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16. Abstract (Limit: 200 words)

Occupationally caused carpal tunnel syndrome (CTS) in women was investigated through three studies: test battery development for workplace surveillance of CTS; effects of work pace, wrist splints, light duty work, and time off on CTS; and an anatomic study of the pathomechanics of CTS. The test battery included measures of median and ulnar nerve performance in the hand and wrist. Age was determined to be the most consistent and significant factor of normal subject performance. The test battery was then used to study the effectiveness of common interventions for CTS. Workers from two automobile upholstery factories were used to evaluate the effectiveness of specific changes in work pace and work with and without wrist splints. Results of the pace study tend to support the use of pacing as a control measure for occupational CTS. The use of wrist splints actually served to aggravate CTS. In a longitudinal study, seven of eight subjects demonstrated some improvements in performance corresponding to time off or light duty work; two subjects who worked overtime demonstrated a worsening of performance; and all subjects given splints showed immediate worsening of symptoms. The anatomical study revealed marked mononuclear infiltration in vascular walls of vessels within the carpal tunnel which in similar to a pathological condition found in rheumatoid arthritis.

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INVESTIGATION OF OCCUPATIONAL WRIST INJURIES IN WOMEN

Terminal Progress Report

May 28, 1981

US DHHS CDC NIOSH Grant Number

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I. Introduction

The overall goal of this research is the control of occupational carpal tunnel syndrome. Towards this goal, three specific aims were established:

1. Development of a test battery for inplant surveillance of carpal tunnel syndrome.
2. Evaluation of how work pace, wrist splints, light duty work, and time off affect carpal tunnel syndrome.
3. Investigation of the pathomechanics of carpal tunnel syndrome vis an anatomic study.

II. Development of a Test Battery

A test battery was developed for inplant surveillance of carpal tunnel syndrome; it include the following measures of median and ulnar nerve performance in the hand and wrist.

1. Two point discrimination
2. Force discrimination
3. Thenar motor function
4. Temperature discrimination
5. Sweat test
6. Dexterity
7. Sensory latency
8. Motor latency and conduction velocity.

The ulnar nerve was used as an internal control for the median nerve. The test battery was evaluated with three study populations: normal, diseased-Factory one, diseased-Factory two, and diseased-clinical. The normal study population was composed of 15 males and 15 females between the ages of 20 and 70. Test performance data were evaluated for age, gender, and hand effects via stepwise least squared error regression.

Age was found as the most consistant and significant factor of normal subject performance. Age or interactions of age were significant at $\alpha \leq .05$ level for 12 of the 26 performance measures and accounting for 10% to 40% of the measured variance. Normal performance tends to decrease with age.

Hand-age effects significant at the $\alpha \leq .01$ level were found for 3 of the 26 performance measures. These results indicate that right hand, also the preferred hand, sensory function tends to age faster than the left hand, also the preferred hand, sensory function tends to age faster than the left hand. This finding raises an interesting question about pattern of usage of the preferred hand and degeneration of nerve function. Further work is required before conclusions can be drawn.

Gender and gender-age interactions significant at the $\alpha \leq .01$ level were found for 5 of the 26 performance measures. The gender age interaction indicates that certain measures of hand performance age faster for males than for females. Gender as a significant factor of dexterity is consistent with findings of other investigations.

The test performance norms were used to establish the severity of

the diseased factory one, factory two, and the diseased clinical population. These results will be summarized in a paper entitled "A Test Battery for Surveillance of Occupational Carpal Tunnel Syndrome."

In conjunction with this study, a questionnaire for sampling worker symptoms of carpal tunnel syndrome was prepared and administered to the normal subjects. Plans are to use the questionnaire with parts of the test battery to supplement use of medical records for future studies.

III. Intervention studies

The carpal tunnel test battery is being used in the workplace to evaluate the effectiveness of common interventions for occupational CTS. With the cooperation of two automobile upholstery factories-factory one and factory two, populations of workers with CTS affected hands are tested before reporting to work on Monday and again on Monday and Friday after work to evaluate the effectiveness of changes in:

1. work pace
2. work with and without wrist splints

These populations are referred to as "paced-factory one", "pacedfactory two", "splint-factory one", and "splint-factory two" respectively.

