ERGONOMICS, 1994, VOL. 37, NO. 9, 1449–1459

Rapid Communication

Industrial wrist motions and incidence of hand/wrist cumulative trauma disorders

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Keywords: Cumulative trauma disorders (CTDs); Carpal tunnel syndrome (CTS); Kinematics; Biomechanics; Acceleration.

One of the major research voids in the study of occupational hand/wrist cumulative trauma disorders (CTDs) is the lack of quantification of the relationship between the known kinematic risk factors, such as wrist angle and repetition, and CTD risk. A previously published article in this journal (Marras and Schoenmarklin 1993) reported the descriptive results from a quantitative surveillance study performed in industry in which worker's wrist motions were monitored on the factory floor. The wrist motion components that were monitored on each subject were position, velocity, and acceleration measures in each plane of movement (radial/ulnar, flexion/extension, and pronation/supination). The objective of this article was to form a metric that associates the degree of incidence of hand/wrist CTDs with those types of wrist motions that were significant in the earlier paper. Of all the kinematic parameters measured, multivariate analysis of the motion data revealed that acceleration in the flexion/extension plane discriminated the best between groups of low and high incidence rates of CTDs. The epidemiological association between flexion/extension acceleration and CTD incidence rate is compatible with results from empirical studies and theoretical models in the physiologic and biomechanical literature. The flexion/extension acceleration values from this study can serve as preliminary motion benchmarks that establish relative risk levels of CTDs for hand-intensive, highly repetitive jobs that do not require hand tools. Industrial practitioners can use this methodology, along with other accepted tools, to enhance ergonomic assessments of jobs.

1. Introduction

Occupational risk factors of hand/wrist cumulative trauma disorders (CDTs) include wrist posture, grip force, and repetition. However, these risk factors have limited use in the ergonomic assessment of jobs primarily because there are few, if any, reliable quantitative methods suitable for assessing the actual level of these risk factors and also for measuring the degree that repetitiveness is reduced through ergonomic interventions. In addition, there are no benchmarks that define acceptable quantitative levels for these risk factors in jobs.

Based on epidemiological studies, Silverstein *et al.* (1986, 1987) concluded that repetitive movements of the hand and wrist are a risk factor for carpal tunnel syndrome (CTS) and wrist tendinitis. Although repetition has been found to be a risk factor, the relationship between components of repetitive wrist movements—namely position, angular velocity, and angular acceleration, and plane of movement—and CTD risk has not been quantified. Since ergonomists have been unable to quantify the type and magnitude of wrist motion in repetitive industrial jobs, safe and injurious levels of wrist motion have not been established. Progress in preventing occupational hand/wrist CTDs depends, to a large extent, on quantifying the association between kinematic aspects of wrist motion and CTD risk.

Previous studies have shown an association between kinematic parameters of repetitive body motion and incidence of occupational illnesses. A surveillance study was conducted in industry on workers who lifted and lowered industrial stock of various weights (Marras *et al.* 1993). Worker's back motions were measured by a lumbar motion monitor (LMM) and correlated with risk of low back injury (Marras *et al.* 1992). There researchers found that the kinematic parameters of angular velocity in specific planes of motion were significant predictors of low back pain.

An article previously published in this journal (Marras and Schoenmarklin 1993) reported the descriptive results from a quantitative surveillance study performed in industry in which workers' wrist motions were monitored on the factory floor. This study was similar to the surveillance study on occupational back motion (Marras *et al.* 1993). Forty industrial workers, who performed highly-repetitive, hand-intensive tasks, were chosen randomly from jobs that were of low and high incidence rate of CTDs. The wrist motion components that were monitored on each subject were position, velocity, and acceleration measures in each plane of movement (radial/ulnar (rad/uln), flexion/extension (flex/ext), and pronation/supination (pron/sup)). Significantly differences were found in all of the velocity and acceleration wrist motion variables between workers who performed jobs of low and high incidence of hand/wrist CTDs.

