THE EFFECT OF PINCH GRIP ON UPPER EXTREMITY CUMULATIVE TRAUMA DISORDERS IN FEMALE GARMENT WORKERS

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ABSTRACT

A pilot study of the effect of pinch postures on carpal tunnel syndrome and other cumulative trauma disorders was performed. Initial data were collected as part of a larger study by ergonomics and medical teams from the University of Utah. Representative videos of 77 female subjects performing sewing machine tasks were analyzed using a Pinch Analyzer program designed for use in this study. Each video was analyzed at a constant time step of 5 video frames (.017 seconds). Grasp and pinch postures were split into three categories: lateral pinch, finger tip pinch, and working grasp. The workplace parameters investigated for comparison to health outcomes were (1) type of pinch, (2) wrist posture during pinch, (3) duration of pinch, (4) percent of cycle in pinch, and (5) frequency of pinching. A subset of 47 subjects from the initial population was also studied to minimize the confounding effects of smoking, diabetes, high BMI (>40), and pregnancy by removing subjects with any of these effects from the initial population. Bivariate and multivariate comparisons were made of each population. Results of the study indicate pinching postures do have an effect on the risk of cumulative trauma disorders like chronic pain in the digits or wrist but have no significant relationship to median neuropathy.

INTRODUCTION

Background

Research has shown that repetitive motion is a factor in the development of cumulative trauma disorders (CTDs) in many industry workers (NIOSH, 1997). CTDs include disorders of the bones, joints, muscles, ligaments, blood vessels and nerves which develop over time. The main indicators identified to be associated with the development of CTDs are awkward posture, high repetition, duration of pinch, and high force. Related studies suggest that force and duration are the main contributors to the risk of CTDs (Moore S, Garg A, 1995). It appears that higher force combined with long exertions increase the risk for developing cumulative trauma as a result of employment. These studies offer some explanation for cumulative trauma in high force, high duration, high frequency work environments. But the question remains, why do carpal tunnel syndrome and other wrist/hand CTDs still occur frequently in low force, short duration, high repetition tasks?

A number of studies have investigated CTDs among garment workers. Punnett et al. studied the effects of sewing operations performed by hand on soft tissue disorders in the upper limbs of female garment workers. Garment workers complained more of persistent pain, numbness, and tingling in the wrist and hand, symptoms associated with carpal tunnel syndrome, than hospital employees used in the study (Punnett et al., 1985). Sokas et al. stated that repetitive hand motions such as the rapid pinching and pulling movements made by sewing machine operators in the garment industry have been demonstrated to cause carpal tunnel syndrome and other tenosynoviites (Sokas et al., 1989). Fingertip loading and its relation to carpal tunnel pressure during a pinching task was studied (Keir et al., 1998). Keir et al. found that low levels of pinching force caused pressures in the carpal tunnel, which if prolonged, were more likely to lead to carpal tunnel syndrome.

The United States Bureau of Labor Statistics reported 1,436,200 cases of nonfatal injuries and illnesses in the private industry involving days away from work or lost days (BLS, 2004). Nearly one-third of these cases, 487,900, involved musculoskeletal disorders (MSDs) including time away from work exceeding 31 days. Force is the main risk factor positively associated with carpal tunnel syndrome/hand-wrist tendonitis (NIOSH, 1997). However, there is evidence of a positive association between highly repetitive work alone and carpal tunnel syndrome/hand-wrist tendonitis (NIOSH, 1997). Although insufficient evidence exists to demonstrate that awkward postures alone are associated with carpal tunnel syndrome, strong evidence does exist that a positive association exists between any combination of repetition, force, and posture and carpal tunnel syndrome/ hand-wrist tendonitis (NIOSH, 1997).

STUDY DESIGN

Purpose of Research

The purpose of this study is to investigate the effects of sewing machine pinching tasks on CTDs of the wrist and hand. These tasks involve various pinches exerted statically for short durations combined with highly repetitive arm movements. The workplace parameters investigated were type of pinch, wrist posture during pinch, duration of pinch, and frequency of pinch. The personal parameters investigated were sewing productivity, sewing job history, and medical history. The type of pinch was defined after preliminary review of a random sample of sewing tasks. Wrist posture considered wrist movement while pinching including ulnar and radial deviation as well as flexion and extension at three levels of deviation away from functional neutral. Various combinations of the pinch types with wrist postures were considered. Duration was observed for each pinch exertion. The frequency of pinch exertions was calculated. Pinch forces were assumed to be low force (<.05 kgf), since the weight of the cloth was negligible and difficult to quantify with current force measuring devices. Job history was studied to compare workers doing the same task for multiple years to those workers doing various garment operations within those years. Each of the workplace and personal parameters were compared to the medical outcomes of the workers to determine if CTDs may be linked to the sewing tasks performed.

Project Clarification

The data used in this study were collected as part of an upper extremity disorder study performed by the University of Utah in conjunction with the University of Wisconsin-Milwaukee for a grant awarded by the National Institute for Occupational Safety and Health (NIOSH) for this purpose. The in-house name of the study was the General Arm Risk Factors Study (GARF). The original purpose of the research was to determine potential risk factors for upper extremity cumulative trauma disorders in the working population. Descriptive information about each subject and the job they performed was recorded. Postural data were acquired for each subject by the ergonomic team. Symptom data were collected for each subject by a medical team initially at enrollment and subsequently during a monthly follow up exam.

The current study compares data relating to employee symptoms with the postures of the wrist during four types of pinching activity. Data relating to symptoms were accessed from the medical evaluations performed by medical residents and occupational medicine physicians as part of the GARF study. Baseline medical data were reviewed. Focusing on the wrist and hand, the medical outcomes of pain and nerve conduction velocity were investigated. Results of these examinations were recorded as either presence or absence of pain. Nerve conduction was measured on all subjects by a trained electrodiagnostic physician and included latency and amplitude of transcarpal, motor, and sensory nerves. The results were determined to be normal, mild, or moderate/severe based on a priori case definitions. A nerve conduction study is considered the gold standard for diagnosing median neuropathies. The most common median neuropathy is Carpal Tunnel Syndrome (CTS), a compression of the median nerve in the carpal tunnel. Median neuropathy was defined as two median served digits with numbness and tingling along with abnormal nerve conduction. The resulting medical outcome variables were *wrist pain*, *digit pain*, *digit or wrist pain*, *numbness/tingling*, *nerve conduction*, and *median neuropathy*.