In addition, a third study is being conducted to demonstrate the use of the test battery for monitoring the condition of workers' hands as various interventions are introduced into the work activities by the employer; this study is referred to as the "longitudinal" study. Interventions included use of splints, pacing, light duty work assignments, time off, and surgery. Cases where CTS affected subjects worked overtime were also studied for possible adverse effects.

Pace Study

The effect of work pace was evaluated with the diagnostic test battery before and after mildly diseased subjects between the ages of 20 and 40 worked for one day and one week at process paced and self-paced rates. Process paced rates were established by delivering stock in equally spaced intervals during the work shift. Self paced rates were established by delivering stock as fast as it was used. Unpaced rates were from 10-25% faster than paced rates. The paced-factory one population consisted of fourteen hands in ten persons; the paced-factory two population consisted of three hands in two people. Although all of the data have been reduced and stored on a computer, a preliminary analysis has been completed on 12 hands of 9 subjects in the paced factory one population.

Median motor and sensory latencies, median minus ulnar mator and sensory latencies, median minus ulnar temperature and two point discrimination scores for subjects before the first shift, after the first shift, and after the last shift of the week for paced and unpaced work were analyzed via paired t test, repeated measures test, and analysis of variance with scheffe's multiple confidence intervals. While none of the differences among means were statistically significant ($\alpha \leq .05$), several important trends were observed.

First, average test scores for successive weeks before the first shifts approximately were equal; this indicates that subjects hands tended to recover over the weekends to the same starting condition before the paced and nonpaced trials. Second, the average of all tests scores after the first shift were consistently better following

work at paced rates than work at unpaced rates.

Third, the average of most test scores after the first shift were better following work at paced rates than work at unpaced rates. The exception is the median minus ulnar two point discrimination score; this average score following paced work was slightly greater than unpaced work.

While the results of the paced study cannot be regarded as conclusive, they are very supportive of the use of pacing as a control measure for occupational CTS. In many situations, uniform pacing of work is one of the easiest measures to implement for control CTS.

When complete, the results of the paced study will be reported in a report entitled "Investigations of Conservative Intervention Studies for Occupational Carpal Tunnel Syndrome."

Splint Study

The use of wrist splints was evaluated by administration of the test battery before and after subjects between the ages of 20 and 40 had worked one day and one week with and without wrist splints. Wrist splints consisted of a cushion 5 x 17 cm metal plate that could be bent to the shape of the palmar aspect of the hand. The splints were attached with adjustable velcro straps so that the wrist was stablized in a slightly extended position. The splint-factory one population was composed of twelve hands in nine subjects, the splint-factor two population was composed of six hands in five people. Although all of the data have been reduced and stored on a computer; a preliminary analysis has been completed only for twelve hands of nine subjects.

Median motor and sensory latencies, median minus ulnar sensory latencies, median minus temperature, and two point discrimination scores for subjects before work with and without splints, were analyzed via paired t test, repeated measures test, and analysis of variance with Scheffe's multiple confidence intervals. Several important trends and significant differences were identified.

First, average subject performance was better at the beginning of the splint trial following the week of work without the splint. Average median and ulnar motor and sensory latencies, dexterity, and median minus ulnar motor latency scores all were significantly better before work with the splint than before work without the splint. The explanation of this finding might be that the subjects studied were previously diagnosed as CTS affected and given wrist splints by the plant physician. Thus, the week of work without splints followed previous work with splints. If use of the splints aggravates CTS, then recovery could occur during the week of work without splints so that test scores are improved prior to the onset of work with splints.

Second, over the course of one day and of one week average test scores tend to be better for work without splints than work with splints. The difference between median minus ulnar motor latency test scores before and after the first shift is most significant ($\alpha \leq .10$); however, the trends are consistant for the other test scores.