The objective of this article was to form a metric that associates the level of incidence of hand/wrist CTDs with those types of wrist motions that were found significant in the earlier paper (Marras and Schoenmarklin 1993). This metric could lead to defining 'what type' and 'how much' wrist motion is relatively safe and injurious to workers who perform hand-intensive, highly-repetitive jobs that do not require hand tools. Industrial practitioners of ergonomics could utilize these motion benchmarks to evaluate CTD risk of current and alternative job designs, thereby augmenting their efforts to reduce the incidence and cost of CTD illnesses.

2. Methods

2.1. *Approach*

The approach in this study was to determine, using multivariate statistical techniques, which wrist motion variables were the best predictors of hand/wrist CTD incidence rate. Multivariate statistical techniques were performed on the wrist motion data collected in the earlier study (Marras and Schoenmarklin 1993). In addition, a new kinematic variable, peak acceleration, was computed from the continuous trace of data and analysed.

2.2. *Methodology of previous study*

The methodology of the previous quantitative study will be summarized briefly here (Marras and Schoenmarklin 1993). Eight industrial plants in the US Midwest were selected as sites for data collection. The monitored jobs consisted of handling lightweight parts and required minimal use of hand tools. The independent variable in this study was incidence rate of hand/wrist CTDs, with two levels (low and high). The CTD' incidence rate was determined from US Occupational Safety and Health Administration (OSHA) 200 logs, which are required by the US Government to record occupational injuries and illnesses. Additional medical records at the plants were checked to ensure that claims on the OSHA 200 logs that were 'due to repeated trauma' were actually hand/wrist CTDs. Typical hand/wrist CTDs reported on the OSHA 200 log were carpal tunnel syndrome, tenosynovitis, tendinitis, etc. Low and high incidence jobs were defined as having incidence rates of zero and greater than eight per 200 000 h of exposure or 100 person-years, respectively. The position, velocity, and acceleration components of wrist motion were measured in the rad/uln, flex/ext, and pron/sup planes.

A total of 40 industrial workers were monitored in this study. The age of the workers ranged from 25 to 62 years old. Eleven males and nine females comprised the gender distribution in each incidence group. Two workers in each of ten jobs were monitored in each risk category. The jobs from the eight plants were selected, in part, based on number of wrist movements. The minimum acceptable number of fundamental wrist movements for an eligible job was 13 000 during an 8 h shift (Barnes 1991).

Wrist motion and forearm rotation were measured by a wrist monitor and pron/sup device, respectively. Details of the construction, calibration, and validation of these devices are described in Marras and Schoenmarklin (1991). The wrist monitor was composed of two segments of thin metal that were joined by a rotary potentiometer. The potentiometer measured the angle between the two metal segments. The wrist monitor was a small, lightweight, and sensitive instrument that recorded rad/uln and flex/ext angles independently. The results from the wrist monitor were validated by a video-based motion analysis system, and the kinematic results from both the wrist monitor and motion analysis system were within 3%. The pron/sup device consisted of a rod that remained parallel to the forearm during rotation. Rotations of the rod were recorded by a potentiometer. Results from the pron/sup device were also validated by a video-based motion analysis system, and the kinematic results were within 7·5%.

Voltages from the six potentiometers on both upper extremities were sampled at 300 Hz, digitized by an analog to digital converter, and stored on portable PC. The six channels comprised rad/uln, flex/ext, and pron/sup motion of both upper extremities. In the laboratory, the voltage output from the wrist monitor and pron/sup device were converted into angles, and the position, velocity, and acceleration were calculated simultaneously from differential equations using a Laplace transform, as described in Marras and Schoenmarklin (1991). The finite difference method was not used to calculate velocity and acceleration.

The experimental protocol consisted of at least ten 10 s trials for each worker while he/she performed his/her job at a normal pace (the job was not simulated). During each 10 s data trial, the start and end of work cycle intervals were identified by an assistant activating a Schmitt trigger on a separate input channel. The number of intervals within a 10 s trial ranged from one to five. The number and distribution of work intervals were time-weighted in order to represent the percentage of time that each subject spent in each phase of his/her job.