Data for the current study were collected at a sewing facility near Salt Lake City, UT. Garment workers were randomly surveyed and observed. Subjects were asked about their work history and current job. Measurements of grip and pinch capability were performed. The average of three measurements of 3-point pinch capability and lateral pinch capability was recorded. Responses were recorded on a Position/Worker Specific Data Form for each subject. The observation period consisted of recording videos of the job performed focusing on the upper extremity and on-site notes made on a Job Specific Data Form for each subject. Most subjects performed only one job consisting of untying a bundle, performing 20 to 40 sewing cycles, and tying the completed bundle. Videos were recorded of each job. All videos were loaded to a database and referenced by subject ID. A program was written to allow each video to be viewed at a desired frame rate while recording posture data for each desired step. The frame step was chosen at the beginning of the analysis and remained constant throughout the analysis. The program provided drop down menus for each posture category allowing the analyzer opportunity to select the closest posture to what they see in the video. The parameters studied during the video analysis included wrist bend, wrist deviation, and type of pinch. The Pinch Analyzer (PA) allowed the author to choose from 5 to 7 options in a pull down menu for each parameter. The program interface used for video analysis is shown in Figure 1.

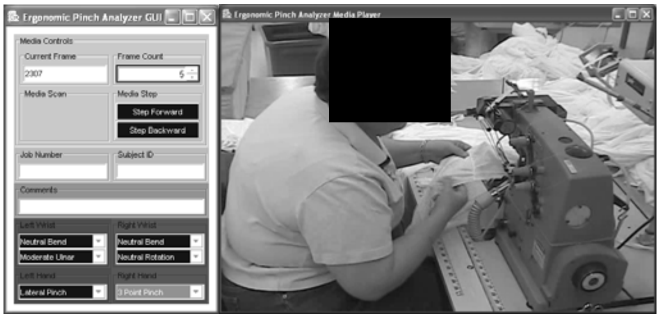


Figure 1. Pinch Analyzer user interface (Typical sewing posture).

Pinch Types

Pinch types were separated after preliminary review of the jobs. Upon review of a random sample of four videos, the categories of pinch were defined. The pinch categories used in the PA were low force grasp, lateral pinch, 3-point pinch, and idle grasp. "3-point pinch" is a pinch performed by placing the object between the tip of the distal phalanx of the finger(s) and the pad of the thumb. "Lateral pinch" is a pinch performed by placing object between the pad of the thumb and the palmer surface of the fingers (but not the tip) or between the pad of the thumb and the radial side of the index or long finger. "Low force grasp" was defined as "working grasp" or any of a number of grasping postures excluding those defined by 3-point pinch and lateral pinch. The reason for including this grasp was to account for activity related to the object/task when the hand was not in an idle grip. Idle grip was assigned when no activity was being performed on the object. If the pinch posture was continued but the object was no longer between the thumb and the fingers and the hand was not performing a low force grasp as described, the posture was assumed to be an idle grip. Depictions of the 3-point and lateral pinch categories as described are shown in Figures 2 and 3, respectively. Low force grasp is described further in Figure 4.

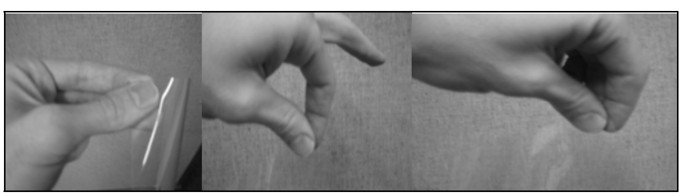


Figure 2. Description of the 3-Point Pinch option used in the Pinch Analyzer.

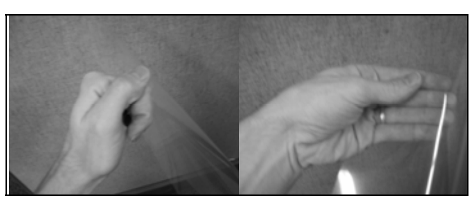


Figure 3. Description of the Lateral Pinch option used in the Pinch Analyzer.

Low Force Grasp: Grasp performed by one of the following

1. Loosely holding object (thumb not touching fingers) in the lateral pinch position.
2. Holding/guiding object along top of palmer surface of hand (hand supinated) with no finger activity.
3. Guiding object along surface with fingers/palm palmer surface down (hand pronated).
4. Guiding object along path with fingers only.

(1) (2) (3) (4)

(This grasp is used to account for activity related to the object/task when the hand is not in an idle grip)

Figure 4. Description of the Low Force Grasp option used in the Pinch Analyzer.

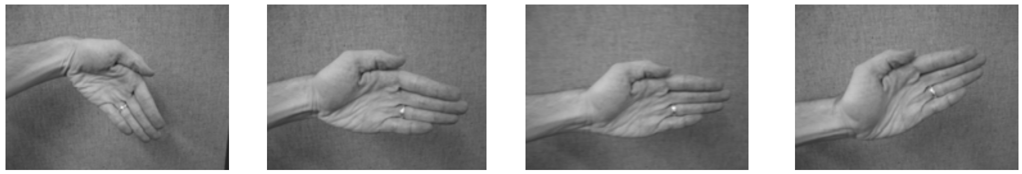
Wrist Posture

Wrist posture included ulnar and radial deviation as well as flexion and extension at three levels of deviation away from functional neutral. The categories for “wrist bend” were high extension, moderate extension, neutral bend, moderate flexion, and high flexion and are depicted in Figure 5. High extension was defined as a wrist bent to the dorsal side of the hand creating an angle greater than 50 degrees between the centerline of the hand and the centerline of the forearm. Moderate extension was a wrist bent to the dorsal side of the hand creating an angle greater than 30 degrees but less than 50 degrees between the centerline of the hand and the centerline of the forearm. Neutral bend was a wrist bent less than 30 degrees in either flexion or extension. Moderate flexion was a wrist bent to the palmer side of the hand creating an angle greater than 30 degrees but less than 50 degrees between the centerline of the hand and the centerline of the forearm. High flexion was a wrist bent to the palmer side of the hand creating an angle greater than 50 degrees between the centerline of the hand and centerline of the forearm.

The “wrist rotation” categories on the PA were high ulnar, moderate ulnar, neutral rotation, moderate radial, and high radial. High ulnar was defined as a wrist deviation towards the 5^{th} digit creating an angle greater than 25 degrees between the midline of the hand and the midline of the forearm. Moderate ulnar was a wrist deviation towards the 5^{th} digit creating an angle greater than 10 degrees but less than 25 degrees between the midline of the hand and the midline of the forearm. Neutral rotation was a wrist deviation in the range between 10 degrees of ulnar deviation and 5 degrees of radial deviation. Moderate radial was any visible deviation of the wrist towards the thumb exceeding 5 degrees and was reserved for confirmed (obvious) radial deviation only. The high radial option was not used because radial deviation is difficult to distinguish as two categories during video observation. Any visible radial deviation was classified as a moderate radial posture. “Wrist rotation” postures are depicted in Figure 6.

High Extension Moderate Extension Neutral Bend Moderate Flexion High Flexion

Figure 5. Wrist Bend categories used in the Pinch Analyzer.



