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Maria J. Qadri
University of Connecticut, maria.qadri@gmail.com

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Noninvasive Assessment of Joint Motion Over Long Durations: System Evaluation and Data Analysis Methods

Maria Jamal Qadri

B.S., University of Hartford, 2009

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APPROVAL PAGE

Master of Science Thesis

Noninvasive Assessment of Joint Motion Over Long Durations: System Evaluation and Data Analysis Methods

Presented by

Maria Jamal Qadri, B.S.

Major Advisor _____

Donald R. Peterson

Associate Advisor _____

Anthony J. Brammer

Associate Advisor _____

Martin G. Cherniack

Associate Advisor _____

Nicholas Warren

University of Connecticut

2011

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Abstract

The development, progression, and treatment of degenerative musculoskeletal diseases, such as carpal tunnel and shoulder impingement syndromes, may be better characterized when joint motions are assessed over long durations outside clinical, laboratory, or rehabilitation settings that involve standardized assessment, exercise protocols, and/or regimented movements. Assessment methods for human movement capture beyond laboratory or clinical experiments are typically limited to short capture times of less than one hour. Noninvasive, long-duration measurements of joint motion in occupational settings provides more insight into movement patterns and quantitative assessments regarding joint usage, which lead to a better understanding of the cumulative effects associated with repetitive joint motions.

A small, autonomous data logging system using several bi-axial electrogoniometers has been developed to record three-dimensional joint motions over long durations of eight or more hours (Bernstein, 2008). The system was used for measurements of the wrists and shoulders to better characterize upper extremity musculoskeletal behaviors across multiple work sites. While the system had been previously constructed, field use of the data logging system and data analysis remained unexplored. The development of the system for practical field use, including sensor placement, data processing, and validation of captured joint movement, was the objective of this thesis.

Fully analyzed wrist data, comparing field subjects completing identical tasks and different tasks at three different work sites, clearly identified variations in joint motion. Results indicate that progressive changes in motion patterns can be identified using frequency distribution histograms. Significant differences in measured motion exist

between the electrogoniometer system and an observational motion analysis method that indicate the estimation of joint movement patterns from select durations within the work-day captured is less than 20% of the time exceeding ergonomic thresholds. Also, a difference of 10% to 20% between the results of the two motion assessment methods occurs within the selected durations.

The information regarding the wrist can be analyzed without translational issues, but the complexity of the shoulder required more research to properly translate the voltage response of the electrogoniometer into shoulder position. To clearly correlate human shoulder movement and sensor response, an experiment was conducted with ten known regions of angular deviation within a range of 0° to 90° flexion and 0° to 90° abduction. The accuracy of prediction of human shoulder movement based on electrogoniometer response was limited to less than 80% within the ten selected regions.

Further analysis of the existing long-duration field data on over 200 subjects will lead to the development of normal and abnormal motion pattern definitions. The quantification of variations in joint motions between subjects during work tasks can assist in identifying occupational risks.

1. Introduction

Musculoskeletal disorders, such as joint pain, nerve compression, and tendon inflammation, are the single largest category of work-related illness and can severely limit worker efficiency and the working lifespan. According to the National Institutes of Occupational Safety and Health (NIOSH), 32% of all injury and illness cases involving days away from work resulted from overexertion or repetitive motion, with 55% of these cases affecting the wrist and 7% affecting the shoulder (NIOSH, 1997). The collaborative project, *The Burden of Musculoskeletal Diseases*, estimates that more than 25% of the American population has a musculoskeletal condition requiring medical attention, and $849 billion is spent annually in direct and indirect cost for bone and joint health, which amounts to 7.7% of the gross domestic product (Jacobs, 2008). Established risk factors for musculoskeletal disease include repetition, forceful motions, vibration, and extreme postures (NIOSH). Monitoring the occurrence of risk factors during tasks can yield insights into the patterns of motion and aid in determining the level of associated risk.

The most frequently used methods to analyze repetitive motion in an occupational setting are based on qualitative observations by trained ergonomists or via worker surveys (Spielholz, 2001). Observational methods result in an estimated time for each body segment or joint within a broadly defined region. Observational tools lead to difficulties in reaching conclusions when comparing different studies and data sets because of the high variability in results between observers, which is caused by differences in previous experience and level of training (NIOSH, 1997). Other methods, such as optoelectronic or magnetic gyroscopic motion capture systems, have been shown to be more accurate than qualitative assessment methods, but these tools are often too bulky and difficult to implement in a real work environment and often violate workplace

safety and security requirements. In addition, equipment intensive measurements also require different analysis methods to produce informative data.

A portable data logger for long-duration biomechanical measurements had been created for field research at the University of Connecticut (Bernstein, 2008). Protocols for use and analysis routines to characterize the interpretation of these measurements are defined in this thesis. A method for long-duration joint motion capture in field settings should identify abnormal movement patterns. Joint motion measurements can potentially be used to determine excessive and repetitive joint stress and fatigue as well as aid in determining the risk of developing such disorders as carpal tunnel and shoulder impingement.

1.1 Anatomy of the Joints of Interest: Wrist and Shoulder

The wrist is defined as the region between the distal ends of the radius and ulna and the proximal end of the metacarpal bones of the hand (Hammer, 2007). Eight carpal bones, intracapsular and interosseous ligaments, and a triangular fibrocartilage complex are included in wrist region as well as a series of tendons proximal to the radio-carpal joint that form the carpal tunnel. While each of these components contributes to the anatomical structure of the wrist, postural deviations of the wrist are measured as the angle between anatomical structures on the dorsal surface of the hand and the forearm. The primary motions for the wrist are flexion and extension and radial and ulnar deviation. Pronation-supination is a primary motion of the elbow but is often attributed to the wrist.

The shoulder is considered the most mobile human joint, because the shoulder is four separate joints that include the acromioclavicular, glenohumeral, sternoclavicular, and the scapulothoracic joints (Hammer, 2007). Each joint has unique motion and

differentiable degrees of freedom. The overall shoulder complex is considered to have 3 degrees of freedom including flexion and extension, abduction and adduction, and internal and external rotation. A combination of flexion and extension and abduction and adduction is commonly termed forward flexion.