Kinematic data were collapsed into a data set containing data from only the injured hand in the high incidence rate jobs and hand of dominant motion in the low incidence jobs.

2.3. *Analysis of kinematic data*

The following variables describing the kinematic data collected in the previous study were computed in the rad/uln, flex/ext, and pron/sup planes for this study;

1. mean, minimum, maximum, and range* of wrist angle
2. mean, minimum, maximum, and range* of angular velocity
3. mean, minimum, maximum, and range* of angular acceleration
4. peak angular acceleration;

where range* = maximum − minimum.

The first three sets of descriptive variables were computed for each work interval that occurred within the 10 s trials, and then subsequently averaged over all intervals. The fourth descriptive variable, peak angular acceleration, was computed for the entire ten second trial, regardless of how many work intervals there were in each trial. The peak acceleration was computed because more information could be gained from continuous kinematic data than just three statistics (mean, minimum, and maximum) computed for disjoint intervals. The peak acceleration is advantageous because it does not depend on the judgement of the experimenter who decides when an interval should begin or end and how long it should last. The peak data were computed for the acceleration components only because the acceleration data were found to be stronger predictors of CTD incidence rate than position or velocity. Peak acceleration differs from maximum acceleration in that it is not a variable representing one point (the highest value for a specific interval), but rather many points, or peaks. A representation of a small sample of continuous acceleration data is depicted graphically in figure 1 to show how peak acceleration is calculated. Each time a peak is seen in the data, the peak's value is recorded. To be considered a peak, the point must increase or decrease by at least 50°/s^2 from the last observed peak. This process filters out the acceleration noise from the wrist monitor, which is 50°/s^2 or less. The technique of calculating peak acceleration can be performed on any duration of data collection, whether it is a 5 s or 60 s trial.

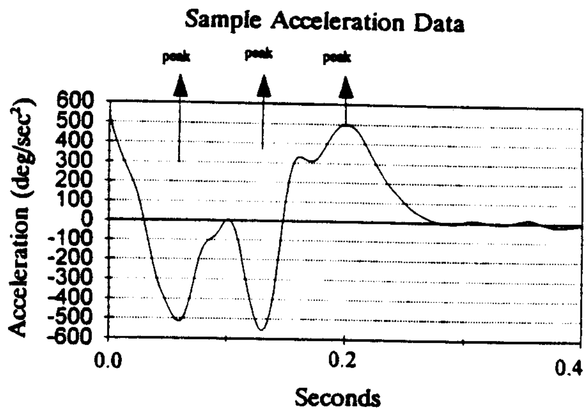

Figure 1. Sample acceleration data to demonstrate peak acceleration.

Table 1. Results of discriminant function analysis on wrist motion variables. The classification variable was incidence rate of hand/wrist CTDs with two discrete levels, low and high. The percentages of correctly classified subjects were calculated by jackknifed stepwise discriminant function analysis (BMDP, procedure 7M).

	Percentage of subjects in low incidence rate jobs correctly classified	Percentage of subjects in high incidence rate jobs correctly classified	Percentage of total subjects correctly classified
Rad/Uln range of POSITION	65	55	60
Flex/Ext range of POSITION	60	45	52·5
Pron/Sup range of POSITION	72·2	47·4	59·5
Rad/Uln average VELOCITY*	70	75	72·5
Flex/Ext average VELOCITY*	85	60	72·5
Pron/Sup average VELOCITY*	77·8	73·7	75·7
Rad/Uln average ACCEL**	80	65	72·5
Flex/Ext average ACCEL**	85	60	72·5
Pron/Sup average ACCEL**	72·2	84·2	78·4

* Absolute value of velocity.
** Absolute value of acceleration.

3. Results

3.1. *Classification of CTD incidence rate groups*

Discrimination function analysis (DFA) was performed on the range of position, average and range of velocity, and average and range of acceleration variables to determine how well these wrist motion variables classified subjects into the correct category of CTD incidence rate (low or high). The range variables were chosen over the maximum and minimum variables for the sake of parsimony and also to avoid multicollinearity in DFA.