High Ulnar | Moderate Ulnar | Neutral Rotation | Moderate Radial

Figure 6. Wrist Rotation categories used in the Pinch Analyzer.

Each of the drop down menus included the option of assigning a “Not Visible” selection for frame observations where the wrist or hand is not visible enough to distinguish the wrist posture or type of pinch. This category was used when there is insufficient information to make an educated decision about the posture. Another option called “Not Observed” was not used since all the parameters were observed during all portions of the analysis.

Subjects

The subjects used in this study included 77 female workers at the sewing facility performing common sewing machine operations. All operations were performed in a sitting posture with the sewing machine positioned anterior to the worker. All workers in the study only worked at one sewing station performing a single task repeatedly. The age of the workers ranged from 28 to 67 years with a mean age of 49. Left-handed workers accounted for 15% of the subject population. The average time at the current job and the sewing facility was 7.3 and 9.6 years, respectively.

Due to the religious nature of the garment factory, a condition of employment was the abstinence by workers from the use of tobacco, alcohol, or illegal drugs. Past use of tobacco, alcohol, or illegal drugs recorded in the baseline medical data was controlled for in the study. Other confounding medical data such as diabetes mellitus, body mass index (BMI), and pregnancy was also controlled. To emphasize the control of these confounding variables, two populations were investigated. The first population included persons having these confounding variables and contained the 77 subjects mentioned above. The second population is a subset of these 77 subjects in which all workers who had any history of smoking, had diabetes, were pregnant at the time of data collection, or had a BMI greater than 40 were removed. This left a population of 47 subjects with the new demographics as follows: average age of 47, average years on job of 6.81, and average years at facility of 9.12. The resulting populations were Population 77 and Population 47 with numeric reference to the number of subjects in each.

ANALYSIS

Data Preparation

Each subject video was analyzed using the PA. The frame step chosen for this study was five frames/step (about .17 seconds). Cycle times for the subjects were calculated using five representative sewing cycles. Frame steps were used as the measure of time. The sewing cycle closest to the mean number of frame steps was assigned as the representative cycle. Each subject video was randomly analyzed using this representative cycle. At the completion of each subject video, the outputs were saved to an Excel (Microsoft) spreadsheet.

Combinations of the pinch types with various wrist postures were considered. Duration of pinch was measured for each pinch exertion. The frequency of pinch exertions was calculated. The resulting task related variables applied to each distal upper extremity were *Percent of Pinching*, *Percent of Busy Time* (Drinkaus, 2004), *Percent of 3-Point Pinch*, *Percent of Lateral Pinch*, *Percent of Low Force Grasp*, *Percent of Extreme Posture*, *Percent of Flexion*, *Percent of Extension*, *Percent of Ulnar*, *Rate of Pinch Posture Change*, and *Rate of Pinch Occurrence*. The job and demographic variables investigated were *Cycle Time*, *Cycles/Day*, *Age*, *Years on Job*, *Years at Facility*, *Diabetes*, *Smoking*, *BMI*, *Blood Pressure*, *Cholesterol Level*, *Dominant Hand*, *Average 3-Point*, and *Average Lateral*. Table 1describes the task related variables. Table 2 describes the job related variables.

Table 1 Task Related Variables.

Variable Name	Description
% of Pinching	Percent of cycle a 3 Point or Lateral Pinch is used
% of Busy Time	Percent of cycle a worker's distal upper extremity is not idle
% of 3-Point Pinch	Percent of cycle the hand is in a 3 point pinch
% of Lateral Pinch	Percent of cycle the hand is in a lateral pinch
% of Low Force Grasp	Percent of cycle the hand is in a low force grasp
% of Extreme Posture	Percent of cycle the wrist is in a high ulnar, high extension, or high flexion posture while performing a 3 point or lateral pinch
% of Flexion	Percent of cycle the wrist is in flexion while performing a 3 point or lateral pinch
% of Extension	Percent of cycle the wrist is in extension while performing a 3 point or lateral pinch
% of Ulnar	Percent of cycle the wrist is in ulnar deviation while performing a 3 point or lateral pinch
Rate of Pinch Posture Change	Rate of grip posture changes per minute (includes changes to idle, 3 point, lateral, or low force grasp)
Rate of Pinch Occurrence	Rate of grip pinches per minute (Accounts for initiations of 3 point or lateral grasp)

Table 2. Job and Demographic Variables.

Variable Name	Description
Cycle Time	Duration of cycle measured in frame steps.
Cycles/Day	Number of cycles performed in one 8 hour working day (calculated from reported production rate)
Age	Age of worker in years at time of data collection
Years on Job	Number of years the worker had consecutively worked at the job station
Years at Facility	Number of years the worker had consecutively worked at the sewing facility
Diabetes	Assigned to those workers diagnosed with diabetes (yes/no)
Smoking	Assigned to those workers having any reported history of smoking tobacco, drugs, etc. (yes/no)
BMI	Measure of body mass index of the worker
Blood Pressure	Assigned to workers with high blood pressure diagnosed by the medical team (yes/no)
Cholesterol Level	Assigned to workers with high choleserol diagnosed by the medical team (yes/no)
Dominant Hand	Hand most used by the worker to do common tasks. If ambedextrous, the right hand was assigned. R=1, L=2
Average 3-Point	Average of three measurements of maximum 3 point pinch (kgf)
Average Lateral	Average of three measurements of maximum lateral pinch (kgf)

Descriptive statistics for task variables applied to both distal upper extremities are shown in Tables 3 and 4, respectively, for Population 77. Table 5 shows the descriptive statistics for the job and demographic variables for Population 77. Descriptive statistics for the medical outcomes of Population 77 are shown in Table 6. Similar tables are displayed in Tables 7 through 10 for Population 47. Dichotomous variables such as *Diabetes*, *Smoking*, etc. are included.

Table 3. Left Distal Upper Extremity Task Variables for Population 77.

Variable Name	Mean	Median	Standard Deviation	Minimum	Maximum
% of Pinching	65.42	69.47	18.790	7.55	98.78
% of Busy Time	88.65	89.87	6.400	63.83	100.00
% of 3-Point Pinch	51.00	52.71	21.680	0.00	90.00
% of Lateral Pinch	14.42	9.38	16.050	0.00	83.08
% of Low Force Grasp	23.22	17.70	18.790	0.00	90.57
% of Extreme Posture	4.75	2.22	7.140	0.00	36.92
% of Flexion	15.37	12.00	12.430	0.00	58.46
% of Extension	14.14	11.00	13.130	0.00	54.47
% of Ulnar	22.57	22.54	15.590	0.00	64.62
Rate of Pinch Posture Change (/min)	48.36	42.60	25.710	4.19	135.00
Rate of Pinch Occurrence (/min)	18.87	16.80	10.836	2.10	67.50

Table 4. Right Distal Upper Extremity Task Variables for Population 77.