1.1.1 Relevant Musculoskeletal Disorders and Causes

Repetitive strain disorders are prevalent in workplaces that rely on repetitive motions on assembly lines and long hours of computer input. Repetitive Motion Disorder includes several conditions affecting the upper body and result in pain, muscle weakness, and other symptoms. According to the University of Missouri's Handbook of Disabilities, the root cause of these conditions are miniscule traumas to either a singular or a series of muscles, tendons, and nerves that occur in multiple instances over a significant period of time without allowing for adequate recovery (Standifer, 2001). Repetitive and awkward motions have been linked to repetitive motion conditions such as tendonitis. Prolonged and extreme postural deviations of joints have been defined as one of seven major risk factors for musculoskeletal disease. Recurrent and excessive joint deviations have been identified as a potential cause for shoulder and wrist musculoskeletal disorders (NIOSH, 1997).

When describing the shoulder conditions, the term "work related neck-shoulder disorders" is often used to describe an accumulation of traumas (Nordin, 2007). The most common conditions related to extreme or awkward postures include shoulder tendinitis, humeral tendonitis, thoracic outlet syndrome, and shoulder impingement.

Carpal tunnel is a musculoskeletal condition that has increased in the number of cases over the past 20 years. One of the likely thoughts for this increase of cases is the prevalence of personal computers and other hand held devices. The disorder is caused by

narrowing of the carpal tunnel cavity from inflammation and edema, which leads to impingement of the medial nerve impingement. Compression of the nerve leads to the symptoms of numbness, pain and weakness in the hand.

Musculoskeletal disorders can limit the range of motion of subjects and decrease the number of years that a subject can continue working productively without pain. To limit the damage to muscles, tendons, and ligaments, preventive intervention can be taken by occupational safety and health professionals. To determine patterns of risk and the need for such interventions, accurate measurement of human movement is necessary.

1.2 Current Methods of Joint Motion Capture

Several different observational and direct measurement techniques, for specific types of collection environments and objectives, exist for joint motion measurement. Manual goniometry can be accomplished using a universal goniometer held adjacent to the joints of interest while lined up to the appropriate reference points. This method requires a thorough understanding of human anatomy as well as the ability to palpate and identify physical markers. To accomplish accurate measurements, a subject must be in a static position for capture. The benefits are low cost and ease of capture; however, manual goniometry is not a viable method for capture while the subject is working.

Visual observations with pen and paper capture categorical measurements of postures within or exceeding thresholds during particular tasks over short periods of time. The Posture, Activity, Tools, and Handling (PATH) system, developed by Buchholz et al. (1996), characterizes ergonomic risk factors for work tasks with irregular cycles. By tracking the orientation of body segments along with tool usage and grip mechanisms, complex tasks and postures are simplified and given context. While observational techniques are relatively inexpensive and minimize interference on the task or

production, coding limitations generally require relatively monotonous jobs or multiple samples. Reliability is questionable due to limited observer training and point of reference uncertainties, which occur when a joint or segment moves within a plane that is indistinguishable to the observer. For example, if the observer is viewing the subject perpendicular to the saggital anatomical plane, abduction and adduction movements can be lost, because movement in the frontal anatomical plane is not captured. To increase reliability and limit variation, observational methods often use video capture to provide additional support. Video recording can provide improved data reliability and may allow for faster sampling periods with two-dimensional images, but point of reference uncertainties in the recording can become a problem, particularly if the video camera remains in a static position.

The most accurate and well known method of three-dimensional motion capture is optoelectronic motion capture. A minimum of two infrared video cameras with high frame rates are positioned to capture a three-dimensional space. Light-emitting diodes or retro-reflective semi-spheres serve as markers of anatomically significant landmarks. Each marker must be captured by at least two cameras at all times during the session to limit point of reference issues. To verify the visibility of each marker, a complex validation procedure must be accomplished before data capture is initiated. Some of the problems with optical systems are skin motion artifact, marker occlusion, and necessity for a large capture volume. This method of capture also requires a significant amount of equipment to be transported and re-calibrated outside a laboratory setting or the re-creation of the work environment within the laboratory. Depending on the analysis

performed on the data and the capture rate, optoelectronic capture may become more computationally intensive than observation.

Inertial and electromagnetic systems have been developed that use pulsed magnetic fields to identify marker positions within a three-dimensional space. Unlike optical motion capture methods, they are not affected by marker occlusion issues. The sensors for inertial systems are gyroscopes that measure rotation rates whereas the sensors for magnetic systems are more often low-frequency sensors measuring distances from a transmitting source. Despite the differences between the two systems, marker range remains a concern for both. Limitations of inertial and electromagnetic systems include interference from other electromagnetic fields, positional drift, accuracy, and large variations in performance at different temperatures.

Sensors for motion capture based on mechanical methods include electrogoniometers. Most mechanical motion sensors measure strain within a physical link spanning the joint of interest. Mechanical strain caused by movement is transduced into a corresponding voltage, using a wheat-stone bridge circuit, which is later converted into a angular displacement. Such sensors can measure translational motion in up to three axes as well as torsion or rotation depending on the sensor design. The limitations of electrogoniometers include restricted range of motion, cross-talk between the two channels of a sensor, and skin-sensor slippage. Comparing these restrictions with the benefits of an electrogoniometer system, which include ease of use, portability, relatively low cost, and high repeatability, electrogoniometers are more suited to capture continuous long-duration measurements.

1.3 Previous Research Work

Previously tested methods for quantifying human movement have determined correlations between various motion capture methods as well as identified the range of human movement for the shoulder and wrist joints. Kiran et al. (2010) tested the knee joint position using an electrogoniometer and two-dimensional video analysis in sitting and standing positions. The correlation between the two methods when used for standing is between 0.94 and 0.98, with a perfect positive correlation having a value of 1.00. Correlations for sitting experiments were much lower because a two-dimensional camera setup was used and set 10º away from the plane of motion. This limitation does not apply to three-dimensional video systems. Yen and Radwin (2000) demonstrated in their comparison between an observational analysis method and a spectral analysis of electrogoniometer data method that the two methods do not have a high correlation (0.53) for posture deviation whereas the two methods have a higher correlation (0.77) for sustained postures. The spectral analysis method used on the electrogoniometer data also resulted in the identification of frequencies within a movement cycle. The results show that spectral analysis is a viable method for extracting the root mean square deviation for posture deviation. Yen and Radwin were the most prominent researchers to have conducted electrogoniometer joint measurement tests in the field and presented their work in the literature. The collection included video recording and was limited to times of less than 75 minutes. Based on the length of collection times used in these and other motion capture studies, long-duration field data on human movement is not readily available for comparison.

An earlier study conducted by Yen and Radwin (1993) in a laboratory setting clearly identified spectral analysis techniques as a viable method to characterize

repetitive wrist motion in observation and electrogoniometer measurements. The movements of the subjects were restricted and each cycle of motion was delineated via break points within the task. Sequences were limited to a maximum of 15 minutes of data. Limiting the motions of human subjects during research studies is not possible when exploring natural movement patterns.

