment of the digits; HR = hazard ratio; OA = osteoarthrosis; RA = rheumatoid arthritis; SI = Strain Index.
[a]Overall significance associated with including each variable in the model using the likelihood ratio test.
[b]For cases, *n* is based on exposure at the time a worker became a case. For noncases, *n* is based on exposure at baseline.

TABLE 5: Multivariate Model for Risk of FTED With the TLV for HAL as Continuous Variable

Variable (overall *p* value)[a]	Category/Function	*n* (cases)	HR	95% CI	*p* Value
TLV for HAL score ($p = .56$)[a]	Continuous (per unit increase)	516 (23)	1.18	0.71–1.98	.52
Covariates					
Age (years; $p < .01$)[a]	Continuous (per unit increase)	516 (23)	1.06	1.02–1.11	< .01
Gender ($p = .03$)[a]	Male	171 (2)	1.0	—	—
	Female	345 (21)	3.8	0.9–16.7	.07
DM/CMC OA/RA ($p < .01$)[a]	No	445 (13)	1.0	—	—
	Yes	71 (10)	3.4	1.5–7.9	< .01

Note. CI = confidence interval; CMC = carpometacarpal; DM = diabetes mellitus; FTED = flexor tendon entrapment of the digits; HAL = hand activity level; HR = hazard ratio; OA = osteoarthrosis; RA = rheumatoid arthritis; SI = Strain Index; TLV = threshold limit value.
[a]Overall significance associated with including each variable in the model using the likelihood ratio test

this study were exposed to SI > 20. Compared to workers exposed to SI = 6 (25th percentile of exposure in this study), workers exposed to SI = 20 (75th percentile) had an HR = 1.75 (i.e., HR for interquartile range of SI). When categorized using the Moore et al. (2006) recommended limit of 6.1, SI was statistically associated with FTED in univariate analyses (HR = 3.1, p = .04) and marginally associated in multivariate analyses (HR = 2.6, p = .07). The results of this study suggest that increased risk of FTED is not pronounced until relatively high exposures, consistent with Moore's (2000) observation. Thus, it is possible that the cut point of 6.1 may be too low to predict increased risk of FTED.

TLV for HAL

The TLV for HAL, using the ACGIH prescribed limits, showed a strong association and a statistical trend of increasing risk of

TABLE 6: Multivariate Model for Risk of Trigger Digit With the TLV for HAL as Categorical Variable Using Its Prescribed Limits (ACGIH, 2002)

Variable (overall *p* value)[a]	Category/Function	*n* (cases)	HR	95% CI	*p* Value
TLV for HAL (*p* = .02)[a]	< AL (< 0.56)	125 (2)[b]	0.18	0.04–0.79	.02
	≥ AL to ≤ TLV	174 (6)[b]	0.45	0.17–1.17	.10
	> TLV (> 0.78)	217 (15)[b]	1.0[c]	—	—
Covariates					
Age (years; *p* < .01)[a]	Continuous (per unit increase)	516 (23)	1.07	1.02–1.12	< .01
Gender (*p* = .06)[a]	Male	171 (2)	1.0	—	—
	Female	345 (21)	3.3	0.8–14.3	.11
DM/CMC OA/RA (*p* < .01)[a]	No	445 (13)	1.0	—	—
	Yes	71 (10)	3.3	1.4–7.7	.01

Note. ACGIH = American Conference of Governmental Industrial Hygienists; AL = action limit; CI = confidence interval; CMC = carpometacarpal; DM = diabetes mellitus; HAL = hand activity level; HR = hazard ratio; OA = osteoarthrosis; RA = rheumatoid arthritis; SI = Strain Index; TLV = threshold limit value.
[a]Overall significance associated with including each variable in the model using the likelihood ratio test.
[b]For cases, *n* is based on exposure at the time a worker became a case. For noncases, *n* is based on exposure at baseline.
[c]Highest exposure group (> TLV) was used as reference because of insufficient cases in low exposure group (< AL).

FTED (*p* = .02); however, when treated as a continuous variable, the association was not statistically significant (*p* = .56). Workers with exposures above the TLV were at more than 5 times the risk for developing FTED as compared to those with exposures below the AL, (HR = 5.6, 95% CI: 1.3–25.0, *p* = .02). Reasons for lack of statistical significance of TLV for HAL as a continuous variable are not clear. It is possible that TLV for HAL has a nonlinear relationship with FTED that was not captured, perhaps because of the small number of FTED cases.