As shown in table 1, the results of DFA found that average velocity and acceleration variables classified CTD incidence rate better than range of position variables. The sets of average velocity and average acceleration predicted group membership about equally well, with a range from 72·5% to 78·4% of subjects correctly classified in their respective risk groups, whereas range of position variables correctly classified only 50% to 60% of subjects. In a DFA of the three planes of motion, the flex/ext plane predicted CTD incidence rate the best.

The results of DFA on the range of velocity and acceleration were similar to the DFA of average velocity and acceleration.

3.2. *Prediction of CTD incidence rate*

Multiple logistic regression (MLR) was performed in order to predict CTD incidence rate from descriptive variables of wrist motion. The predicted variable was CTD

Table 2. Results of multiple logistic regression on the range of position, average velocity and acceleration, and peak acceleration variables. The predicted variable was incidence rate of hand/wrist CTDs with two discrete levels, low and high. The odds ratio statistic was defined as the odds of a high incidence rate of CTDs given a motion variable at the midpoint of the mean low and high incidence values (grand mean) divided by the odds of a high incidence rate of CTDs given a motion variable at the mean low incidence value.

Wrist motion variable	Odds ratio	95% confidence interval
Rad/Uln range of POS	1·52***	1·08–2·13
Flex/Ext range of POS	1·31***	1·02–1·70
Pron/Sup range of POS	1·23	0·97–1·56
Rad/Uln avg VEL*	2·44***	1·37–4·33
Flex/Ext avg VEL*	3·80***	1·50–9·63
Pron/Sup avg VEL*	1·95***	1·38–3·23
Rad/Uln avg ACCEL**	2·69***	1·46–4·93
Flex/Ext avg ACCEL**	6·05***	1·66–22·0
Pron/Sup avg ACCEL**	2·96***	1·37–6·42
Peak rad/uln ACCEL**	3·30***	1·72–6·38
Peak flex/ext ACCEL**	5·03***	2·28–11·08

* Absolute value of velocity.
** Absolute value of acceleration.
*** Significantly different from odds ratio of 1·0 at 0·05 level.

incidence rate with two discrete levels, low and high. For this study, the odds ratio statistic was defined as the odds of a high incidence rate of CTDs given a motion variable at the midpoint of the mean low and high incidence values (grand mean) divided by the odds of a high incidence rate of CTDs given a motion variable at the mean low incidence value.

As indicated in table 2, the average and peak flex/ext acceleration predicted CTD incidence rate better than any other variable, with odds ratios of 6·05 and 5·03, respectively. The second best predictors appeared to be flex/ext average velocity and peak rad/uln acceleration, with odds ratios of 3·8 and 3·3, respectively. Position variables predicted CTD incidence rate poorly, with odds ratios ranging from 1·23 to 1·52.

3.3. *Preliminary wrist motion benchmarks*

Of all the kinematic variables, the results from MLR show that acceleration in the flex/ext plane is the strongest predictor of groups of low and high CTD incidence rate. The data from flex/ext acceleration can now be used to establish preliminary motion benchmarks that serve as indicators of the relative safety and injuriousness of highly-repetitive, hand-intensive jobs that do not require hand tools. In order to establish these benchmarks, the peak acceleration measure was chosen over the average acceleration in the flex/ext plane because the peak is insensitive to the duration of the data trial or the number and length of intervals within the trial. (From here on, the term peak acceleration refers to data from the flex/ext plane only, unless otherwise noted.)