In a study conducted by Peterson (1999), measurements regarding finger and wrist movements during keyboarding typing were analyzed using excursion regions. Peterson used an optoelectronic motion capture system with six cameras with retroreflective markers place on the joints of interest in the hand. Using a method that mimics observational analysis, regions of motion that exceeded thresholds were defined as abnormal excursions and were assessed to yield clinically valuable motion information. Event time and area of each region was calculated in order to quantify the abnormality of each subject's movement, while area and percent area measurements yielded a measurement of intensity for each movement. The information captured was limited to the typing of two sentences and did not exceed more than a few minutes of total measurements. By using a similar analysis process and methodology, identification of abnormal motion within a longer capture time seemed possible and is the basis for this study.

2. Methods

2.1 Data Logger

A custom built data logger, which measured approximately 21 cm by 11 cm by 4.5 cm and was attached to the subject's waist during data capture, was constructed to monitor 10 sensor channels sampled at 2000 Hz (Bernstein, 2008). Eight AA rechargeable nickel-metal hydride batteries power the system, and the data is written to a two gigabyte secure digital card in a binary format. The data logger and battery pack is shown Figure 1. A functional block diagram of the circuitry of the data logger is shown in Figure 2, where the signal conditioning included anti-aliasing filtering.

Figure 1: Data Logger and Battery Pack

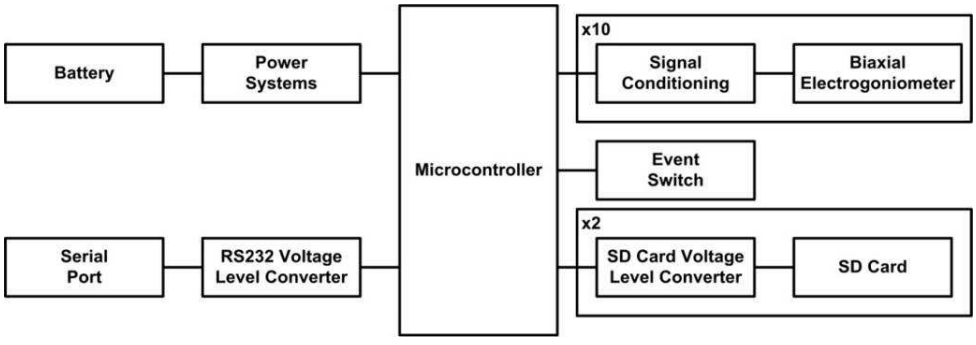


Figure 2: Block Diagram of Data Logger System

2.2 Sensors

Figure 3 shows a biaxial electrogoniometer (Biometrics LTD, Gwent, UK) that measures strain in a metal element that spans the joint of interest, with an accuracy of ±2°. Four biaxial sensors were used to monitor the movement of each wrist and shoulder joint for up to eight hours. The electrogoniometers used in the study included a large and small size for both joints, which was implemented based on subject size and availability of calibrated sensors. Once the sensors are mounted to the subject, the subject can work freely without the system intruding on their work space or observer intervention. Sensor performance was found to be unaffected when used under clothing and with most work gloves.

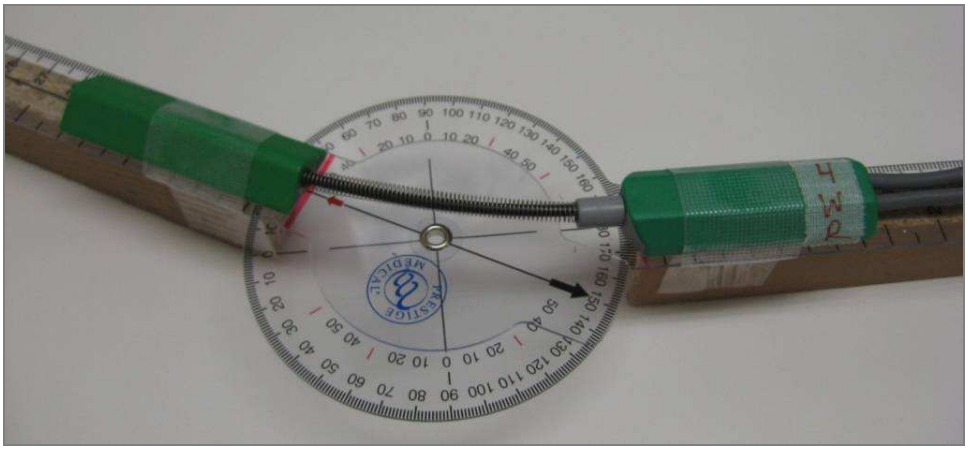


Figure 3: Electrogoniometer Mounted to Calibration Device

2.2.1 Sensor Calibration

Each sensor channel was calibrated using a precision manual goniometer, also seen in Figure 3, which is referred to as the on-table calibration. The voltage reading from each electrogoniometer was recorded after manual manipulation through seven angles from positive 90º to negative 90º in a random order prior to data collection using LabVIEW (National Instruments, Austin TX, v7.1). A linear regression based on the data

from the manual manipulation process was calculated to relate recorded voltage to angle. Errors that occurred during calibration were noted on the observer log sheets (see Appendix A.2).

Once the sensors were mounted upon each subject, a pre-specified series of movements were recorded for calibration of the sensors before and after each collection period. Movements were captured symmetrically across the sagittal anatomic plane and each position was held for at least five seconds. In between movements, the subject was requested to return to a resting position, which for the shoulder was 0º abduction/adduction with 0º flexion/extension and for the wrist was 0º flexion/extension and 0º radial/ulnar deviation with the shoulders at 90º forward flexion. The on-subject calibration routine positions included maximum achievable abduction with internal and external rotation, 90º of forward flexion, maximum achievable backward flexion, and neutral (90º abduction, 0º flexion/extension) for both shoulders. For the wrist calibration, the neutral position (0º flexion/extension, 0º radial/ulnar deviation) and maximum achievable extension, flexion, radial deviation, and ulnar deviation were captured for the wrist while the shoulders were at 90º of forward flexion. The event switch on the data logger was used to mark the occurrence of desired positions in the data.

2.2.2 Sensor Placement

Using a single biaxial goniometer, flexion and extension and radial and ulnar deviation motions of the wrist were quantified. For the wrist, the electrogoniometer was placed over and in line with the middle metacarpal and was in a neutral reference position when the hand was at 0º flexion/extension and 0º radial/ulnar deviation. The sensor was mounted using surgical tape in a manner that allowed the subject to achieve maximum flexion and extension as well as radial and ulnar deviation within the operating range of

the sensor. The joint deviation measurements were centered on the dorsal surface at the distal end of the radius and ulna at a midpoint between the radial styloid process and the ulnar styloid process. Figure 4 displays three of the mounting positions that were used to ensure full range of motion for the wrist is achievable.