Variable Name	Mean	Median	Standard Deviation	Minimum	Maximum
% of Pinching	78.19	83.33	16.350	21.21	98.36
% of Busy Time	85.31	86.92	8.175	60.87	98.39
% of 3-Point Pinch	23.12	17.65	15.110	0.00	80.00
% of Lateral Pinch	55.07	59.17	23.155	0.00	98.36
% of Low Force Grasp	7.12	1.16	14.340	0.00	63.00
% of Extreme Posture	2.63	0.00	5.660	0.00	36.92
% of Flexion	9.87	6.47	11.058	0.00	60.94
% of Extension	21.77	11.54	22.295	0.00	78.82
% of Ulnar	27.49	28.73	22.140	0.00	74.01
Rate of Pinch Posture Change (/min)	35.97	30.00	23.304	2.10	123.75
Rate of Pinch Occurrence (/min)	14.16	11.40	10.184	1.05	56.25

Table 5. Job and Demographic Variables for Population 77.

Variable Name	Mean	Median	Standard Deviation	Minimum	Maximum
Cycle Time (frame steps)	175.95	189.00	103.860	16.00	458.00
Cycles/Day	1022.76	740.00	751.078	120.00	3779.00
Age (yrs)	48.60	48.00	7.340	28.00	67.00
Years on Job	7.21	5.00	5.972	0.10	23.00
Years at Facility	9.51	8.00	5.719	1.00	25.00
Diabetes (yes=1, no=0)	0.16	0	0.365	0	1
Smoking (yes=1, no=0)	0.10	0	0.307	0	1
BMI (yes=1, no=0)	32.72	32.12	8.010	14.21	51.65
Blood Pressure (yes=1, no=0)	0.21	0	0.408	0	1
Cholesterol Level (yes=1, no=0)	0.30	0	0.461	0	1
Dominant Hand (R=1, L=2)	1.10	1	0.310	1	2
Average 3-Point (kgf)	6.67	6.83	1.853	1.30	13.30
Average Lateral (kgf)	7.49	7.47	1.705	2.50	12.00

Table 6. Medical Outcomes for Population 77.

Medical Outcome	Mean	Median	Standard Deviation	Min	Max
Left Wrist Pain (yes=1, no=0)	0.38	0	0.488	0	1
Left Digit Pain (yes=1, no=0)	0.31	0	0.466	0	1
Left Wrist or Digit Pain (yes=1, no=0)	0.49	0	0.503	0	1
Left Numbness/Tingling (yes=1, no=0)	0.38	0	0.488	0	1
Left Nerve Conduction (case=2, normal=1)	1.31	1	0.466	1	2
Left Median Neuropathy (case=2, normal=1)	1.21	1	0.408	1	2
Right Wrist Pain (yes=1, no=0)	0.43	0	0.498	0	1
Right Digit Pain (yes=1, no=0)	0.36	0	0.484	0	1
Right Wrist or Digit Pain (yes=1, no=0)	0.58	1	0.496	0	1
Right Numbness/Tingling (yes=1, no=0)	0.42	0	0.496	0	1
Right Nerve Conduction (case=2, normal=1)	1.35	1	0.480	1	2
Right Median Neuropathy (case=2, normal=1)	1.19	1	0.399	1	2

Table 7. Left Distal Upper Extremity Task Variables for Population 47.

Variable Name	Mean	Median	Standard Deviation	Minimum	Maximum
% of Pinching	64.51	70.12	19.886	7.55	90.00
% of Busy Time	88.63	89.19	5.345	78.00	98.21
% of 3-Point Pinch	51.60	49.80	23.080	0.00	90.00
% of Lateral Pinch	12.91	7.79	14.755	0.00	75.41
% of Low Force Grasp	24.12	20.00	19.188	0.00	90.57
% of Extreme Posture	4.84	2.50	6.547	0.00	31.25
% of Flexion	15.56	12.00	11.727	0.00	53.13
% of Extension	14.22	12.46	13.098	0.00	45.77
% of Ulnar	22.34	23.24	14.938	0.00	56.00
Rate of Pinch Posture Change (/min)	43.53	36.36	23.388	4.20	135.00
Rate of Pinch Occurrence (/min)	2.10	14.91	54.000	2.10	54.00

Table 8. Right Distal Upper Extremity Task Variables for Population 47.

Variable Name	Mean	Median	Standard Deviation	Minimum	Maximum
% of Pinching	79.75	85.00	16.27	21.21	98.36
% of Busy Time	86.72	87.50	6.81	68.69	98.36
% of 3-Point Pinch	23.66	17.65	16.04	0.00	80.00
% of Lateral Pinch	56.09	57.08	23.68	0.00	98.36
% of Low Force Grasp	6.97	0.80	14.73	0.00	63.00
% of Extreme Posture	1.78	0.00	3.62	0.00	15.00
% of Flexion	9.79	5.85	12.23	0.00	60.94
% of Extension	22.16	13.33	21.73	0.00	78.11
% of Ulnar	27.57	28.73	22.12	0.00	71.67
Rate of Pinch Posture Change (/min)	32.67	27.08	22.42	2.10	123.75
Rate of Pinch Occurrence (/min)	13.13	11.34	9.69	1.05	56.25

Table 9. Job and Demographic Variables for Population 47.

Variable Name	Mean	Median	Standard Deviation	Minimum	Maximum
Cycle Time (frame steps)	185.40	203.00	99.811	25.00	364.00
Cycles/Day	941.52	740.00	738.578	120.00	3779.00
Age (yrs)	47.77	47.00	6.471	35.00	58.00
Years on Job	6.81	4.00	5.819	0.01	21.00
Years at Facility	9.12	8.00	5.567	1.00	22.00
BMI (yes=1, no=0)	30.66	31.57	5.564	19.53	39.63
Blood Pressure (yes=1, no=0)	0.11	0	0.312	0	1
Cholesterol Level (yes=1, no=0)	0.28	0	0.452	0	1
Dominant Hand (R=1, L=2)	1.11	1	0.312	1	2
Average 3-Point (kgf)	6.67	6.67	1.884	1.80	13.30
Average Lateral (kgf)	7.51	7.42	1.597	4.20	12.00

Table 10. Descriptive Statistics for Medical Outcomes for Population 47.