Of all the peak accelerations that were recorded, only the top 10% of peak accelerations from both incidence rate groups were saved for future analysis. The rationale for this method of analysis is that it filters out the peak accelerations that occurred during idle periods or periods of minimal wrist motion. The top 10% of all peak accelerations were normally distributed and are shown in figure 2. Table 3 shows the summary statistics for peak acceleration. The 50th and 75th percentile peak

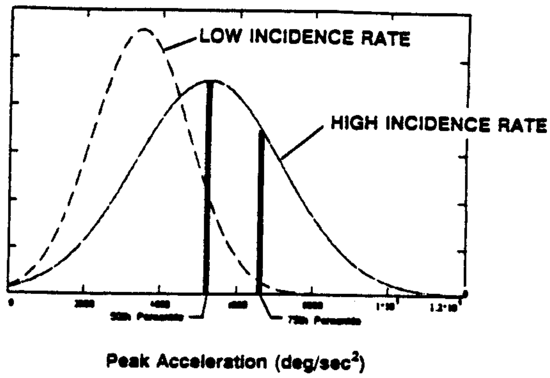

Figure 2. Normal distributions of the peak flexion/extension accelerations for the groups that had low and high incidence rates of hand/wrist CTDs. Only the top 10% of peak accelerations were included in these distributions.

Table 3. Summary statistics of the top 10% of the peak acceleration data from the flexion/extension plane of motion, in °/s^2.

	Mean	Standard deviation	75th percentile
Low incidence rate group	3445	1277	4306
High incidence rate group	5220	1958	6541

accelerations for the high CTD incidence rate group were computed. It is apparent from figure 2 that the 75th percentile peak acceleration from the high incidence group is greater than all but a few of the peak accelerations from the low incidence group. One can conclude from figure 2 that if a job's peak accelerations are above the high incidence 75th percentile level, then there is a 98% probability that the job has a high level of CTD incidence. If the peak acceleration lies between the 50th and 75th benchmarks, there is approximately 75% probability that the job has a high level of CTD incidence. If the peak acceleration is less than the 50th percentile benchmark, then there is approximately 67% probability that the job could be classified as having a low level of CTD incidence.

4. Discussion

4.1. *Predictive models*

The results from MLR demonstrated the parsimony and strength of the predictive models. As indicated in the statistical analysis, flex/ext acceleration was consistently the best discriminator between groups of low and high incidence rate of hand/wrist CTDs. The odds ratios between high and low incidence groups for flex/ext average and peak acceleration were 6·05 and 5·03, respectively (refer to table 2). The results from discriminant function analysis (DFA) corroborated the predictive power of flex/ext acceleration (refer to table 1). Flex/ext acceleration was able to correctly classify approximately 70% of all subjects into their respective risk groups. In both DFA and MLR, all the position variables were poor discriminators of CTD incidence rate.

The association between the flex/ext plane and hand/wrist CTD incidence rate is supported by anatomical, physiological, and biomechanical modelling literature.

According to Robbins (1963), extreme flexion and extension of the wrist reduce the volume of the carpal tunnel, thereby augmenting compression on the median nerve. Phalen (1966) stated that wrist flexion and extension increase pressure within the proximal half of the carpal tunnel. Phalen (1966) developed a diagnostic test for CTS in which patients push their forearms together in an axial direction while flexing their wrists maximally. In an anatomical study on cadavers, Smith *et al.* (1977) replaced the median nerve with a water-filled cylindrical balloon and found that pressure on the median nerve increased when the wrist was flexed to an extreme angle and also when the flexor tendons were tensed at various wrist flexion angles. During a flexed posture, the median nerve is squeezed between the flexor retinaculum (carpal ligament) and the underlying flexor tendons, thereby exposing a worker to CTS.

Armstrong *et al.* (1984) investigated the histological changes in the flexor tendons as they pass through the carpal tunnel, and they found hyperplasia and increased density in the synovial tissue in the carpal tunnel area. These authors suggested that biomechanical factors, such as repeated exertions with a flexed or extended wrist posture, could partially cause these degenerative changes in tendon tissue. In an investigation of the viscoelastic properties of tendons and their sheaths, Goldstein *et al.* (1987) found that flex/ext wrist angle increased the shear traction forces between tendons, their sheaths, and bones and ligaments that form the anatomical pulley. These authors concluded that stresses at the tendon-sheath interface are significant and depends on flex/ext wrist angle.