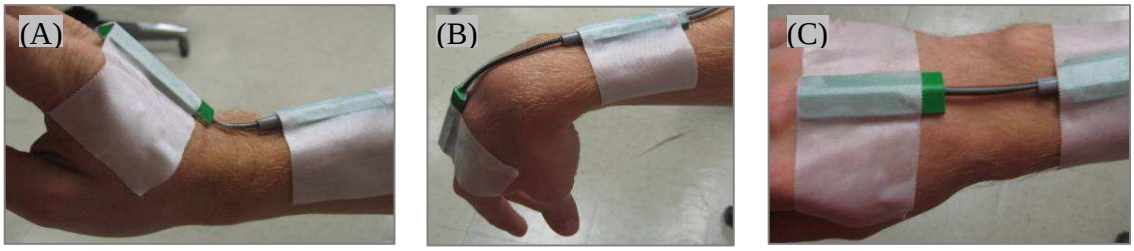


Figure 4: Mounted Sensor Flexibility and Positioning: A) Full Extension, B) Full Flexion, C) Dorsal View of Neutral Posture

Considering the complex motion of the shoulder joint and the placement of the sensor, a single biaxial electrogoniometer can only capture motion in two perpendicular planes. The center of joint deviation was placed above the head of the acromion. For placement on the shoulder, the electrogoniometer was mounted in a straight line when the arm is at 0º abduction/adduction and 0º flexion/extension. The sensor was in the neutral reference position when the arm is at 90º abduction with 0º flexion/extension and mounted in a manner that limits twisting and unnecessary strain.

2.3 Subjects

Across multiple research studies, the joint motions of 238 subjects have been collected using the electrogoniometer data logging system. The results of participants from three field sites, described in Table 1, that participated in the "Aging, Musculoskeletal Disorders, and Work Capacity Project" (NIOSH 5R01OH008929) were selected as exemplars. Subjects were excluded for irregularities in the data collection process, including, but not limited to, sensor disconnection, sensor breakage, low battery voltage of the data logger, or multiple files within data collection session.

Table 1: Descriptions of Selected Sites

Site 1	Paper Mill
Site 2	Tool Manufacturer
Site 3	Aerospace Component Manufacturer

For Site 1, the data for each subject were processed for full waveforms as well as separated observation windows. The analysis of an individual subject performing a packing task was highlighted, and average results of four subjects with the same job description were calculated. Also, the average of the 18 subjects from that particular site was also determined.

In addition, the results measured during six observation windows for two subjects performing identical tasks at Site 2 was compared along with three observation windows of three specific tasks at Site 3.

2.4 Field Usage Protocols

Each biaxial goniometer has two output channels, where each channel corresponds to a plane of motion. Each channel was calibrated to a particular data logger prior to initiating a field measurement because of the variability in the instrumentation amplifiers within the data logger. Acquisition protocols for field usage of the system required a minimum data collection time period of 90 minutes and a minimum of 2 PATH observation windows within each collection period. A stopwatch recorded the time of each visual observation window within the full capture period. The stopwatch time and event switch press was noted on the observer log (see Appendix A.1). During the capture of joint motion using the electrogoniometer data logging system, visual observational assessments were taken in 15-minute windows several times over the capture period as defined by the PATH protocol (see Appendix A.2). Postural assessments were taken at 30-second intervals to capture positional information for the

whole body, such as the neck position and elbow position. These joints and body postures are not measured by the electrogoniometer system. Special note was taken of glove type and use if the subject wore gloves. An event switch was pressed at the beginning and end of every PATH window as well as other notable events, including breaks, returning to work, sensor placement adjustment, etc.

Sensor breakage was noted during the calibration prior to field usage and cataloged to develop system lifetime estimates, which typically occurs due to mishandling or improper mounting. Component breakage was also cataloged, including breakage of the cables connecting the sensors to the data logger, the circuit components within the data logger, and detaching of the power connectors. These issues arose during normal use of the data loggers in a field setting. Other recorded data included the hours captured, corrupted data files, and segmented data files. Corruption and segmentation of the data files occurred due to software issues within the data logger or accidental removal of the SD card during normal usage of the data logger.

2.5 Data Analysis Process

The analysis routine was created in Matlab (Mathworks, Natick MA, 2010b), and the first step of the data analysis was the conversion of the data through various representations as is outlined in Figure 5.

The data output from the data logger is in a binary file format, which is converted into twelve ASCII files that represent the voltage output of the system by using a C-based program (Bernstein, 2008). The twelve files include 10 channel files, one event log file, and one information file. The information file contains the slope and intercept values measured during the on-table calibration regression performed with LabVIEW.

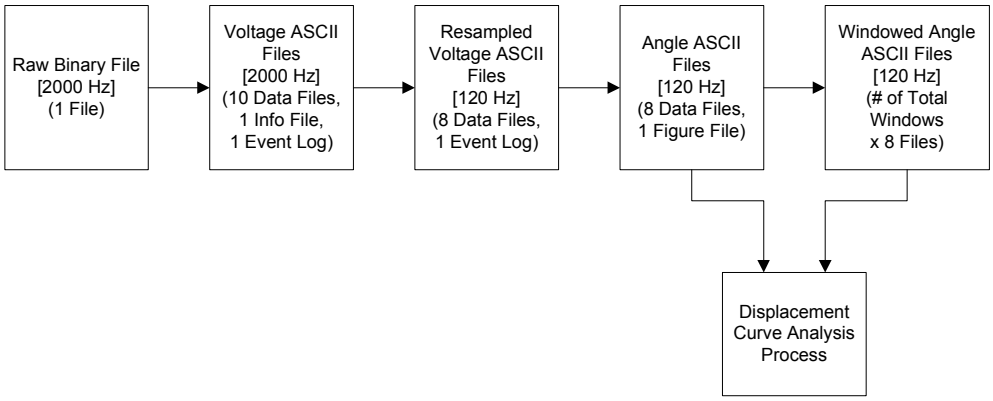


Figure 5: Data Analysis Process 1: File Conversion

After the data are converted to the ASCII data format, they were re-sampled from 2000 Hz to 120 Hz using a polyphase filter implementation with a 10th order least-squares linear-phase FIR filter and Kaiser windowing. Each sensor channel file then underwent a fast Fourier transform to identify the frequency components present in the signal. Any significant frequency spikes above 10 Hz indicated an error with the file (most often due to sensor breakage) and the absence of higher frequency spikes served as verification that the data were meaningful.