Medical Outcome	Mean	Median	Standard Deviation	Min	Max
Left Wrist Pain (yes=1, no=0)	0.28	0	0.452	0	1
Left Digit Pain (yes=1, no=0)	0.19	0	0.398	0	1
Left Wrist or Digit Pain (yes=1, no=0)	0.38	0	0.491	0	1
Left Numbness/Tingling (yes=1, no=0)	0.30	0	0.462	0	1
Left Nerve Conduction (case=2, normal=1)	1.19	1	0.398	1	2
Left Median Neuropathy (case=2, normal=1)	1.11	1	0.312	1	2
Right Wrist Pain (yes=1, no=0)	0.36	0	0.486	0	1
Right Digit Pain (yes=1, no=0)	0.30	0	0.462	0	1
Right Wrist or Digit Pain (yes=1, no=0)	0.51	1	0.505	0	1
Right Numbness/Tingling (yes=1, no=0)	0.32	0	0.471	0	1
Right Nerve Conduction (case=2, normal=1)	1.28	1	0.452	1	2
Right Median Neuropathy (case=2, normal=1)	1.13	1	0.337	1	2

Bivariate Analysis

A non-parametric Mann-Whitney test was used to make a bivariate comparison of the data to each of the symptoms, since most of the variables had a non-normal distribution. The non-parametric Mann-Whitney test sums the ranks of two independent variable groups and compares them. The main assumption required for this test is that the variables being compared, in this study the variable of interest and the medical outcome, are independent of each other. Population 77 and Population 47 were investigated. SPSS was used to compute all statistics.

Odds ratios were computed for the bivariate data and 95% confidence intervals on the odds ratio were calculated for all variables for comparison. Outcome matrices were formed for each variable compared to each symptom. The median was used as the cut-value for all bivariate matrices. The top left box shows the number of subjects with no symptoms having a variable value below the median value, NN. The top right box shows the number of subjects having no symptoms with a variable value equal to or above the median value, NY. The bottom left box indicates the number of subjects having symptoms with a variable value below the median value, YN. The bottom right box indicates the number of subjects having symptoms with a variable value equal to or above the cut point, YY.

Table 11 shows the matrix using these variables. Equation 1 was used to compute the odds ratios. The 95% confidence interval on the odds ratios was calculated using Equation 2. For example, an odds ratio of 3.00 when comparing the variable *Percent of 3-Point Pinch* and the medical outcome median neuropathy indicates that an employee with a high occurrence of finger-tip pinching is three times more likely to be diagnosed with median neuropathy than other subjects in the study. An odds ratio of 1.00 indicates equal effect between the subjects with a high occurrence of finger-tip pinching and those with lower occurrence when investigating median neuropathy. If the 95% confidence interval includes 1.00, it is difficult to determine if the parameter tested is harmful (predictive) or protective. To indicate significance, a 95% confidence interval with an odds ratio greater than 1.00 is desired.

$$\text{Odds Ratio} = \frac{NN \cdot YY}{YN \cdot NY} \tag{1}$$

95% Confidence Interval

$$\left[e^{\left(\ln(OddsRatio) - 1.96\left(\frac{1}{NN} + \frac{1}{NY} + \frac{1}{YN} + \frac{1}{YY} \right) \right)}, e^{\left(\ln(OddsRatio) + 1.96\left(\frac{1}{NN} + \frac{1}{NY} + \frac{1}{YN} + \frac{1}{YY} \right) \right)} \right] \tag{2}$$

Table 11. Sample Outcome Matrix.

		Medical Outcome N	Medical Outcome Y
Input Variable	N	NN	NY
Cut Point=Median	Y	YN	YY

Multiple Regression

Upon review of the data in the bivariate analysis, variables were chosen for a multivariate logistic regression on each of the medical outcomes for each upper extremity. Each model was performed in SPSS using the “Enter” method. This method places all chosen variables in the equation at once to determine the regression equation for a certain medical outcome. The use of this method allows all variables equal opportunity to contribute to the model. A Spearman r analysis was performed on the variables used in the model to check for multicolinearity between variables by observing correlation coefficients. In the case of multicolinearity, or a correlation coefficient greater than 0.4, the variable with better statistical significance to the medical outcome was chosen and the revised model was tested. In some cases, the variable with less statistical significance, but better biological plausibility, was accepted as the predictor of the medical outcome.

Each multiple regression model was compared to its Omnibus, Nagelkerke, and Hosmer/Lemeshow statistic. The Omnibus statistic indicates the overall significance of the model to the outcome variable based on the alpha value chosen for the test. The alpha value for this study was .05. The Nagelkerke statistic represents the pseudo proportion of explained variance in the outcome among the subjects. The Hosmer/Lemeshow statistic demonstrates how well the model fits the observed variation in the medical outcome among the subjects. Both the Nagelkerke and the Hosmer/Lemeshow values indicate a more predictive relationship as they approach unity. Values greater than 0.5 are desired for these tests.

The logistic regression output in SPSS also displayed a classification table. An example of the classification table is given in Table 12. All models were run at a cut value of 0.5. If the regression equation resulted in a value greater than 0.5, a positive prediction of the medical outcome was indicated by the model. The top left box of the classification table showed the number of controls correctly predicted by the model, NN. The other boxes indicated the number of cases or controls correctly or incorrectly predicted by the model in a similar fashion. Only models showing overall predictability greater than 75 percent and having outcome sensitivity of greater than 50 percent were considered acceptable. The beta weights (parameter estimates), test statistics, and 95% confidence intervals were determined for each variable in the regression model. From these values a regression equation was derived for the symptom tested. Odds ratios on the classification table and 95% confidence intervals were computed for each statistically significant model. Equations 1 and 2 were used to perform these analyses. Equation 3 was used to derive the equation for each logistic regression model.

Regression Equation

$$\bar{x} = \beta_1 x_1 + \beta_2 x_2 + \ldots + \beta_{n-1} x_{n-1} + \beta_n x_n \tag{3}$$

Table 12. Sample Classification Table.

		Predicted by Model N	Predicted by Model Y
Observed Symptoms	N	NN	NY
Cut Point=0.5	Y	YN	YY

Bivariate Results

All variables were compared to each medical outcome. A non-parametric Mann-Whitney test was performed for each comparison. Table 13 indicates the variables showing statistical significance from the Mann-Whitney tests for Population 77 and Population 47. Odds ratios and 95% confidence intervals were also computed for each comparison. Only one variable shows a significant odds ratio with a 95% confidence interval containing a lower bound above 1.00 when the median was used as a cut point. Years on Job has an odds ratio of 3.93 with a confidence interval of 1.02 to 15.18 when investigating Median Neuropathy of the left upper extremity for Population 77. For Population 47, Years on Job shows the following, reported as [odds ratio, 95% confidence interval]: Left Digit or Wrist Pain [4.74, (1.37, 16.45)], Right Digit or Wrist Pain [4.44, (1.27, 15.62)], Right Numbness/Tingling [4.28, (1.21, 15.15)].

Table 13. Summary of Non-Parametric Mann-Whitney Test Results.

