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Using Computerized Cinematography to Develop a Predictive Model Relating Muscle Stress and Wrist Movement

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by

Joseph M. Kaczmar

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Workers in many jobs are required to perform the same tasks day after day. As a result of this repetitious work, many employees are developing what is know as Cumulative Trauma Disorders (CTD). There has been much research done on ways to prevent these disorders. Cumulative Trauma Disorders involving the wrist are of special concern. Repetitive motions and awkward positions of the wrist are a major cause of CTD's in the wrist. One such factor dealing with the posture is the angle between the hand and the forearm. In order to help limit the affects of CTD's of the wrist, a system was developed to compare the amount of muscle activity with the angle of wrist deviation. Muscle activity can be related to the amount of stress occurring in the wrist. This system can be used to help evaluate current jobs and proposed techniques for wrist stress.

Acknowledgements

I would like to thank my mentor, Dr. Bob White for his encouragement and support through the trying times. I would also like to thank my committee members, Dr. Liwana Bringelson and Dr. Bob Wygant.

THE CARL AND WINIFRED LEE HONORS COLLEGE

CERTIFICATE OF ORAL EXAMINATION

Joseph Kaczmar, having been admitted to the Carl and Winifred Lee Honors College in 1988, has satisfactorily completed the senior oral examination for the Lee Honors College on April 13, 1992.

The title of the paper is:

"Using Computerized Cinematography to Develop a Predictive Model Relating Muscle Stress and Wrist Movement"

Dr. Bob White
Industrial Engineering

Dr. Liwana Bringelson
Industrial Engineering

Dr. Robert Wygant
Industrial Engineering

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Overview

Workers in many jobs are required to repeatedly perform the same tasks day after day. As a result of this job activity, many workers are, over time, developing what one calls cumulative trauma disorders (CTD). These cumulative trauma disorders are striking a growing number of workers each year and are largely caused by repetitive motions. As jobs become more specific, these repetitive motions occur more frequently. In the past, a worker might work on many parts of a product. Today's jobs are much more specific, and many jobs involve just one action, such as tightening a nut on a wheel of an automobile. These highly repetitive motions are increasing the potential for developing a CTD; thereby, placing new challenges on the industrial engineer to develop a safe work environment.

Previous Research

Some original research on this subject has been conducted at Western Michigan University. This research dealt with identifying the relative stress placed on the wrist by particular wrist movements. This research was conducted by Karen Kleinfeld, as her thesis for the Master of Science program in Industrial Engineering (June 1990). Ms. Kleinfeld has investigated the relationship between muscle stress and various wrist positions commonly found in the work place. She found that some movements were more stressful than others. For example, her research showed that flexion at 70 degrees of the hand is more stressful than a bend of 45 degrees. For types of bends, please see Appendix A-Figure 1. This research showed the stress levels at various predetermined angles. Ms. Kleinfeld was not able to quantify how the stress increases as the angle varies. She was not able to determine this quantitative relationship because equipment was not available to record the exact movements of the hand and fingers. The equipment necessary to quantify hand and finger movement has since been made available in the WMU Industrial Engineering Department through a National Science Foundation grant. This equipment is referred to as Motion Analysis equipment and consists of a computer work station, two high speed video cameras, a video processor/digitizer, and reflectors. These reflectors are attached to the subject's fingers and provide an image for the computer to track. The system can then record a continuous measurement of the movement of digits of the hand and of the wrist. Without the use of Motion Analysis equipment, continuous readings and exact angle measurements would be difficult to obtain.

Rationale for the Project

The goal of this research is to find a mathematical relationship between wrist movements and the amount of muscle activity (stress) used to control various motions of the hand. Once developed, this relationship can be used to predict muscle stress levels and can be applied to industrial applications before an employee ever starts working on a particular job. When designing individual job elements, the engineer will have a model to help determine how stressful a job will be. The alternative is to let someone work at a job and wait to see if the activity will do harm to that person.

Methodology

Research was conducted on a random sample of human subjects. A petition was filed with the Human Subjects Institutional Review Board. Approval was received to conduct the research (see Appendix B). The Motion Analysis equipment was integrated with the electromyography (EMG) equipment which measures muscle electrical activity through surface electrodes. Data was collected simultaneously from both sets of equipment. This data was then analyzed using statistical regression to look for a mathematical relationship that could be used to predict muscle stress.

Equipment Used

Muscle Activity

The electrical activity of the finger flexor muscles in the forearm were measured using a Lafayette Model #76409 (EMG recorder), an EMG amplifier, and auxiliary output jacks. The auxiliary output of the EMG equipment was wired to a model MP280 Motion Analysis Corporation Analog data board. This board was then wired to a personal computer using the **Analog Data** collection **System** (**ADS**) (for details of equipment use, see

Appendix C). A trouble shooting guide for all equipment can be found in appendix G. The analog data is collected on the personal computer and then sent to the Sun scientific workstation.

Muscle activity is directly related to the force exerted by the hand and fingers. The EMG equipment involves placing three small electrodes on surface locations on the subject's forearm. One set of electrodes was placed over the carpal tunnel approximately one inch away from the wrist in the middle of the forearm with the palm facing up. The electrodes were placed one inch apart. The other set of electrodes was placed two to three inches away from the elbow on the ulnar side of the forearm. These electrodes neither enter the subject's skin nor do they apply any energy to the subjects's body. These sensors measure the electrical activity of the muscles, as seen at the level of the skin.

Video Images

Motion Analysis Corporation Equipment was used to record the motions of the wrist. A model VP320 video processor was used to collect the video data. This data was then sent to the Sun scientific workstation (see Appendix C for equipment use).

Small reflectors were placed on the subject to allow the motion analysis equipment to track the exact angle movement of the wrist. The motion analysis equipment uses a high speed camera to record the motions of the subject. These images are then digitized and sent to a computer which is used to calculate the total degree of motion that the hand or finger has gone through. There were three ping pong ball sized reflectors placed on each subject. One was placed on the forearm, one on the wrist and one on the first knuckle of the middle finger. The reflector on the forearm was placed so that the camera could view the entire reflector whether the subject was moving through ulnar/radial deviation or flexion/extension. The reflector over the wrist was placed by having the subject move through radial and ulnar deviation and then placing the reflector over the portion of the wrist which was not moving.

Results

The average data was entered into a program called Storm. Storm produced a regression equation for both sets of data. A description of the assumptions and the location of data files can be found in appendix D. A description of the subject population can be found in appendix E.