In the next step, the corresponding linear regression to each data file was applied, in order to translate the voltage response of the sensor into angular position. The second program of the analysis process, as seen in Figure 6, was applied after this step.

Each channel file was then cropped into the logged PATH windows via the use of an event marker. If the event marker was not present in the data but was recorded in the log sheet, it was artificially inserted into the data using the time reference. Each window was isolated in such a manner that ensured no loss of data. The second program in the data analysis process can also be applied after this step, as well (Figure 6).

Due to the lack of clarity of shoulder sensor behavior, the analyses performed in the second program of the analysis process were performed only on the wrist data. Once

the behavior of the shoulder sensor is accurately discerned, the subsequent data will be processed in an equivalent manner. The analysis was run on the full data capture files as well as on each isolated PATH window. Figure 6 shows the flow chart for the second data analysis program, which yields frequency distribution and excursion information (see Appendix A.3). This procedure is completed four times for the full data set per subject and then repeated four times for each windowed data set.

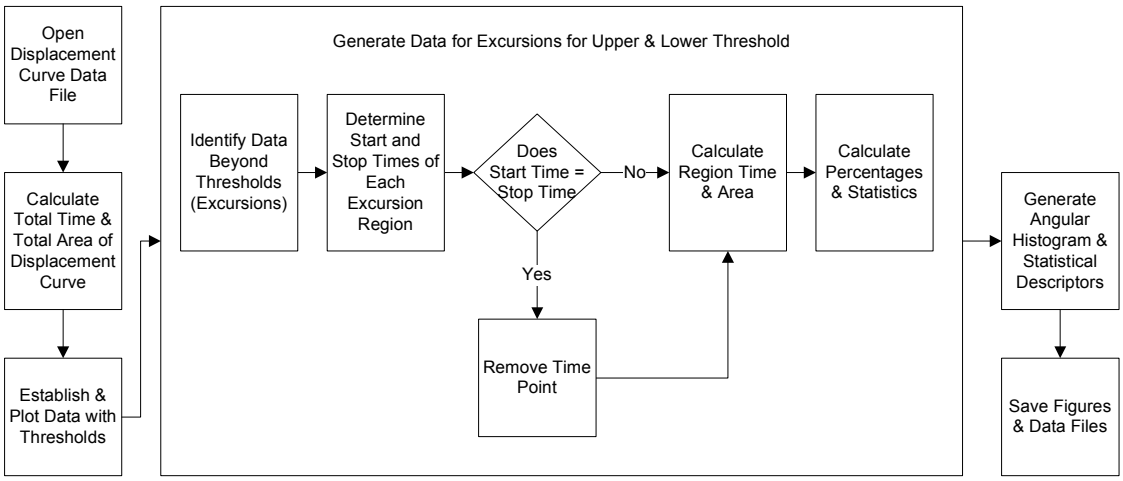


Figure 6: Data Analysis Process 2: Displacement Curve Analysis for Frequency Distribution and Excursion Information

After opening the data file, the off-subject neutral position of the sensors to the on-subject neutral positions of the sensors was aligned to remove sensor offset. The on-subject calibration was used to identify the response of the sensor at the neutral position of the wrist. By subtracting the average angle value of the on-subject calibration before and after the data collection, the sensor offset was removed in a manner that also adjusts for sensor drift.

The next step isolated the excursion regions, which are regions where the signal exceeds the thresholds established by the PATH mechanism. The thresholds are +/- 15° for flexion and extension and +/- 15° for ulnar and radial deviation of the wrist.

When determining the excursion regions, instances where a singular point exceeded the threshold resulted in an error. To alleviate this issue, the program ensures that if the start and stop times of a region are identical, the time point is removed from the excursion data set.

For each excursion region, the total percentage of time and the total percentage of area exceeding abnormal thresholds were extracted from the electrogoniometer signal. From the PATH data, the total percentage of time can be estimated based on the cumulative observations and was used for comparison. Consideration of total deviation of the wrist without directionality was taken into account for determining the percentage of time values.

The last function of the data analysis was a simple statistical analysis of the file to extract features from the angular displacement curve including the range, mean, mode, standard error, kurtosis, skewness, and a frequency distribution histogram of angles present. All of the statistical information regarding frequency distribution and excursion region measurements was stored in ASCII text files for future analyses.

For the several of the presented displacement curves, the patterns of repetitive motion were visually isolated from within the PATH window waveforms as examples of the system's capability to reliably track repetitive motions.

2.6 Validation of Data Capture and Analysis Process for Wrist Motion

The constructed analysis program was validated with a controlled experiment on one subject, where one calibrated electrogoniometer was mounted on the right wrist. A manual goniometer was used to measure the maximum range of motion achievable for flexion and extension and radial and ulnar deviation. The subject was then asked to displace the wrist to the maximum position three times for ulnar and radial deviation of

the wrist and for flexion and extension. After ensuring the data capture and analysis method was valid, the data analysis processes (see Section 2.5) was applied to the subjects outlined in Section 2.3.

2.7 Validation for Shoulder Motion

To date, the sensors have only been applied to shoulder use to identify specific postures. In order to analyze shoulder sensor data to yield the specific angles of flexion and extension and abduction and adduction, extensive validation of shoulder motion collected by the sensors is required. After the validation, the data analysis process of Section 2.5 can be applied.

Ten repeated trials of a single randomized test were conducted as a regional proprioception test, where the data were marked by the event switch when the desired position was reached. In each test, the subject was instructed to move only the upper arm and to limit torso movement. The initial position was defined as 0º flexion and 90º abduction, which is also described as 0º forward flexion. Also, 0º to 90º of forward flexion and 0º to 90º of abduction was the maximum range to be tested within the scope of this study.

For the regional proprioception test, the subject was asked to move their arm into one predefined region of three levels of abduction-adduction and three levels of flexion-extension as defined in Table 2. After each movement the subject was asked to return to the initial position, and for each trial, four data points were collected within each region. The measurements were analyzed in several ways, including base voltage values, yaw-pitch angles, and spherical coordinate transformations. A basic maximum likelihood estimator with normal Gaussian distributions was used to predict the sensor location

based on electrogoniometer response, in order to statistically determine accurate region definitions for the overlapping sensor response regions.