Population 77

Medical Outcome	Significant Variables	
	Left	Right
Wrist Pain	Years on Job (.022)	Years on Job(.020) % of Pinching (.035) % of Busy Time (.032)
Digit Pain	Years on Job (.000) Years at Facility (.002) % of Ulnar (.050) % of Pinching (.049) % of 3-Point Pinch (.017) Age (.023) Blood Pressure (.016)	Average 3 Point (.025) Average Lateral (.022)
Digit or Wrist Pain	Years on Job (.000) % of 3-Point Pinch (.028) % of Ulnar (.038)	Years on Job (.018) Years at Facility (.013) % of Pinching (.027) % of Busy Time (.007)
Numbness/ Tingling	Years on Job (.023) BMI (.023)	Years on Job (.046) % of Flexion (.012) % of Ulnar (.045)
Nerve Conduction	Age (.050) BMI (.000) Diabetes (.028) Blood Pressure (.016) Average Lateral (.004)	Age (.036) BMI (.000) Years at Facility (.043)
Median Neuropathy	BMI (.027) Blood Pressure (.011) Years on Job (.020)	BMI (.008) Blood Pressure (.042) % of Flexion (.025)

Population 47

Medical Outcome	Significant Variables	
	Left	Right
Wrist Pain	Years on Job (0.019)	Years on Job (.020) % of Busy Time (.019)
Digit Pain	Years on Job (.000) Years at Facility (.004) % of Flexion (.037) % of Pinching (.005) % of Low Force Grasp (.015) Cycle Time (.046)	
Digit or Wrist Pain	Years on Job (.000) % of 3-Point Pinch (.024) % of Pinching (.049)	Years on Job (.018) % of Busy Time (.012)
Numbness/ Tingling		Years on Job (.049) Average 3 Point (.043)
Nerve Conduction	BMI (.037) Average Lateral (.046)	BMI (.004)
Median Neuropathy		Years on Job (.031) % of Flexion (.048)

Multivariate Analysis

Multivariate logistic regression models were built for each medical outcome. Two predictive models for Population 77 resulted. Table 14 describes the 77LDWP model derived for *Left Digit or Wrist Pain*. The 77RMN model derived for *Right Median Neuropathy* is described in Table 15. The classification table and resulting odds ratio for each model are shown. No models were predictive for other medical outcomes tested.

Three predictive models for Population 47 were derived. The resulting models were 47LWP for *Left Wrist Pain*, 47LDP for *Left Digit Pain*, and 47LDWP for *Left Digit or Wrist Pain*. Tables 16 through 18 describe each of these models respectively. The classification table and resulting odds ratio for each model are shown.

Table 14. The 77LDWP Model.

Variable	Parameter Estimate	Adj. Odds Ratio	Confidence Interval (95%) Lower	Upper
Left % of 3-Point Pinch	0.060	1.06	1.02	1.10
Left % of Extension	-0.097	0.91	0.85	0.97
Left % of Flexion	-0.076	0.93	0.86	1.00
Left % of Ulnar	0.063	1.07	1.10	1.12
Left % of Extreme Posture	0.014	1.01	0.92	1.12
Left Rate of Pinch Occurrence	-0.114	0.89	0.03	31.60
Diabetes	1.777	5.91	1.10	31.74
BMI	0.050	1.05	0.97	1.14
Years on Job	0.228	1.26	1.10	1.43
Constant	-5.464	0.00		

		Predicted 0	Predicted 1	% Predicted	
Observed	0	32	7	82.05	**80.5**
	1	8	30	78.95	

Comparison	observed	desired
Omnibus	0.000	<0.05
Nagelkerke	0.505	>0.50
Hosmer/Lemeshow	0.967	>0.3

Odds Ratio	17.14286	
95% Confidence Interval	Lower	Upper
	5.54	53.07

Table 15. The 77RMN Model.

Variable	Parameter Estimate	Adj. Odds Ratio	Confidence Interval (95%) Lower	Upper
Right % of 3-Point Pinch	-0.064	0.94	0.88	1.00
Right % of Extension	0.014	1.01	0.98	1.05
Right % of Flexion	0.067	1.07	1.01	1.14
Right % of Ulnar	-0.044	0.96	0.91	1.00
Age	0.046	1.05	0.95	1.16
Diabetes	0.607	1.84	0.29	11.44
BMI	0.089	1.09	1.00	1.20
Years on Job	0.081	1.08	0.95	1.23
Constant	-6.261	0.00		

		Predicted 0	Predicted 1	% Predicted	
Observed	0	59	3	95.16	**87.0**
	1	7	8	53.33	

Comparison	observed	desired
Omnibus	0.006	<0.05
Nagelkerke	0.390	>0.50
Hosmer/Lemeshow	0.611	>0.3

Odds Ratio	22.47619	
95% Confidence Interval	Lower	Upper
	4.81	104.95

Table 16. The 47LWP Model.

Variable	Parameter Estimate	Adj. Odds Ratio	Confidence Interval (95%) Lower	Upper
Left % of 3-Point Pinch	0.065	1.07	1.01	1.12
Left % of Extension	-0.164	0.85	0.76	0.95
Left % of Flexion	-0.093	0.91	0.83	1.00
Left % of Ulnar	0.041	1.04	0.97	1.12
Years on Job	0.131	1.14	0.98	1.33
Constant	-2.824	0.06		

		Predicted 0	Predicted 1	% Predicted	
Observed	0	30	4	88.24	**78.7**
	1	6	7	53.85	

Comparison	observed	desired
Omnibus	0.004	<0.05
Nagelkerke	0.444	>0.50
Hosmer/Lemeshow	0.707	>0.7

Odds Ratio	8.75	
95% Confidence Interval	Lower	Upper
	1.93	39.58

Table 17. The 47LDP Model.

Variable	Parameter Estimate	Adj. Odds Ratio	Confidence Interval (95%) Lower	Upper
Left % of 3-Point Pinch	0.135	1.14	1.01	1.30
Left % of Extension	-0.014	0.99	0.88	1.10
Left % of Flexion	0.047	1.05	0.94	1.17
Left % of Extreme Posture	-0.132	0.88	0.72	1.07
Years on Job	0.415	1.52	1.11	2.06
Constant	-13.597	0.00		

		Predicted 0	Predicted 1	% Predicted	
Observed	0	37	1	97.37	**91.5**
	1	3	6	66.67	

Comparison	observed	desired
Omnibus	0.000	<0.05
Nagelkerke	0.623	>0.50
Hosmer/Lemeshow	0.982	>0.7

Odds Ratio	74.00	
95% Confidence Interval	Lower	Upper
	6.57	833.88

Table 18. The 47LDWP Model.