Neutral to Full Flexion-No Load

The motion of neutral to full flexion was the first to be studied. This motion is referred to as motion 01 in the appendix. The plot of the individual data and the average data can be found under figure 1 and figure 2. This graph represents the motions of four subjects. Several subjects' data were thrown out for the following reasons: 1. There was heavy random background noise during collection 2. There was no change in activity during movement. The lack of change in activity could be caused by poor placement of the electrodes. In figure 2, the **percent of peak muscle activity was plotted against degrees from full flexion.** The following equation was derived by placing this average data into a program called Storm.

Neutral To Full Flexion

$$\text{Percent Activity} = 0.0954 - (0.0400 * \text{Angle From Full Deviation}) + (0.000413 * \text{Angle From Full Deviation Squared})$$

The above equation produced an excellent fit for the data. Details on the goodness of fit can be found in appendix F under the title "Wrist01."

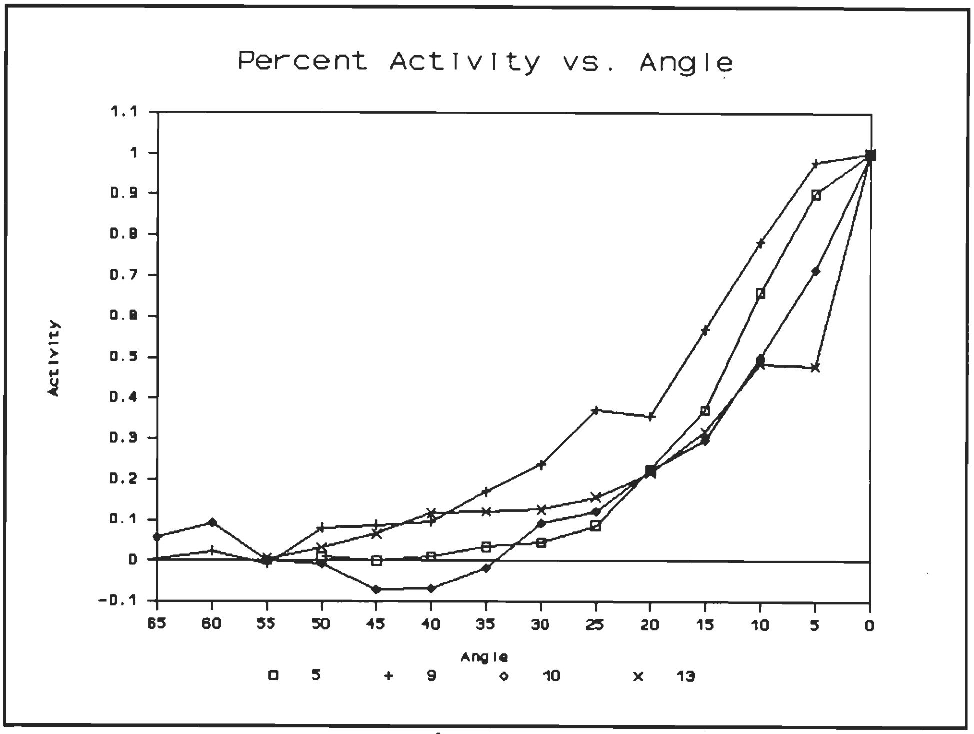


Figure 1

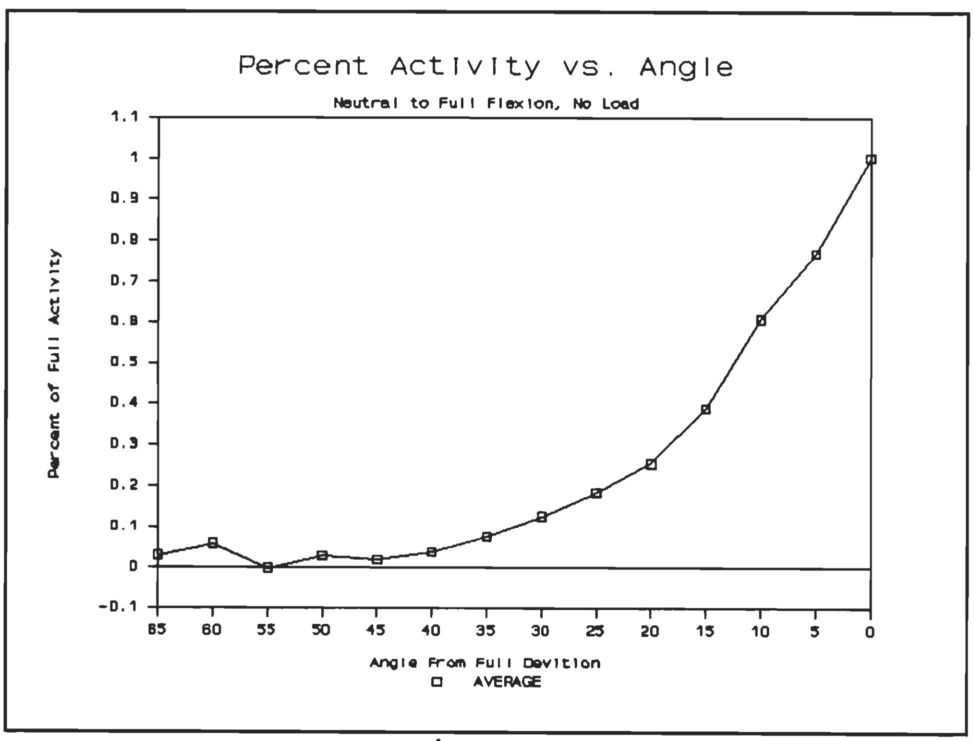


Figure 2

Neutral To Full Flexion Under a Load

Next the motion of neutral to full flexion under a load was studied. In Appendix A, this motion is listed as move 25. The subject moved his/her wrist while pulling against a nearly perfectly elastic strip of fabric. The force applied was minimal. The graphs of the data can be found on the following page. Figure 3 represents the data from five subjects. Figure 4 represents the average from those five subjects. The X-axis shows the percent of total angle that the wrist has deviated. The Y-axis shows the percent of maximum activity. Next the average data was entered into Storm. The following equation was derived:

Percent Activity= 0.0516 + 0.00728 *(Percent of Full Angle)

The angle was measured opposite from the previous analysis. In this section, zero degrees corresponds to a neutral wrist position. The above Storm Equation had an excellent fit. Details about the goodness of fit can be found in Appendix F.