Table 2: Regions Used in Shoulder Proprioception Test

Region 0 = Neutral Position, 0° Forward Flexion		**Extension / Flexion**		
		Frontal (~90°)	**In-between (~45°)**	**Adjacent(~0°)**
Abduction / Adduction	**High (~0°)**	7	8	9
	Medium (~30°)	4	5	6
	Low (~60°)	1	2	3

3. Results

3.1 Field Use Statistics

The monthly use and sensor failure of the electrogoniometer data logging system is shown in Figure **7** for three separate research studies and a total of 238 subjects. The electrogoniometers that broke per month during the use of the data logging system included 20 large wrist sensors, 13 small wrist sensors, and one small shoulder sensor. Based on the system usage and the sensor breakage data presented, it was predicted that approximately seven subjects, 50 hours, or 10 days can be captured by one wrist sensor.

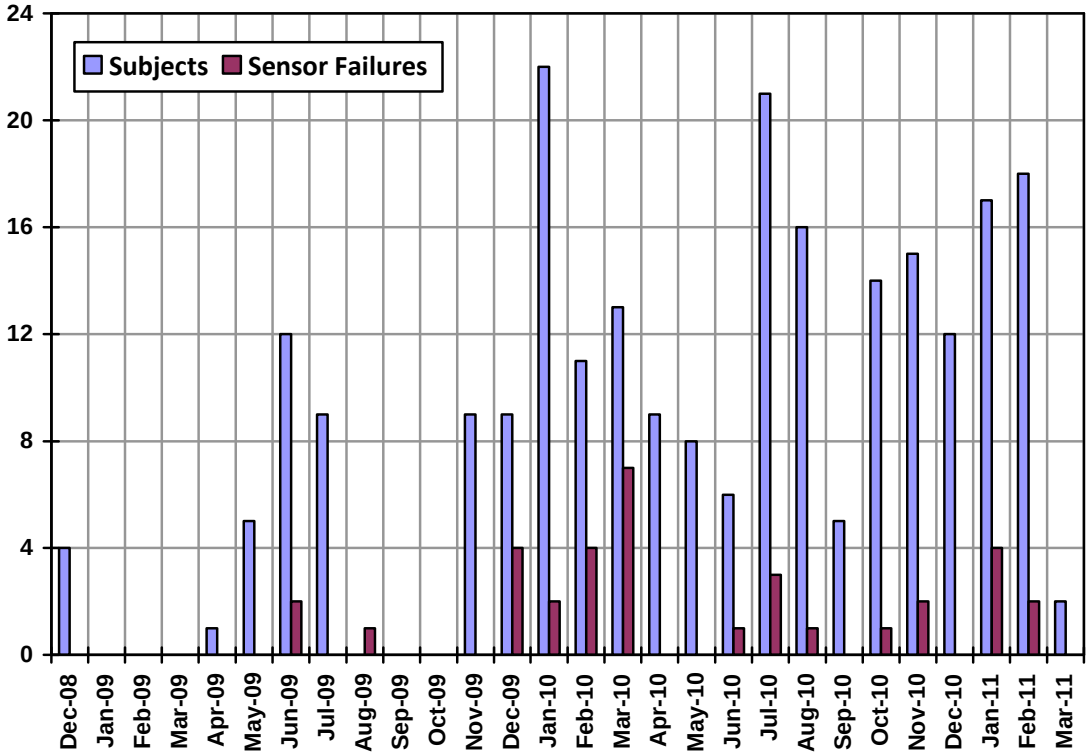


Figure 7: Monthly Field Use and Sensor Failure of Electrogoniometer Data Logging System

The malfunctioning or failure of components of the electrogoniometer data logging system are listed in Table 3 and was captured during system use from December 2008 to March 2011.

Table 3: Data Logger Parts Malfunction Occurrence

Part	# of Occurrences
Battery Terminal	43
Microprocessor	1
Instrumentation Amplifiers	7
Power Resistors	2
Power Switch	1
Sensors	34
Sensor Cords	12

3.2 Validation of Data Capture and Analysis Process for Wrist Motion

In order to validate the data analysis process, the full range of wrist motion was measured using a manual goniometer and the electrogoniometer data logging system in the laboratory, where the values for the maximum achievable position for each wrist motion were measured manually and are presented in Table 4. Wrist flexion and radial deviation are presented as negative displacements, while wrist extension and ulnar deviation are presented as positive displacements within the analysis protocols. The tables and figures that result from the data analysis process follow the protocols introduced by Peterson (1999) for complex distal upper extremity movements.

Table 4: Manual Goniometer Measurements for Subject Range of Motion

Wrist Motion	Maximum Achievable Position (deg)
Flexion	-84
Extension	74
Radial Deviation	-18
Ulnar Deviation	44

Three cycles of maximum flexion followed by maximum extension of the right wrist over 14 seconds are plotted in blue in Figure 8, and three cycles of maximum ulnar deviation followed by maximum radial deviation of the right wrist are plotted in blue in Figure 10. Each plane of motion (e.g. flexion/extension or radial/ulnar deviation) was measured separately. In Figure 8, samples of excursion regions are highlighted by black

circles, while the directions of each motion within the plot are highlighted by blue arrows. The orange lines represent the threshold values of +15° and -15°.

The results of the data analysis process for each wrist motion exceeding upper thresholds are presented in Table 5 for extension and Table 8 for radial deviation, while motions exceeding lower thresholds are presented in Table 6 for flexion and Table 9 for ulnar deviation. The area beneath the displacement curve while above the abnormal threshold, which is defined as the excursion region area, is indicative of the intensity of movement beyond a threshold.

In addition to information regarding excursion regions, the data analysis process also outputs statistical information about all the angles presented in the waveform. The data measured during the validation test is presented graphically in histograms, which can be seen in Figure 9 for flexion and extension motions and Figure 11 for radial and ulnar deviation motions. Descriptive statistics derived from the frequency distribution of the angles seen in the histograms is shown in Table 7 for flexion and extension motions and Table 10 for radial and ulnar deviation motions.