The literature on static modelling of the wrist also supports the association between the flex/ext plane and hand/wrist CTD incidence. Armstrong and Chaffin (1979a) modelled the wrist's tendons statically in the flex/ext plane, and they showed theoretically that angular flex/ext deviations from the neutral position generated large resultant reaction forces on the flexor tendons.

Based upon the results from this research, we propose an additional hand/wrist CTD risk factor of flex/ext acceleration. There is theoretical support for claiming flex/ext acceleration as a risk factor. First, Schoenmarklin and Marras (1990) used the basic structure of Armstrong's and Chaffin's (1979a) model and added the dynamic component of acceleration. When the tendons are accelerated, the resultant reaction force exerted on the tendons by bones and ligaments increased dramatically as compared to static loading. The resultant reaction force on the tendons from flex/ext acceleration could degenerate and inflame the flexor tendons passing through the carpal tunnel, thereby causing tenosynovitis, or compress the median nerve between the flexor retinaculum and tendons, which could cause CTS. Quick decelerations in the flex/ext plane could likewise generate high loads on the wrist joint. Compared to static loading on the elbow joint, Amis *et al.* (1980) predicted a 25–30% increase in the elbow joint forces during the deceleration phase of fast elbow flexions.

Second, the association between flex/ext acceleration and CTD incidence can also be explained biomechanically by the concepts of Newtonian mechanics and friction. In addition to producing static grip or pinch force, the tendons have to exert force to accelerate the wrist, based on Newton's second law ($F = M \times A$). The forearm muscular force required to accelerate the wrist and exert grip or pinch force is transmitted through the tendons, which pass through the wrist. Some of the force transmitted through the tendon is lost to friction against the ligaments and bones that form the carpal tunnel. This frictional force could irritate the tendons' synovial membranes and cause 'synovitis', the thickening of the synovial membrane (Armstrong 1983). Irritation could precipitate tendon inflammation, which could result in tenosynovitis or CTS through compression of the median nerve. In a histological investigation of tendon sheaths, Armstrong *et al.* (1984) found sizeable increases in synovial hyperplasia and synovium density in the carpal tunnel area, which they attributed to repeated flex/ext exertions.

Tanaka and McGlothin (1989) hypothesized that the friction between tendons and adjacent structures is a major cause of hand/wrist CTDs, and Moore *et al.* (1991) showed that the frictional work generated in the carpal tunnel supported Silverstein's *et al.* (1986, 1987) dose–response relationship between repetition and CTD risk. The deleterious effects of frictional work generated between the tendons and their sheaths is exacerbated by coactivation of the extensor muscles during movements. Varying amounts of extensor muscle force during any static or dynamic movement are required to guide and stabilize the hand so it can generate power or pinch force. In order for the wrist and hand to maintain the same external flexor torque or power/pinch force, the flexor muscles have to exert more force to overcome the force from the extensor muscles. Greater forces in the flexor muscles will generate increased frictional work between the flexor tendons and their adjacent structures, thereby exposing workers to increased risk of CTDs. Research into quantifying tendon force and frictional work under dynamic conditions is now in progress at The Ohio State University and Marquette University.

4.2. *Dose–response relationship between wrist motion and CTD incidence rate*

The relationship between incidence rate of hand/wrist CTDs and occupational factors, such as repetition and wrist posture, has been established qualitatively by extensive discussions in the literature (Armstrong 1986, Armstrong and Chaffin 1979b, Schoenmarklin and Marras 1990, Birkbeck and Beer 1975, Jensen *et al.* 1983, Tichauer 1966, 1978, Welch 1972) and surveillance studies (Silverstein *et al.* 1986, 1987, Armstrong and Chaffin 1979b, Hymovich and Lindholm 1966, Tanaka *et al.* 1988, Armstrong *et al.* 1982). Qualitative links are ineffective tools for industry to use to prevent CTD illnesses because they do not relate the magnitude of specific wrist motions to risk of hand/wrist CTDs.