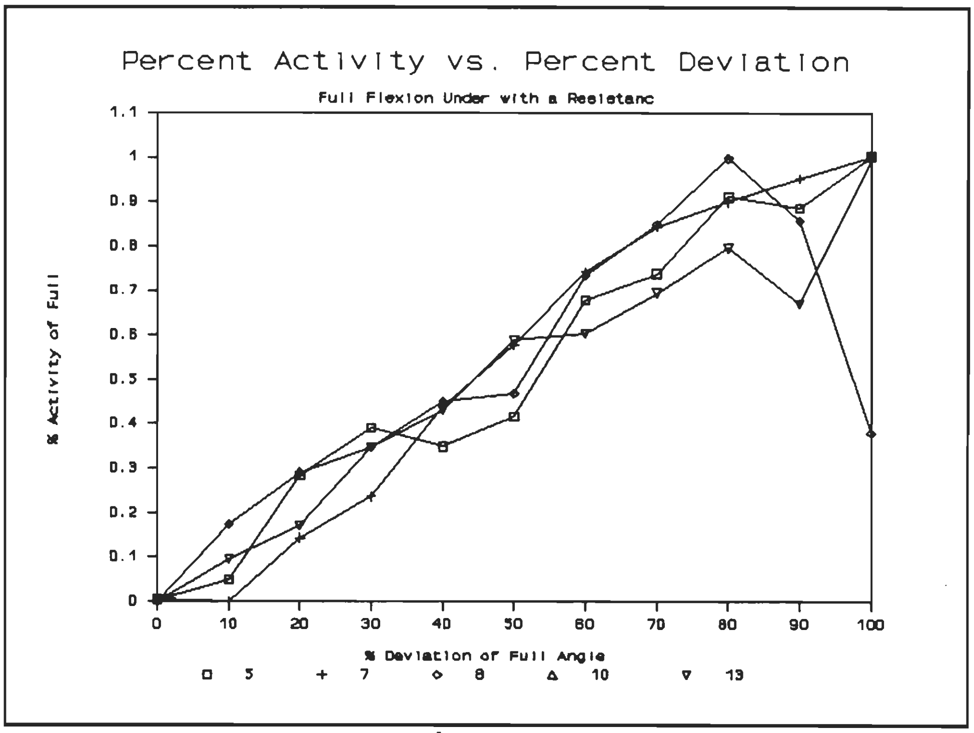


Figure 3

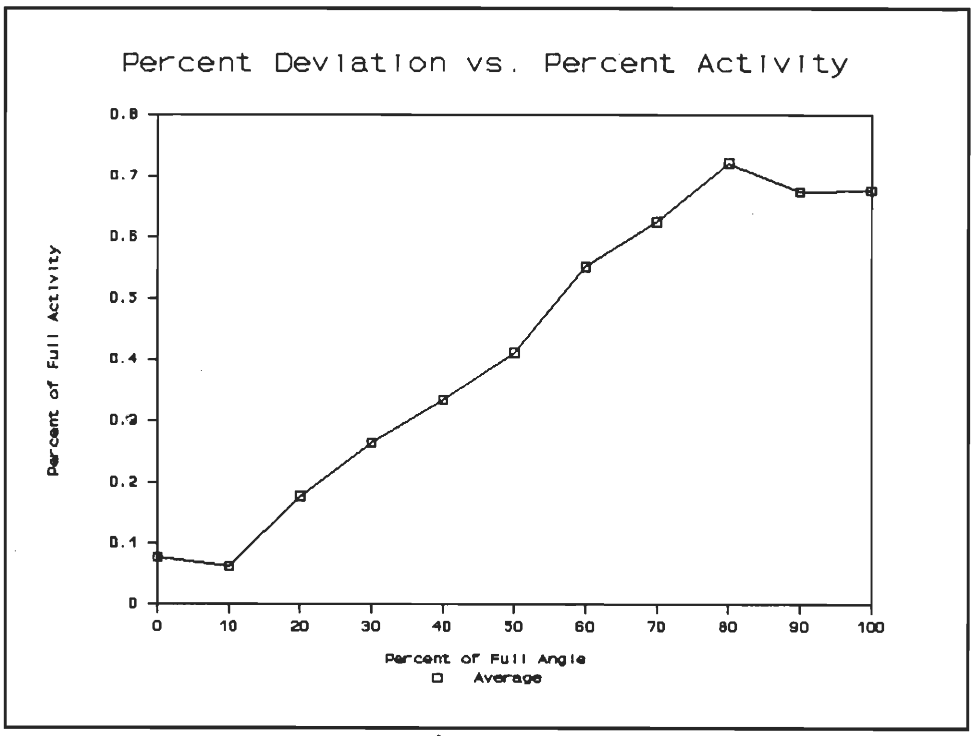


Figure 4

Conclusion

Deviated wrist postures should be avoided whenever possible. When deviating without applying a force the amount of muscle activity increases with the square of the angle. When a person is deviating while applying a force, the muscle activity increases linearly. These relationships can be applied to industrial settings. During this project, more data was collected than analyzed. Each of the wrist postures could be analyzed in order to determine a mathematical relationship for each.

Future research could also look at any number of variables including: differences between men and women, differences between large people and small people, and differences in activity depending on shoulder angle. In short, muscle activity is directly related to angle of wrist movement. This relationship is dependent on the type of movement being performed.

Appendix A

Motions Studied

Motions Studied

The various wrist deviations and hand postures are arranged into five groups depending on the apparatus needed to perform the motion and/or grasp, and on the subject's location required to perform the variable. The following is a listing of each group, the independent variables within that group, and the specific instructions explaining subject placement and variable performance. For an illustration of the motions, see the figures at the end of this appendix. The arrangement of the groups was randomized, but the four motions within the group were not. This was done in order to organize data collection on the Sun system. If all files were random, data collection would take much longer and the correct recording of the data would be questionable.

Groups

Group 1

1. Group 1-The subject is seated in a chair with the right hand/forearm resting on a table parallel to the floor. Each variable is repeated a total of 5 times. Data is collected for a twenty second period. There is a baseline collection during the first two seconds of data collection. The subject is asked to flex and hold the posture for approximately two seconds. The researcher tried to assure that exactly five repetitions were performed during the twenty second period. The subject's hand must always start and end in the neutral position. Each motion

is held for two seconds before releasing to the neutral position. After all four variables have been performed **(see table below)**, a rest period of one minute is given.