Variable	Parameter Estimate	Adj. Odds Ratio	Confidence Interval (95%) Lower	Upper
Left % of 3-Point Pinch	0.095	1.10	1.03	1.17
Left % of Extension	-0.118	0.89	0.81	0.98
Left % of Flexion	-0.067	0.94	0.86	1.02
Years on Job	0.290	1.34	1.11	1.61
Constant	-5.093	0.01		

		Predicted 0	Predicted 1	% Predicted	
Observed	0	25	4	86.21	**83.0**
	1	4	14	77.78	

Comparison	observed	desired
Omnibus	0.000	<0.05
Nagelkerke	0.563	>0.50
Hosmer/Lemeshow	0.828	>0.7

Odds Ratio	21.88	
95% Confidence Interval	Lower	Upper
	4.72	101.29

DISCUSSION

Analysis

The purpose of this study was to investigate the relationship between pinch postures and cumulative trauma disorders. Two populations were studied. Population 77 is the initial population of garment workers enrolled in the GARF study performing repetitive sewing operations. Population 47 is a subset of Population 77 which excluded all subjects diagnosed with diabetes, with any reported history of smoking, pregnant during time of study, and having a BMI exceeding 40. Population 47 was investigated after discovering the statistical significance of BMI and diabetes to the medical outcomes studied. Pregnancy and smoking were removed for Population 47 based on the confounding effect of these shown by other studies investigating upper extremity CTDs (Padua et al., 2002; Tanaka et al., 1997). Although most of the subjects with a history of smoking had not done so in a number of years, they were removed to eliminate possible bias. With 47 subjects, the population size remained large enough to examine which task parameters contributed most to the risk of developing medical outcomes.

Subject videos were analyzed using the PA and all data were referenced by subject ID. During the course of the video analyses, it was observed that the majority of subjects used their right hand to resist the pulling motion of the sewing machine and their left hand for maintaining correct alignment of the garment pieces as they were fed through the machine. The machine was typically positioned to feed the material on the left side of the machine with reference to the subject. The right wrist and hand used more static postures than the left when performing a task, while the left hand and wrist was more dynamic throughout the cycle. Further analysis revealed the effect this difference in hand movements had on the results of this study.

Results: Population 77

Analysis of the parameters for Population 77 was performed in two stages. First, a bivariate analysis was performed using a non-parametric Mann-Whitney test. Following this analysis, a multivariate logistic regression was performed on the parameters for each medical outcome. The bivariate analysis revealed a number of significant variables for the medical outcomes investigated. These results were presented previously in Table 14. Focusing on the pinching postures, *Percent of Pinching* is significant for *Wrist Pain* and *Digit or Wrist Pain* for the right upper extremity, but not for the left. *Percent of 3-Point Pinch* is statistically significant for *Digit Pain* and *Digit or Wrist Pain* in the left upper extremity, but not for the right. This variation in significant pinch variables may be due to the aforementioned difference in left and right hand tasks. The average *Percent of 3-Point Pinch* for the right hand is half that of the average *Percent of 3-Point Pinch* for the left. Likewise, the average *Percent of Pinching* for the left upper extremity is less than that of the right.

Wrist postures while pinching such as *Percent of Flexion*, *Percent of Extension*, and *Percent of Ulnar* are generally not significant. *Percent of Busy Time* is statistically significant only for the right upper extremity for *Wrist Pain* and *Digit or Wrist Pain*. Since the tasks for the right upper extremity were more static than the left, it appears that pinching performed at longer durations shows more risk of developing CTDs of the upper extremity. *BMI* is highly significant for *Nerve Conduction* and *Median Neuropathy* in both left and right upper extremities. *Diabetes* is statistically significant for *Nerve Conduction* in the left upper extremity. For this reason, subjects with high *BMI* or *Diabetes* were removed when Population 47 was studied.

The most common statistically significant variable for nearly all medical outcomes is *Years on Job*. Although this study focused on pinch postures, the significance of the variable *Years on Job* indicates that the longer a person performs the same repetitive task, the more at risk they are to develop cumulative trauma in the upper extremity. *Years on Job* is the only individual variable with an odds ratio having a confidence interval that does not include 1.0.

The contribution of *Years on Job* continued to be evident during the multivariate analyses. Models for *Left Digit or Wrist Pain* (77LDWP) and *Right Median Neuropathy* (77RMN) resulted from the multivariate analyses. Again, the result for the left upper extremity is different than the right. These models indicate that dynamic pinching, such as that used in the left hand tasks, shows more risk for pain in the digits or the wrist, but not abnormal nerve conduction. However, the more static movements of the right upper extremity show more risk for abnormal nerve conduction, a prerequisite for median neuropathy. Both the 77LDWP model and the 77RMN model have significant contributions from Years on Job. The other variables common to both models are *BMI*, *Diabetes*, *Percent of 3-Point Pinch*, *Percent of Extension*, *Percent of Flexion*, and *Percent of Ulnar*. Although the models are for different upper extremities, both include these common variables to create strong predictive models for their respective medical outcome.
The 77LDWP model shows a sensitivity of 79 percent with an overall predictability of 80 percent. This is very significant with a good explained variance. The odds ratio for the 77LDWP model is 24.36. Its Hosmer/Lemeshow score is .982, which indicates very strong matching to the observed cases of digit or wrist pain in the left upper extremity.

In occupational economics, the importance of model sensitivity depends primarily on what contributes more to lowering the cost of injury. Is it more important to predict cases or to limit false positives? Which is going to be more cost effective for the specific occupational setting? The 77LDWP model predicts cases well and captures false positives making it a good model for both scenarios. The 77RMN model, however, limits false positives even more but has a sensitivity of only 53 percent. It does have a good significance value and matching ability, but does not appear to explain variance very well (Nagelkerke of .39). Although it predicts 87 percent of the observed cases and controls, the 77RMN model would not be sufficient when correct prediction of median neuropathy is important.

Results: Population 47

Similar results were obtained by the analysis of Population 47. The major variables that maintain significance for the same medical outcomes are *Right Percent of Busy Time* and *Years on Job*. *Percent of Flexion* while pinching for the right upper extremity maintains significance for cases of median neuropathy indicating that static pinching while in flexion shows more risk for cumulative trauma in the wrist and hand.

The multivariate analyses of Population 47 results in models for all three pain outcomes for the left upper extremity, but no models are significantly predictive for the right hand. The 47LDWP model shows the best fit when compared to the 47LDP and 47LWP models. so this model could be used generally to help predict digit or wrist pain in the left upper extremity. When digit pain is the main concern, however, the 47LDP model includes nearly all of the controls practically eliminating false positives. The determination of which model fits a population best is dependent on the importance of correctly predicting cases or controls.