The thrust of this study was to quantify the dose–response relationship between wrist motion parameters and incidence rate of hand/wrist CTDs. This initial dose–response relationship can serve as preliminary quantitative guidelines on the type and amount of wrist motion that expose workers to hand/wrist CTDs. The types of jobs monitored in this study were limited to highly-repetitive, hand-intensive jobs that did not require hand tools. As stated earlier, the variables that appear to best discriminate between low and high levels of incidence rate of hand/wrist CTDs are mean, range, and peak acceleration in the flex/ext plane (odds ratio of 6·05, 5·18, and 5·03, respectively). Peak acceleration appears to be the most robust predictor of hand/wrist CTDs because, unlike the mean and range, peak acceleration is not dependent on the beginning and ending points of time intervals or the duration of the entire trial. The 50th and 75th percentile levels of peak acceleration can serve as wrist motion benchmarks that establish relatively safe and injurious levels of wrist motion for hand-intensive, highly-repetitive jobs that do not require hand tools. These data suggest that it is feasible to detect those injurious industrial jobs where high wrist accelerations are required.

Even though results from this analysis are not generalizable to all industries, these results do suggest the importance of dynamic components of wrist motion in the ergonomic assessment of repetitive, hand-intensive jobs that do not require hand tools. In order to enhance generalizability, more data from field studies similar to the one conducted in Marras and Schoenmarklin (1993) need to be collected and analysed to establish quantitative guidelines on the type and amount of wrist motion that expose workers to hand/wrist CTDs. In addition, monitored jobs should have a continuous range of CTD incidence rates in order to predict CTD incidence more accurately. Analysis of the kinemetic data should also include coupling of kinematic variables, such as position, velocity, and acceleration, in order to determine whether a combination of coupled predictor variables enhances the predictability of hand/wrist CTD incidence rate over orthogonal variables.

Two of the traditional occupational risk factors of hand/wrist CTDs, namely tendon force and wrist deviation, apply to primarily static jobs and are difficult to apply to highly-repetitive, dynamic jobs, which are prevalent in industry. The measurement of tendon force has inherent practical difficulties during dynamic movements, and wrist deviation was shown in Marras and Schoenmarklin (1993) and this study that it does not separate significantly dynamic jobs of low and high CTD incidence rate. The third traditional occupational risk factor, repetition, is often too vaguely defined (e.g., parts/min, cycles/min, exertions/min, etc.) to be used as an effective discriminator between jobs of low and high CTD incidence rate. However, we have identified the one occupational risk factor (i.e., flex/ext acceleration) that applies to highly-dynamic, hand-intensive industrial tasks, which often are associated with hand/wrist CTDs and CTS. The results from this study can serve as preliminary wrist motion benchmarks that could aid ergonomists in assessing hazards from repetitive, hand-intensive work.

5. Conclusions

One of the major research voids in the study of occupational hand/wrist CTDs has been the lack of quantification of the relationship between kinematic risk factors, such as wrist angle and repetition, and CTD risk. The objective of this research as to form a metric that associates incidence rate of hand/wrist CTDs with specific wrist motion parameters.

This study has shown that in highly-repetitive industrial tasks that involve hand and wrist motion, acceleration in the flexion/extension plane discriminated the best between jobs of low and high incidence rate of hand/wrist CTDs. 50th and 75th percentile levels of peak acceleration can serve as preliminary quantitative motion benchmarks that establish relatively safe and injurious levels of wrist motion found in highly-repetitive, hand-intensive jobs that do not require hand tools. Kinematic data from this study and its predecessor (Marras and Schoenmarklin 1993) could be used to enhance present methods of ergonomic assessments of jobs and CTD prevention programs. Within the types of industries monitored in this study, ergonomic practitioners now have a methodology and preliminary data that could lead to benchmarks that quantify the risk level of hand/wrist CTDs in repetitive, hand-intensive jobs.

Acknowledgments

This research was supported, in part, by the US National Institute for Occupational Safety and Health, grant 1 R01 OH02621-01 and 02. Special thanks to Ms Katie Lehman for performing some of the advanced statistical analysis.

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