Critical Wrist Deviations Under Study
Passive Motions (no force)

1. Neutral to full Flexion
2. Neutral to full Extension
3. Neutral to full Ulnar Deviation
4. Neutral to full Radial Deviation

Group 2

2. Group 2-The subject is seated in a chair with the forearm resting on a block parallel to the floor. With the wrist in a neutral position, and with the hand dynamometer in the appropriate position, a grasp is exerted to 10 kg. The subject is asked to grip a dynamometer for approximately 30 seconds to get a feel for how hard he/she has to press to maintain a 10 kg. grip. Next the dynamometer is replaced with a tennis ball for the large grip and a flat sheet of rubber for the small grip. The actual dynamometer was not used during data collection because it produces a glare to the collection camera. The subject is asked to relax for the first ten seconds of data collection. Then the subject is asked to hold the 10 kg grip for the last ten seconds of data collection. The same directions involving randomness, repetitions, and holding time apply. A rest period of 1 minute is given after the two variables are performed (i.e. at the end of the group) **(see**

table below).

Critical Wrist Deviations Under Study
Inactive Motions (with force of 10 kg)

GRIP ONLY-WRIST IN NEURAL POSITION
5. Medial Grasp, Grip #1
6. Palm Pinch, Grip #3

Group 3

3. Group 3-The subject is seated with his/her forearm resting parallel to the floor. Again the motions are repeated in repetitions of five. A rest period of 20 seconds is given between repetitions of the two variables. There will be two variables, 20 seconds of rest, two variables, 20 seconds of rest, two variables, 20 seconds of rest, and two variables (see table below).

Critical Wrist Deviations Under Study
Active Motions (with force of 10 kg)

GRIP PLUS WRIST DEVIATION
7. Neutral to Full Flexion, Grip #1
8. Neutral to Full Extension, Grip #1
9. Neutral to Full Ulnar Deviation, Grip #1
10. Neutral to Full Radial Deviation, Grip #1
11. Neutral to Full Flexion, Grip #3
12. Neural to Full Extension, Grip #3
13. Neutral to Full Ulnar Deviation, Grip #1
14. Neutral to Full Radial Deviation, Grip #3

Group 4

4. Group 4-The subject is seated with his/her forearm resting parallel to the floor. Both variables are performed in repetitions of 5 as stated earlier. A rest period of 20 seconds is given between repetitions of two variables. There will be two variables, 20 seconds of rest, two variables, 20 seconds of rest, two variables, 20 seconds of rest, and two variables (see table below).

Critical Wrist Deviations Under Study

15. Resting Baseline
17. Neutral to 10 degree Flexion
18. Neutral to 10 degree Extension
19. Neutral to 10 degree Ulnar Deviation
20. Neutral to 10 degree Radial Deviation
21. Neutral to 20 degree Flexion
22. Neural to 20 degree Extension
23. Neutral to 20 degree Ulnar Deviation
24. Neutral to 20 degree Radial Deviation

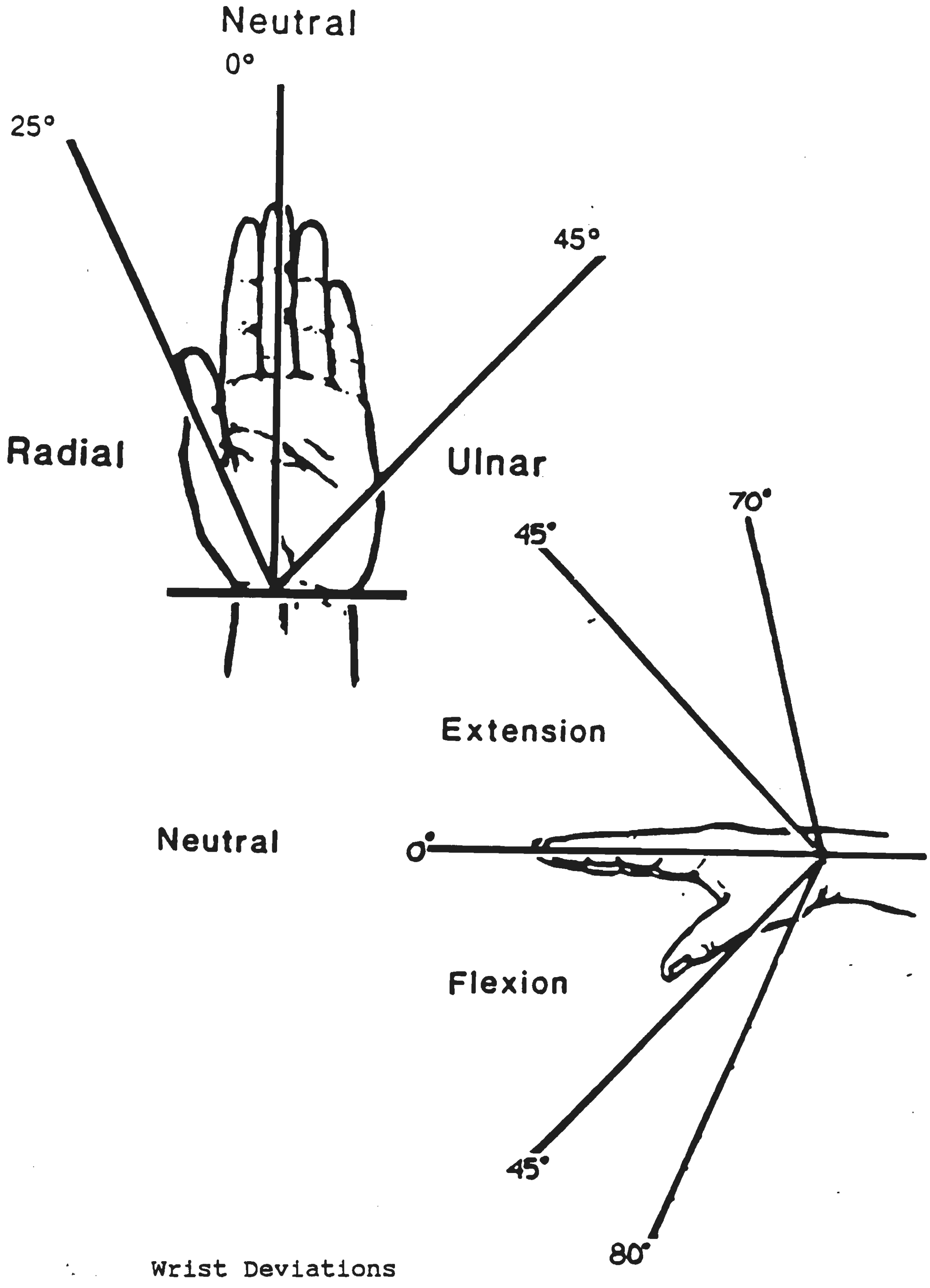
Group 5

5. The setup is the same for group 4. Test number 29 involves the subject simply relaxing his/her arm for 20 seconds. The load being pulled is a nearly perfectly elastic strip of fabric. The force being pulled is minimal.