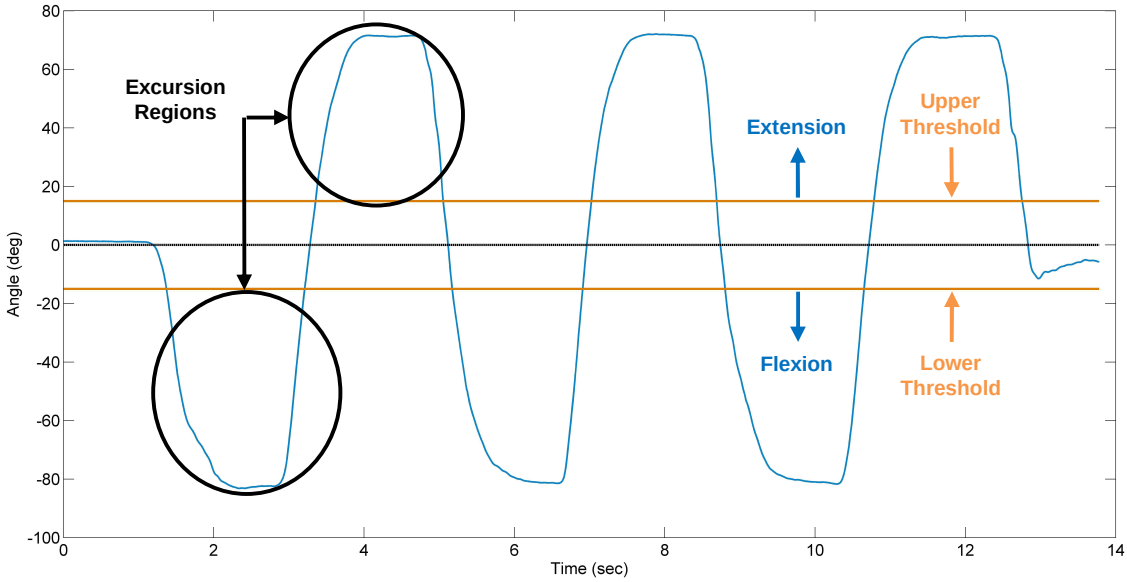


Figure 8: Wrist Flexion[-] / Extension[+] with Thresholds for Validation

Table 5: Upper Excursion Regions (Extension) for Validation

Region	Start Time (s)	Event Time (s)	Area (deg-sec)	Peak (deg)	Time Ratio (%)	Area Ratio (%)
1	3.36	1.69	78.17	79.34	12.25	11.04
2	7.03	1.66	77.67	79.81	12.06	10.97
3	10.79	1.96	91.75	79.23	14.24	12.96
Total	3 Regions	5.31	247.61		38.56	34.96
Average		1.77	82.54	79.46	12.85	11.65
Maximum		1.96	91.75	79.81	14.24	12.96
Minimum		1.66	77.67	79.23	12.06	10.97

Table 6: Lower Excursion Regions (Flexion) for Validation

Region	Start Time (s)	Event Time (s)	Area (deg-sec)	Peak (deg)	Time Ratio (%)	Area Ratio (%)
1	1.37	1.84	-97.71	-75.42	13.31	-13.80
2	5.18	1.73	-90.64	-73.71	12.56	-12.80
3	8.81	1.84	-96.25	-73.93	13.37	-13.59
Total	3 Regions	5.41	-284.57		39.24	-40.18
Average		1.80	-94.87	-74.35	13.08	-13.39
Maximum		1.84	-90.64	-73.71	13.37	-12.80
Minimum		1.73	-97.71	-75.42	12.56	-13.80

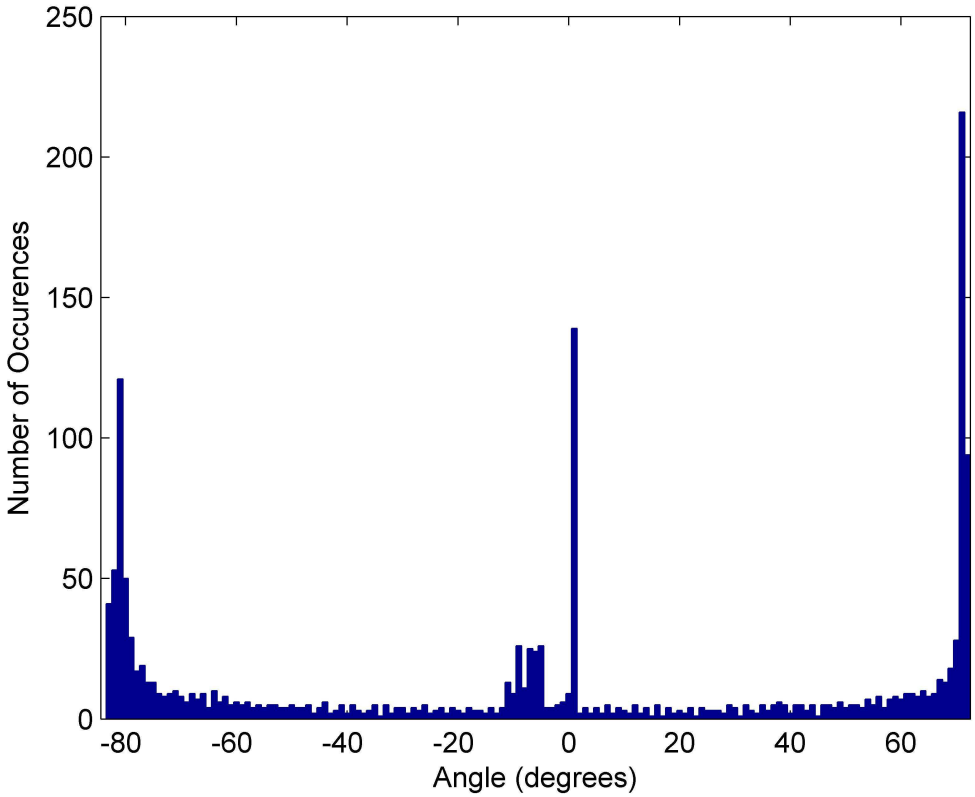


Figure 9: Histogram of Flexion/Extension for Validation

Table 7: Histogram Statistics of Wrist Flexion/Extension for Validation

Statistic	Value
Mean (deg)	-3.21
Median (deg)	0.36
Mode (deg)	71
Standard Deviation (deg)	23.95
Kurtosis	44.57
Skewness	6.06
Range (deg)	155.23
Minimum (deg)	-83.16
Maximum (deg)	72.07
Total Time (sec)	13.78
Total Area (deg-sec)	708.25