Individual Factors and Medical History

This study found strong evidence that age plays a role in development of FTED (HR = 1.06, 95% CI: 1.01–1.11, *p* ≤ .01). Risk of FTED at age ≥ 50 was more than 5 times the risk at age 20. This finding is consistent with those previous case series that have shown prevalence of FTED is greatest in the mid-fifth to sixth decades of life (Makkouk et al., 2008; Moore, 2000). Gender was statistically associated with FTED in univariate analyses (*p* = .03) and was marginally associated in most multivariate analyses (*p* ≤ .07). In this study, females had more than 3 times the risk of FTED than males, which is consistent with prior reports suggesting that females are at higher risk (Makkouk et al., 2008; Moore, 2000).

This study found evidence to support that RA (HR = 8.8, 95% CI: 2.0–38.8, *p* < .01), DM (HR = 4.7, 95% CI: 1.4–16.0, *p* = .01), and CMC OA (HR = 3.2, 95% CI: 1.3–8.1, *p* < .01) are associated with increased risk of FTED, consistent with previous studies (Makkouk et al., 2008; Moore, 2000; Ryzewicz & Wolf, 2006). Previous studies have suggested that there is an association between CTS and FTED (Kumar & Chakrabarti, 2009). This study found no evidence of association (*p* = .93), but sample size was small (2 cases, among 54 workers with CTS).

Case Definition

The case definition used in this study requiring demonstrated triggering/locking on physical examination was likely more specific than those used in prior studies that did not require triggering to identify FTED (Kim & Lee, 2010; Makkouk et al., 2008). However, the restrictive nature of this definition likely misses many workers who would be clinically diagnosed as having FTED (e.g., those with pain and a nodule, but without triggering). Thus, this study likely underestimates both the prevalence and incidence of FTED in this cohort.

Study Strengths

This study's strengths include (a) prospective methods, (b) enrolment of a large number of workers from diverse employers performing different types of work, (c) inclusion of several individual/medical history risk factors, (d) structured interviews and physical examinations of all workers regardless of symptoms, (e) reproducible case definition of FTED, (f) monthly monitoring of symptoms, (g) detailed quantification of each worker's job physical factors, (h) quarterly job physical exposure assessments, (i) blinding of team members, and (j) cohort follow-up of up to 6 years.

This study used a strict case definition of FTED, and it is likely that the combination of a well-defined case definition and individualized, quantified biomechanical stressors (SI and TLV for HAL) resulted in the strong associations between job physical factors and FTED.

Study Limitations

Workers were primarily from manufacturing environments, thus the results of this study might not be directly applicable to other environments. Furthermore, the effect of facility/industry could not be evaluated because of small sample size (23 FTED cases and 10 facilities).

Monthly health follow-ups queried explicitly about symptoms of pain, but not triggering. However, we observed that most workers readily volunteered such symptoms throughout the cohort follow-up period. It is possible that some workers with triggering, but no pain, did not volunteer their triggering and thus were not identified as cases.

A positive CMC grind test at baseline was used as an objective measure of CMC OA, and this served as a surrogate for hand OA. Using this definition likely underestimated the true prevalence of hand OA in the cohort and may have reduced the strength of association and effect of OA.

The small number of incident cases of FTED limited the number of variables in the multivariate models. Thus, DM, RA, and CMC OA were combined into a single variable. The combined variable, although statistically relevant, may have limited prognostic value.

This study did not address the association among hobbies, physical activities outside of work, and psychosocial factors and risk of developing FTED, and it is possible that these factors play roles in FTED etiology. The roles of these factors need further investigation.

CONCLUSIONS

Biomechanical stressors are associated with increased risk of FTED. The SI was associated with statistically significant increased risk of FTED when treated as both a continuous variable and a categorical variable. The risk increased with an increase in SI score. The TLV for HAL showed a trend for increasing risk of FTED when treated as categorical variable but not when treated as a continuous variable. This study adds to the growing body of evidence that exposure to elevated levels of biomechanical stressors in the workplace increases risk for DUE MSDs such as FTED.

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KEY POINTS

- Biomechanical stressors in the workplace are associated with flexor tendon entrapment of the digits (trigger digit).
- Age, gender, diabetes mellitus, rheumatoid arthritis, and carpometacarpal osteoarthrosis are risk factors for flexor tendon entrapment of the digits (trigger digit).
- The Strain Index and ACGIH TLV for HAL are useful tools for quantifying distal upper extremity biomechanical stressors in workplaces.

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