Critical Wrist Deviations Under Study

25. Neutral to Full Flexion Pulling a Load
26. Neutral to Full Extension Pulling a Load
27. Neutral to Full Ulnar Deviation Pulling a Load
28. Neutral to Full Radial Deviation Pulling a Load
29. Resting Baseline

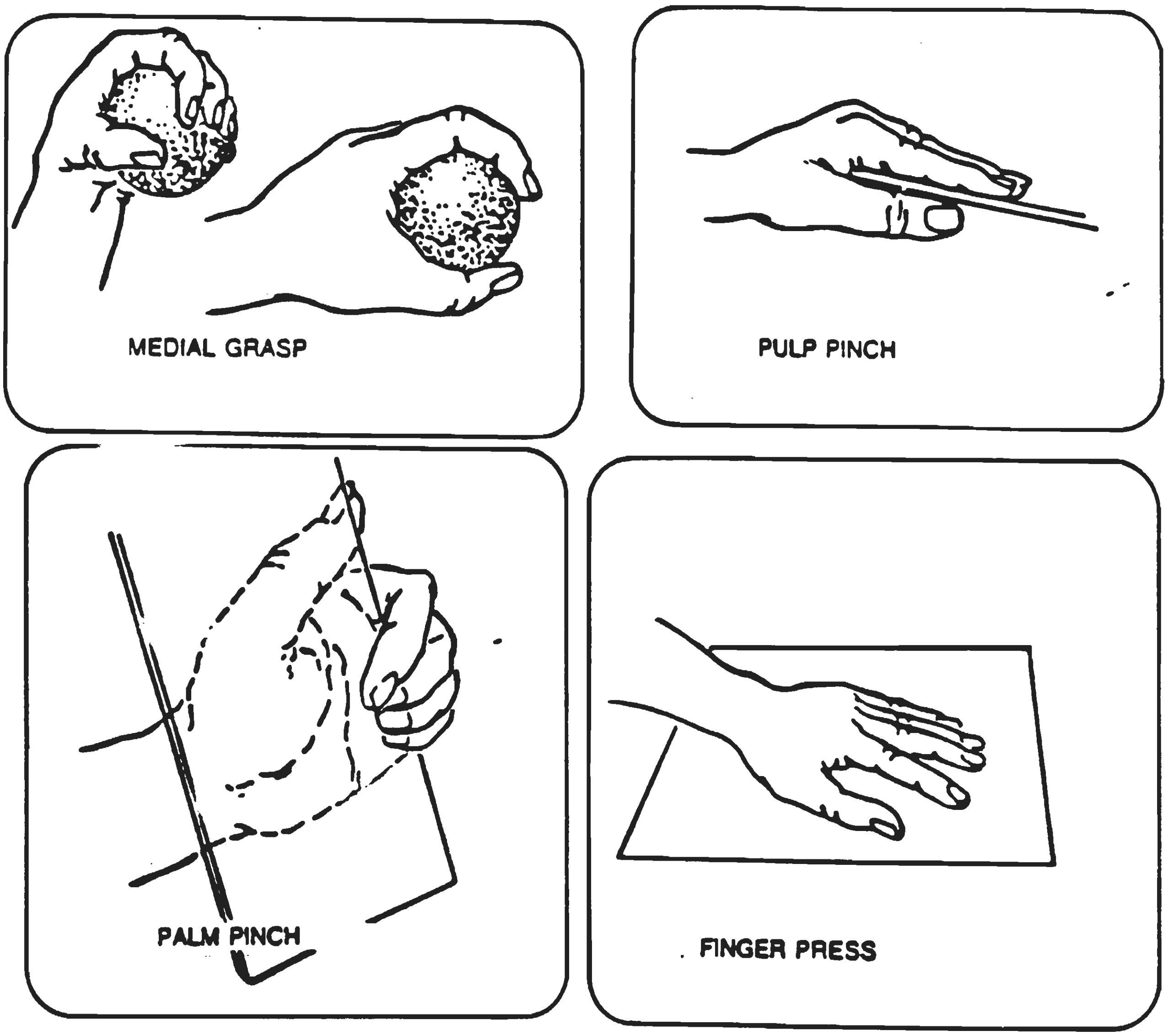
Figure 1



Wrist Deviations

Source: Vern Putz-Anderson (Eds.). (1988). Cumulative trauma disorders: A manual for musculoskeletal diseases of the upper limbs. London: Taylor & Francis.

Figure 2



Hand Formations

Source: Vern Putz-Anderson (Eds.). (1988). Cumulative trauma disorders: A manual for musculoskeletal diseases of the upper limbs. London: Taylor & Francis.

Appendix B

Human Subjects Review Board

Recruitment

The subjects will be students and faculty here at WMU. Recruitment will be conducted among people that I, Joe Kaczmar, know. The most likely class of people will be male students between the ages of 19 to 23 years old.

RECRUITMENT SCRIPT

Hi, how are you today? As you know, my name is Joe Kaczmar. You may not know that I am conducting research in the field of cumulative trauma disorders. I am looking for people to volunteer approximately one hour of their time for the researcher, me, to collect data from them. Participation in this research project is completely voluntary. The subject may discontinue participation at any time for any reason. Also, if any discomfort is felt, the subject may discontinue participation. Participation or refusal to participate will in no way involve penalties of any kind nor will it in no way affect the grades of students. If you are not interested at all, please tell me now. If you are interested, I will explain in detail what the commitment involves.