Another benefit to the 47LDWP model is the reduction in variables needed. By calculating the percent of cycle using a 3-Point pinch, pinching while in extension and flexion, and determining the work history of the subject, a prediction of risk for developing pain in the wrist or digits in dynamic low force tasks may be attainable. Further studies of more general, dynamic low force tasks would be necessary to verify the application of the 47LDWP model to the more general workforce.

Strength of the Models

All of the models fit closely to the Nunnely Rule for sample size when performing multivariate logistic regression (Nunnely, 1978). Nunnely states that for every variable in the regression equation, the sample size should have ten subjects. So, the 77LDWP and 77RMN models should have 8 variables or less. The 77LDWP model had 9 variables, and the 77RMN model had 8. To verify the 77LDWP model sample size, a power calculation for generalized regression models was performed using the power function program built by Tosteson et al. (Tosteson et al., 2003). The suggested sample size was 80. The size of Population 77 is nearly 80 supporting the statistical validity of the model. Figure 7 is a plot of the sample size curve derived from this method. The models for Population 47 also fit the Nunnely Rule. The 47LWP and 47LDP models both had 5 contributing variables, and the 47LDWP had only 4. According to Nunnely, the sample size is sufficient for all of the Population 47 models presented. No further verifications were made.

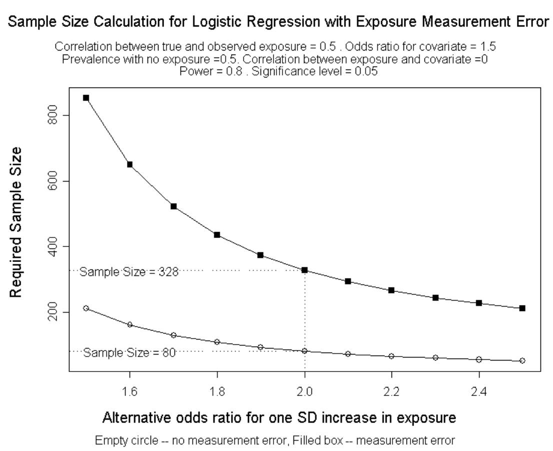


Figure 7. Sample size calculation using the power function program.

Comparison

The results of the analysis for Population 77 and Population 47 were very similar. Both analyses revealed a predictive model for *Left Digit or Wrist Pain* suggesting that dynamic low force repetitive tasks may elevate the risk of developing chronic pain in the wrist or hand. A common pinching variable among all of the models was *Percent of 3-Point Pinch*, indicating that finger tip pinching is more predictive of injury than lateral pinching or low force grasp. Some evidence of this is visible in the descriptive statistics for *Average 3-Point* and *Average Lateral*. In general, the subjects had higher maximum pinches when using a lateral pinch than when using a 3-Point pinch.

Only the dominant hand was used to determine pinch capability measurements. Although capability measurements of the non-dominant hand would be useful, *% of 3-Point Pinch* was much more significant than *% of Lateral Pinch* in all cases even though lateral pinch was used by both hands. The right hand, the more dominant hand, used lateral pinch over 50 percent of the time yet showed little significance to the medical outcomes tested. Since the majority of predictive models were for the left hand or wrist, generally the non-dominant side, it may be suggested that the non-dominant upper extremity may be at more risk for developing cumulative trauma. However, we do not have sufficient data to determine if "handedness" increases risk of CTDs.

By comparing the two populations, a significant effect is seen when the subjects with high BMIs, diabetes, and a history of smoking are removed. *BMI* was statistically significant especially for medical outcomes involving nerve conduction in Population 77. These outcomes are *Numbness/Tingling*, *Nerve Conduction*, and *Median Neuropathy*. This relationship suggests that subjects with excessive body tissue for their height are at a higher risk for constricting the nerves serving the wrist and hand, particularly the median nerve. When more tissue is present, less swelling is needed to cause this type of constriction. It, therefore, makes intuitive sense that a higher BMI may increase the risk of cumulative trauma involving nerve conduction.

Diabetes is found to be significant as well. In the 77LDWP model, *Diabetes* has an adjusted odds ratio of 5.91 showing it contributed a great deal to *Left Digit or Wrist Pain*. This may be due to its bivariate significance to *Nerve Conduction* in the left upper extremity. However, the adjusted odds ratio for *Diabetes* in the 77RMN model is much lower suggesting that diabetes plays a role, but not as significantly, in the risk of median neuropathy as compared to digit pain.

The opportunity given to compare a population of subjects with little to no history of smoking is rare. Even in Population 77, the average age of workers who had a history of smoking was 47 while the average age of the *Smoking* workers when they stopped smoking was 25. The mean time since quitting for these subjects was 22 years. Therefore, even Population 77 is uninhibited by physiological effects, such as vasoconstriction and decreased median nerve conduction (Tanaka et al., 1997), more common in less dormant smoking populations. *Smoking* was not included in any of the predictive models and accounted for only 8 subjects. But, not one of the smoking subjects were cases for *Right* or *Left Median Neuropathy* indicating further that the dormancy may have reduced any effect smoking may normally have on this medical outcome.

RECOMMENDATIONS AND CONCLUSION

Future Analysis

Throughout this study, improvements were noted that could be used in future analysis. One limitation to the study was the lack of personal information such as ethnicity and non-dominant pinch capability. By collecting these data, some unseen or unclear relationships may be explained.

Other medical outcomes such as Dequervin's and tendonitis should be studied using this database. This study focused mainly on reported pain in the digits and abnormal nerve conduction related outcomes. Investigation of other medical outcomes may better explain the effect of pinching postures on upper extremity cumulative trauma disorders.

The effect of pinch capability on cases of cumulative trauma in the wrist and hand should be considered. Since the current study only tested pinch capability for the dominant hand, comparing the more significant left hand regression models is difficult. By having similar data for the right hand, being more dominant, confidence can be given to the conclusions made in this study regarding the effect of pinch capability on pinching tasks.

A study of a more general population of workers performing repetitive, low force tasks may show different results than what is indicated by the current study. In particular, a larger population using tasks with similar pinching postures performed by both hands would be valuable for comparison. The tasks performed by each hand in this study were very different. So, similar tasks performed equally by both hands would improve the significance of this study.

Parameters not investigated by this study are radial deviation while pinching and whether wrist devices such as watches, wrist bands, and so forth cause unnecessary pressure to the median nerve. Radial deviation while pinching was not investigated statistically due to the rarity of the event. Extra pressure on the wrist from contact force may limit expansion of the tendons increasing the risk of swelling. So, further study of the effects of these two parameters could be important.

Conclusion

In summary, this study observed an effect relating pinching postures and the occurrence of upper extremity cumulative trauma disorders. Finger tip pinch accompanied with extreme wrist postures seems to increase the risk of upper extremity cumulative trauma disorders such as chronic pain in the wrist and digits. Verification of the results with a larger population performing more general pinching tasks is suggested.

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