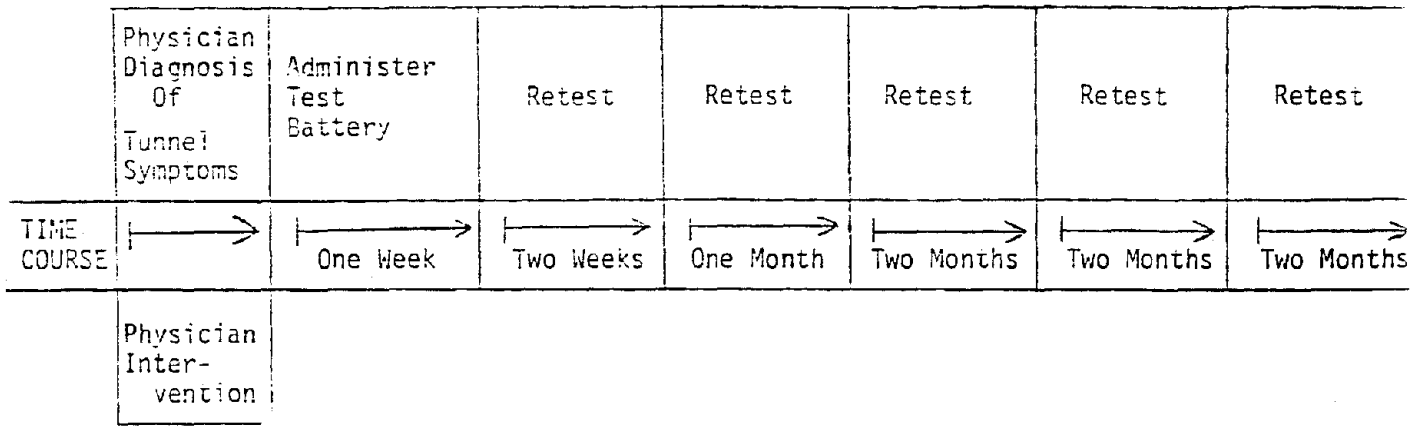
These results suggest that the wrist splints as used in this study actually aggravated CTS rather than facilitate recovery. The rational for use of wrist splints is that immobilization of the wrist prevents wrist excursions that result in compression of the median nerve by

adjacent tissues; however, immobilizing the wrist can increase the force that is exerted to perform certain reaches. Thus, work with a splint could be more stressful than work without a splint.

Wrist splints are probably one of the most commonly used therapeutic measures for CTS; in addition splints are commonly used for other cumulative trauma disorders of tendons, tendon sheaths, ligaments, and muscles of the hand and wrist. Previous studies of the effectiveness of wrist splints as an intervention for occupational CTS could not be found in the available literature. When complete, the results of the splint study will be reported in a report entitled, "Investigation of Conservative Intervention Studies for Occupational Carpal Tunnel Syndrome."

Longitudinal study

A longitudinal study was conducted to demonstrate the use of the test battery for monitoring the condition of workers hands as various interventions were introduced into the work activities by the employer. As new cases of CTS were identified, they were evaluated with the diagnostic test battery to quantify the neurological state of their hand. The state of the hand was then re-evaluated as shown in the Figure below. Eighteen hands in nine subjects all from factory one were included in the longitudinal study. All of the data have been reduced and stored on a computer but the analysis has been completed on part of the data from eight subjects.



Approximate time table for monitoring CTS affected workers.

Six subjects were given time off during the study period; three of these also were given light duty work assignments. CTS as measured by median minus lunar motor and sensory latency improved for four of these subjects during or following these interventions. Two point discrimination scores following interventions improved for four of these subjects.

One subject was given a job change; the new job was not considered extremely light or heavy duty. Subsequent changes in hand performance did not show any remarkable trends.

One subject was given a heavier duty job because of production needs. While median minus motor latency and two point discrimination scores are stable, sensory latency increased significantly following the job change indicating worsening of CTS.

Two subjects worked overtime because of production needs. Both show worsening of CTS as measured by median minus ulnar motor and sensory latencies. One of these subjects also showed worsening two median minus ulnar two point discrimination.

Three subjects were given wrist splints at the onset of the study. In all cases, CTS as measured by median minus ulnar motor and sensory latency immediately proceeded to get worse. Two of these subjects showed worsening median minus ulnar two point discrimination performance.

In summary, the remarkable findings for longitudinal study of CTS affected workers are: (1) seven of eight subjects showed some corresponding performance improvements following time off or light duty work; (2) both of two subjects working overtime showed corresponding worsening of performance, and; (3) all of the subjects given splints showed immediate worsening of symptoms. Perhaps most importantly, this study demonstrates the feasability of using a diagnostic test battery to monitor hand performance for management of CTS in industry.

When the analyses are complete, the results will be reported in a paper entitled, "Investigation of Conservative Intervention Measures for Occupational Carpal Tunnel Syndrome."