The research involves a time commitment of approximately 1 hour. There will be approximately 15 minutes of instruction with 45 minutes of testing. The testing involves flexing your wrist in this manner (visual demonstration) or this manner for a total of 60 times. For most of the flexes, you will be pushing against a weight of 10 kilograms. I can show you all of the details and rest periods of the motions right now if you would like (I can show Appendix A). There are no benefits for the subject, other than helping the advancement of science. Confidentiality of records will be maintained by the issuance of an identification number to all subjects prior to experimentation. Subjects will only be identified by that number, his/her age, and sex. The experiment will solely involve the study of wrist movements. The purpose of this research is to find a mathematical relationship between wrist movements and the amount of muscle stress used to control the motions of the hand. The above mentioned relationship can be applied before an employee ever starts working on a particular job. While creating a job, an engineer will have a relationship which will determine how stressful a motion will be. The alternative is to let someone work at a job and wait to see if the activity will do harm to that person. The research will use EMG (surface electrodes) to collect muscle activity data at various hand positions. These surface electrodes are commonly used in clinics and pose no danger to the subjects. Also, motion analysis equipment will be used to gather information on how far the hand has moved. The motion analysis equipment involves placing a sticky reflector on the subject's hand. All experiments will be conducted in a lab located in Kohrman hall.

Informed Consent

A variety of wrist deviations and hand positions involving varying forces can be encountered during manual work. Particular motions are more stressful to the wrist and hand than others. Repetitive and forceful motions of the hand and wrist, over a significant period of time, may cause a disorder such as Carpal Tunnel Syndrome (CTS).

This research is aimed at identifying the stress caused by various deviations of the wrist and hand. Stress levels can be measured through the attachment of surface electrodes to the forearm flexor muscles which pass through the carpal tunnel of the wrist. As a specific motion is performed (ie. grasp, pinch), an ECG reading can be recorded. An analysis can then be made to compare the various motions and associated stress levels. Subjects in this research project will be instructed to perform various wrist deviations and hand positions.

Participation will involve a time commitment of less than 1.5 hours which will include approximately 15 minutes of instruction and 45 minutes of testing. Exact motions to be performed can be found in Appendix A (see Appendix A).

Once specific hand and wrist positions have been identified as stressful, industrial tasks can be designed and/or modified to minimize the occurrence of such exertions. A reduction of employee trauma, may be the result.

There are no foreseeable risks to a subject participating in this research. Due to the limited hand and wrist motions performed and the minimal forces involved, there is no risk of developing CTS. The ECG procedure is of common practice in clinical settings, and presents no risk to the participant.

Confidentiality of records will be maintained by the issuance of an identification number to all subjects prior to experimentation. Subjects will only be identified by that number, his/her age, and sex.

Any questions regarding the research, its purpose and intent or subject rights can be forwarded to:

Joe Kaczmar - Principle Investigator 387-9684
Dr. B. White - Faculty Advisor 387-3745

Participation in this research project is completely voluntary. The subject may discontinue participation at any time. Participation or refusal to participate will in no way involve penalties of any kind or will in no way affect grades of students.

Subject ____________________ Date ______________
Witness ____________________ Date ______________

This form taken from the M.S.I.E. (1990) research of Karen Kleinfeld with some modifications.

Human Subjects Approval Letter

Human Subjects Institutional Review Board

Kalamazoo, Michigan 49008-3899

WESTERN MICHIGAN UNIVERSITY

Date: December 11, 1991

To: Joseph Kaczmar

From: Mary Anne Bunda, Chair *Mary Anne Bunda*

Re: HSIRB Project Number 91-11-02

This letter will serve as confirmation that your research protocol, "A system to predict muscle stress of the wrist" has been approved after full review by the HSIRB. The conditions and duration of this approval are specified in the Policies of Western Michigan University. You may now begin to implement the research as described in the approval application.

You must seek reapproval for any change in this design. You must also seek reapproval if the project extends beyond the termination date.

The Board wishes you success in the pursuit of your research goals.

xc: White, Engineering

Approval Termination: December 11, 1992

Appendix C

Using Motion Analysis Equipment

Contacts

The researcher spent approximately 60 hours performing equipment set up. The researcher dealt often with the Motion Analysis corporation. There are several key contact people within the company.

Location	Phone Number
Motion Analysis Corporation	1-800-733-6746
Motion Analysis FAX	(707) 526-0629

The following people were helpful in gathering information Ravi (a programmer) and John Greaves. Mr. Jerry Sherman was not helpful.

Phone Calls from Lab

If a person working in the lab needs to make a call to an outside line, he/she needs to perform the following instructions:

1. Call the department office (industrial engineering office)
2. Have the receptionist perform the following steps
    a. push transfer
    b. dial the off campus number
    c. ask for the person on the other end
    d. press transfer again
    e. have the receptionist say good bye to the researcher
3. As soon as the person in the lab hears the receptionist say

good bye and hang up, he/she is connected to the outside caller.

Collecting Data Using VAC

On the Motion Analysis Equipment there are two ways to collect video data. One method uses the "mev" command. This command collects video data only. The other command uses the **V**ideo **A**nalog **C**ollection system (**VAC**). This system can collect video data, analog data, or simultaneous video and analog data. In this research project, simultaneous video/analog data was collected using the VAC module. The procedures to collect data are outlined below.

Rebooting

First login as root on the Sun and type the word "reboot." The system needs to be rebooted before data collection. The password for the root user is "ergo." If the system is not rebooted, the personal computer used to collect the analog data will print the error message "can't open data" immediately after collecting the data.

PC/Analog Setup

After waiting for the Sun to return to the "login:" prompt, turn the PC on and let it boot. On the PC at the C> prompt, type the word "ads." This command will start up the collection system on the PC. When the software starts, type "e" for execute and then type "r" for remote. This puts the PC in a mode ready to receive instructions from the Sun on how to collect data.

Sun/Analog Setup

Next login into the Sun system. If the user does not have a personal account, he/she can use the login name "evdemo." This account is not password protected. The login screen should have a grey background. Next the user needs to type the word "sunview." After a few seconds, the window operating program will appear on the Sun workstation. Next the user needs to type the word "vac." This will bring up the VAC system. The VAC system is window driven and is fairly user friendly. An error message may appear stating: "Note: ADS system is not connected or responding." This message means that the user has not set up the PC to receive instructions from the Sun workstation. If this message appears, click the LEFT mouse button on the word "OK."

Use the left mouse button to select the directory where the data collection should take place. Next use the left mouse button to select the setup option. The setup used in this experiment is called "wrst." The user can create his/her own setup file. The entire screen is mouse driven. Most commands are run using the left mouse button.

Analog Options

Several simple commands control the analog data collection. There is a time selection for both the analog and video data under the setup option. The trace column on this screen shows in what row the data will be displayed on the PC during collection. The column titled "size" did not have any bearing on the research project and was set to one. The name column is used to provide a location to save the analog data. **Every channel that is collecting and saving data has to have a NAME.** If the analog channel does not have a name, no data will be collected. In this experiment, the two EMG channels were called "right" and "left." The gain command tells the analog system, what voltage range the data will be. The "ADS drive" command allows the user to collect the data on the Sun, the A:, B:, or C: drive on the PC. For this research project, the data was collected on the Sun. After the appropriate setup is created, the user can save the setup by clicking on the save command with the left mouse button. **The final command that has to be run on this screen is clicking the ACTIVATE command with the left mouse button.** The ACTIVATE command must be clicked before the data collection session. If the user forgets to click the activate button, the VAC system will warn him. This command downloads the collection instructions to the PC. Next the user should use the left mouse button to click on the exit setup command.

VP320 Setup

The video processor must be set up prior to starting data collection. In order to collect video and analog data simultaneously, the following setup procedure must be followed on the VP320 video processor.

1. Turn on the processor, camera, and monitor.
2. Press the Send Mode/"Event 1" switch (text written in blue)
3. Press the yellow set up button (the set up light should be blinking)
4. While in setup mode, press the "Event Select" button (text written in green) until the display shows a "3"
5. Press the "Camera/VCR Enable;2" until the camera display for camera/VCR #2 is off. In the Camera/VCR bank of indicator lights, only the camera 1 light should be lit.
6. Depress the yellow setup button again. The setup light should go off.
7. Turn on the spot light located next to the camera
8. Place a reflector in the view of the camera with the light source on.
9. Adjust the "Threshold" knob until the only highlighted image is the Motion Analysis reflector. Throughout the data collection, make sure that the equipment is not picking up reflections off of watches, rings, or the table.
10. To view just the outline of the reflector press the "Video" button (text in blue).

VP320 Useful Features

There are several features on the video processor which can be helpful, but are not essential to the operation of the equipment. First, one can adjust the active viewing area of the screen. In other words, if a reflector is outside of the active viewing area, the video processor will not recognize it as an image to track. The user needs to perform the following steps in order to adjust the active area: First press one of the four "Set Window" buttons on the front of the processor. Second adjust the threshold and watch the borders change. This function can be used to eliminate video noise.

During this project, a sampling rate of 30 frames per second was used. The sampling rate can be adjusted by pressing the sampling rate "+" and "-" buttons.

Starting Data Collection

At the main VAC screen on the Sun, the user should click the left mouse button on the "Data Collect" option. Using the left mouse button on the next/previous command alternates the file collection number. The three numbers at the end of a video file name stand for the following: the two right digits are the file extension; the last digit stands for the camera number. For example the file wrst021.vid means the file name is wrst, the file number is 02, and the camera used is camera 1. All analog files have a ".ana" extension, and all video files have a ".vid" extension. Video data collection is begun by clicking the left mouse button on the "NOW/Trigger on Event 1." Analog collection is begun by clicking the left mouse button on "Trigger on Event 1." As stated above either analog or video data or both can be collected. The "Preview" button previews the analog data on the PC. All commands sent from the Sun to the PC are conducted through a serial cable. All information going from the PC to the Sun is sent through an Ethernet cable. If the Sun is able to communicate with the PC, but the PC cannot communicate with the Sun, the serial cable is working, but the Ethernet network in not.

Now the data collection will begin as soon as the Event 1 terminals on the Motion Analysis MP280 are grounded together. This grounding can be achieved by wiring a push button to the terminals or by wiring a photocell to these terminals. This project used a doorbell button as the triggering device.

Aborting/Leaving Data Collection

If the user needs to abort data collection after the Trigger's have been clicked with the mouse, the user needs to use the right mouse button. The user needs to go to the bottom of the VAC screen and hold the right mouse button. While still holding the button move to the option "quit." Release the button, and then use the left mouse button to click on the word "Confirm." To exit the rest of the way, follow the instructions on the screen. The above procedure should be followed when the data collection session is completed.

Errors in the System

On several occasions while exiting in the above manner, the Sun produced a Data Fault/Panic. This means that the Sun is dumping its memory into a file called "core." Next the Sun reboots itself. There is no explanation for this error. This error has occurred at random times. If it does occur, wait for the Sun to reboot and login again. The user should go to the directory he/she was working. Next he/she should type the command "ls" to list the files in the directory. If a "core" file exists, it should be removed by typing the command "rm core." If left, this file does not cause any problems but is a rather large file taking up valuable disk space.

As was discussed earlier, the PC will not send data to the

Sun unless the Sun is rebooted first. The research never asked Motion Analysis for a solution to this problem.

Network Maintenance

Network Not Working

If an error or NFS message is displayed while the PC is booting up, then the network is not working. One of these error messages is NFS Error message #18. If this condition occurs, the network software needs to be reinstalled. Data transfer from the PC to the Sun goes through a network (an Ethernet network). If the above mentioned problem occurs, the user must perform the following steps:

1. Copy the autoexec.bak file to the autoexec.bat file
2. Copy the config.bak file to the config.sys file
3. Install the PC-NFS software. This is done by inserting the first disk of the software into the "A" drive of the PC. At the A prompt type the word "install." The software will guide the user. The following two choices need to be made: the network type is ethernet and the user should not update the software.

Using Word Perfect/Lotus

In order to run Word Perfect or Lotus, the network software must be disabled. Much of the computer's memory is taken up by the network. There is not enough memory to keep Word Perfect and the network on line at the same time. Disabling the network is done by copying the following files: autoexec.wp to the autoexec.bat and the config.wp to the config.sys file. When the user needs to use the network again, he/she will have to perform the instructions found in the section titled "Network Not Working." The following software has been used on the PC: Word Perfect, Lotus, STORM, and an antivirus program.

Analyzing Data in the Expert Vision System

After data collection is complete, the user needs to use an analysis program called "Expert Vision." There are several commands in UNIX (the disk operating system) which are helpful to know while using the Expert Vision System.

UNIX

The disk operating system used by the Sun Workstation is called UNIX. This system is different from "DOS" used on personal computers. Below is a list of useful commands. Data must be moved through UNIX in order to analyze it.