IV. Anatomical Study

The anatomical investigation was undertaken in order to determine microscopic changes in (1) fibrous connective tissue density of the epineurial layer of the median nerve, (2) synovial cell layer, subsynovial and adjacent connective tissue, (3) presence of muscular hypertrophy in arterioles and venules, (4) presence and location of

inflammatory infiltration. The dorsal, palmar and lateral aspects of the histological sections were rated separately for each of these changes.

Materials and Methods

The material used in the present investigation consisted of 6 hands and the distal fourth of the forearm obtained from adult human cadavers (embalmed within 24 hours after death) used for teaching purposes in the Department of Anatomy, The University of Michigan Medical School.

The distal flexure crease of the wrist was marked so that transverse sections of the hand could be identified by their distance (proximal or distal) from the flexure crease. After marking the flexure crease the specimens were placed in a large mold and embedded in liquid polyurethane foam with the hand in the neutral, flexed, or extended position (Figure 1). The embedded specimens were frozen and then cut into serial sections with a band saw. After the initial sections at the distal flexure crease was done, additional sections were cut at 0.5 cm proximal and distal to the crease. Then the carpal tunnel contents were carefully removed from the whole cross sections and prepared for histological examinations by serially sectioning and staining with standard Harris' hematoxylin and alcoholic eosin.

An analysis of variance of the histological data was made with MIDAS (Michigan Interactive Data Analysis System) to determine if there were any statistically significant differences between the means of the histological variables for the sections proximal or distal to the flexure crease.

Results

The mean value for each of the histological variables is usually greatest in the sections closest to the flexure crease and from there gradually decrease in a proximal or distal direction. Generally, the mean values for the variables are greater in sections distal to the crease.

An analysis of variance between the means for the density of the epineurial layer of the median nerve showed the tissue density in sections distal to the flexure crease to be significantly greater, at the 0.01 level, than those proximal to it. The mean value for synovial hyperplasia was just barely significantly greater, at the 0.05 level, in the distal segments than in the proximal ones. However, the mean density of the subsynovial and adjacent connective tissue of the distal segments was greater at a high significance level (0.001), than that of the proximal segments.

The highest significant difference was found between the means for the muscular layer hypertrophy in arterioles and venules which was greater, at the 0.0000 significance level, in the distal than in the proximal segments. In addition to the excessive hypertrophy of the muscular layer of the blood vessels in the sections distal to the flexure crease there was a marked infiltration of the blood vessel walls by inflammatory cells.

No statistically significance difference was found between the means for endothelial reduplication in arterioles or venules of proximal and distal segments.

Discussion

An interesting result in this investigation was the demonstration that the hypertrophy of the vascular walls of arterioles and venules was very much greater in the sections distal to the flexure crease than in sections proximal to the crease. We noted this condition in a previous study on the median nerve within the carpal tunnel (Castelli, et al., 1980), but the data were not statistically analyzed. However, it was suggested that the hypertrophy of the blood vessel walls would better oppose vascular collapse and thus prevent median nerve ischemia.

Effects of increasing physiological pressure within the carpal tunnel resulting in compression of median nerve vasa nervorum and accompanying anoxia, edema, and probale destruction of median nerve fibers have been discussed by Sunderland, 1976.

The marked mononuclear infiltration in vascular walls of vessels within the carpal tunnel is suggestive of a pathological condition found in rheumatic arthritis. These results are to be reported in a manuscript entitled: Histological Changes in Carpal Tunnel Contents and Their Biomechanical Implications" by Armstrong, Castelli, Evans, Diaz-Perez and Goldstein, to be submitted to The Journal of Biomechanics.

PROJECT INVESTIGATORS

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Publications

Armstrong, T., Chaffin, D. and Foulke, J. "Methodology for Documenting Hand Positions and Forces During Manual Work." J. Biomech., 12:131-133, 1979.

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Papers in Preparation

1. "Development of a test battery for surveillance of occupational carpal tunnel syndrome."

2. "Investigations of conservative intervention measures for carpal tunnel syndrome."

3. "Histological changes in carpal tunnel contents and their biomechanical implications." Armstrong, T., Castelli, W., Evans, F.G., Diaz-Perez, R., Goldstein, S.