UNIX Commands

<table>
<tr><th>Command</th><th>Description</th></tr>
<tr><td>put directory name</td><td>this command archives the named directory onto a backup tape</td></tr>
<tr><td>ls</td><td>displays the short form of a directory</td></tr>
<tr><td>ls -lt</td><td>displays the long form of the current directory</td></tr>
<tr><td>ls -lt|more</td><td>displays directory one screen at a time</td></tr>
<tr><td>ls -lt>filename</td><td>lists the current directory into the named file. This file can later be printed.</td></tr>
<tr><td>pwd</td><td>print the current directory to the screen (print working directory)</td></tr>
<tr><td>rm filename</td><td>removes (deletes) the named file</td></tr>
<tr><td>rm -r directory</td><td>removes the named directory</td></tr>
<tr><td>date</td><td>displays the current date and time</td></tr>
<tr><td>passwd</td><td>allows the user to set his/her pass word</td></tr>
<tr><td>cd ..</td><td>changes directory to the next highest level</td></tr>
<tr><td>cd directory name</td><td>changes the current directory to the named directory</td></tr>
<tr><td>mkdir directory name</td><td>creates the named directory</td></tr>
<tr><td>lpr filename</td><td>sends the named file to the line printer</td></tr>
<tr><td>lpq</td><td>displays the current status of the line printer</td></tr>
<tr><td>cancel job number</td><td>after running the lpq command, the cancel command can be run to cancel a print job in the queue</td></tr>
</table>

Data Manipulation in Expert Vision

Several steps must be followed in order to convert the video and analog data into a usable form on the Sun. First the programmer needs to use the "cd directory-name" command to change the directory to the location of the data. Next type the command "ev." Note to run UNIX commands in the "ev" software, one can precede the UNIX command by an "!." For example while in ev, the command "!ls" will provide a listing of all of the files in the directory. A summary of the commands discussed on the following pages can be found in appendix H.

Video Data on the Sun

To convert raw video data into a usable form, several steps must be taken. The commands listed below need to be executed. The example below assumes the file to analyzed is titled: wrst011.vid.

1. cent wrst011.vid
2. path
3. @angle wrst011 1 2 3

4 a. list/re wrst011.an2

4 b. /home/evdata/wrst011.an2

Step one converts each image into its centroid. When prompted to enter analysis values, simply hit return to accept the default values. Step two connects each of the centroids. Step two may have to be typed twice if an error message is given on the first try. Please note that each command can be followed by the filename. In the example, the default file name is taken in step two if step two is preceded by step one. Step three calculates the angle between three points. Step 4a lists the newly created angle data into a file in ASCII form. When prompted for the output file, one should type step 4b. **The directory /home/evdata on the Sun is seen as the g: drive on the personal computer.** Any data listed into home/evdata can be used by the personal computer. The list/re command converts the file into standard ASCII characters and places the output in the named file. To view the data, type the command "list" and then the file name. To view a plot of the data, type the command "plot" and then the file name. To produce a hard copy of the screen, type the command "hdcp."

Analog Data on the Sun

Two steps must be followed in order to convert analog data into a usable form. This example assumes that the file is titled "wrst01.ana." Type the following commands as written while in the ev software package (blue background)

1. read wrst01.ana

2 a. list/re

2 b. /home/evdata/wrst01.ats

When an analog file has been "read," it is converted from the .ana extension to the .ats extension. Files with the .ats extension can be plotted out. Files with the .ana extension are written in code. After executing commands 2a and 2b, the file wrst01.ats will appear in the /home/evdata/ directory on the Sun and also on the g: drive on the pc. This file is listed in standard ASCII characters.

Analysis on the Personal Computer

There are several steps which must be followed in order to convert the data into a usable format on the personal computer. First the user must retrieve the data files into Word Perfect from the g: drive. Then using the text out command in Word Perfect, the file should be saved as Dos Text. Next the user should go into Lotus and use the "/File Import Numbers" command in order to import the data. Now the data can be analyzed in Lotus or exported to another statistical package.

Appendix D

Calibration and Location of Data

Calibration

Calibration readings were taken in case they are needed at a later time. The file was saved under the name /home/kaz/wrist/20cen011.vid and contains an image of two reflectors 20 centimeters apart. Likewise the file 30cen011.vid contains the image of two reflectors 30 centimeters apart.

Naming Convention

The directory /home/kaz/wrist/1/*.* contains all of the files collected on subject one. Within that directory each of the motions are recorded under the file name "wrst." For example, the file wrst011.vid contains the video data for the first motion. The file wrst01.ana contains corresponding analog data for both channels for the first motion. The first four subjects contain data on the first 14 motions, and subjects 5 through 14 contain all 28 of the motions.

Appendix E

Subject Description

Description of Subjects

ID #	Sex	Age	R/L Hand
1	M	21	R
2	M	22	R
3	F	27	R
4	M	22	R
5	M	23	R
6	M	24	R
7	F	21	R
8	M	45	R
9	M	22	R
10	F	21	R
11	F	31	R
12	M	22	R
13	M	22	R
14	M	41	R

Appendix F

Storm Regression

Wrist01 (Storm Analysis)

REGRESSION FUNCTION & ANOVA FOR WRST01 ACT

WRST01 ACT = 0.954032 - 0.040046 WRST01 ANG + 0.000413 ANG01 SQRD

R-Squared = 0.985526
Adjusted R-Squared = 0.982894
Standard error of estimate = 0.041731
Number of cases used = 14

Analysis of Variance

Source	SS	df	MS	F Value	Sig Prob
Regression	1.30429	2	0.65215	374.48030	0.000000
Residual	0.01916	11	0.00174		
Total	1.32345	13			

Wrist25 (Storm Analysis)

REGRESSION FUNCTION & ANOVA FOR WRST25 ACT

WRST25 ACT = 0.051636 + 0.007278 WRST25 ANG

R-Squared	= 0.947323
Adjusted R-Squared	= 0.94147
Standard error of estimate	= 0.060001
Number of cases used	= 11

Analysis of Variance

Source	SS	df	MS	F Value	Sig Prob
Regression	0.58269	1	0.58269	161.85120	0.000000
Residual	0.03240	9	0.00360		
Total	0.61509	10			

Appendix G

Trouble Shooting Guide

Appendix H

Useful Expert Vision Commands

Command	Description	Page
!	used to precede UNIX commands	34
cent	used to calculate the centroid of an image	34
path	used to calculate the path of a series of centroids (follows the centroid command)	34
@angle	calculates the two dimensional angle between three points	34
list	displays data in a file on the screen	34
list/re	lists data in ASCII format into a file	34
plot	produces a graph on the screen of the data in a file	35
hdcp	prints a hard copy of the named file	35
read	converts analog files into ASCII form	35