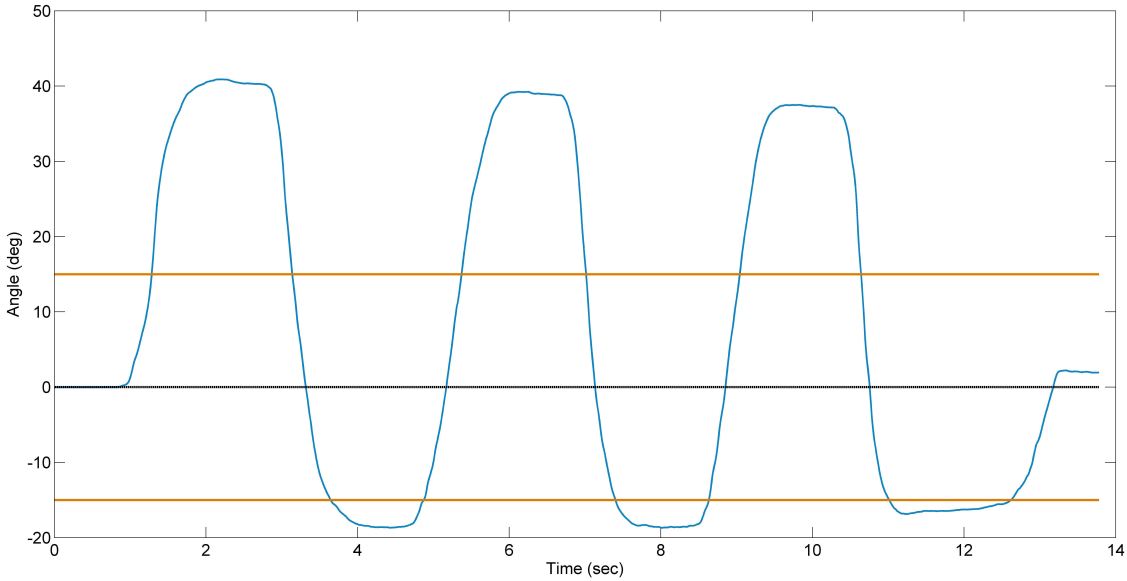


Figure 10: Wrist Radial[-] / Ulnar[+] Deviation with Thresholds for Validation

Table 8: Upper Excursion Regions (Ulnar Deviation) for Validation

Region	Start Time (s)	Event Time (s)	Area (deg-sec)	Peak (deg)	Time Ratio (%)	Area Ratio (%)
1	1.29	1.85	39.83	45.25	13.43	14.52
2	5.37	1.64	31.84	43.61	11.88	11.60
3	9.05	1.59	29.74	41.88	11.51	10.84
Total	3 Regions	5.07	101.42		36.82	36.96
Average		1.69	33.81	43.58	12.27	12.32
Maximum		1.85	39.83	45.25	13.43	14.52
Minimum		1.59	29.74	41.88	11.51	10.84

Table 9: Lower Excursion Regions (Radial Deviation) for Validation

Region	Start Time (s)	Event Time (s)	Area (deg-sec)	Peak (deg)	Time Ratio (%)	Area Ratio (%)
1	3.65	1.22	-3.48	-14.33	8.83	-1.27
2	7.40	1.23	-3.73	-14.35	8.89	-1.36
3	11.02	1.59	-1.97	-12.51	11.57	-0.72
Total	3 Regions	4.04	-9.18		29.29	-3.34
Average		1.35	-3.06	-13.73	9.76	-1.11
Maximum		1.59	-1.97	-12.51	11.57	-0.72
Minimum		1.22	-3.73	-14.35	8.83	-1.36

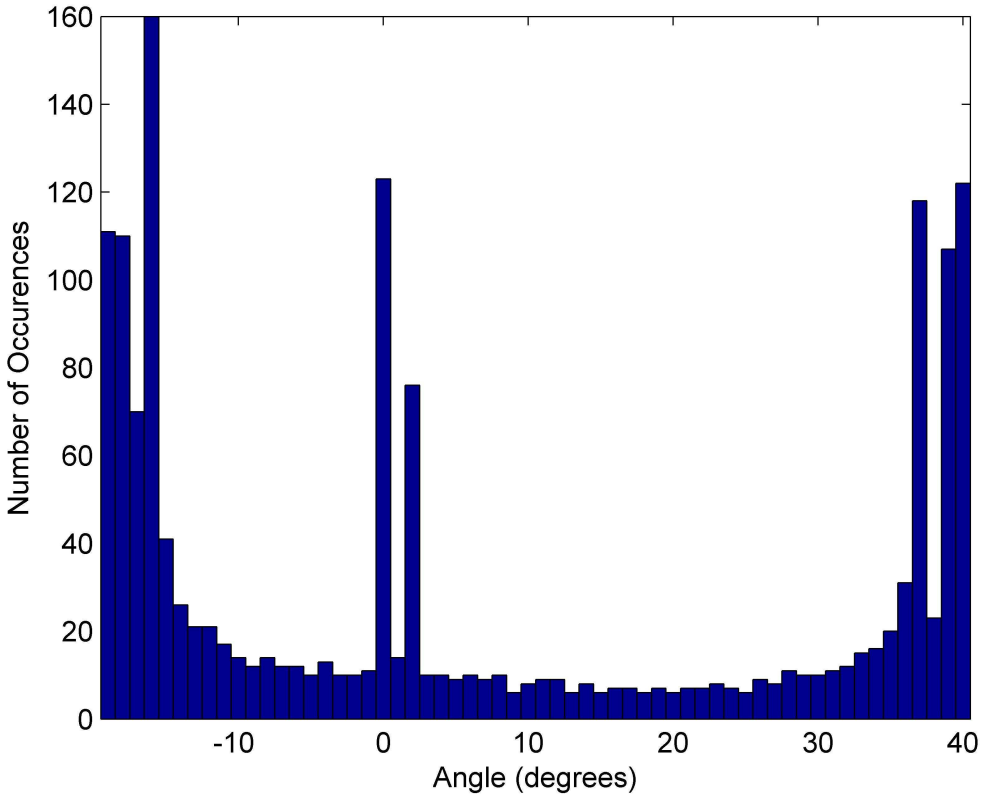


Figure 11: Histogram of Radial/Ulnar Deviation for Validation

Table 10: Histogram Statistics of Wrist Radial/Ulnar Deviation for Validation

Statistic	Value
Mean (deg)	7.22
Median (deg)	0.13
Mode (deg)	-16
Standard Deviation (deg)	37.42
Kurtosis	6.20
Skewness	2.13
Range (deg)	59.61
Minimum (deg)	-18.71
Maximum (deg)	40.89
Total Time (sec)	13.78
Total Area (deg-sec)	274.38

3.3 Long-Duration Wrist Motion Results

3.3.1. Site 1 Data

Each channel of data for a selected subject is shown in Figure 12, where the vertical lines indicate presses of the event switch during the data logging session. From the full displacement curves, the 15-minute observation windows were isolated. Figure 13 displays a sample of data demonstrating a repetitive pattern that was taken from the full waveforms of the right wrist (Figure 12). The histograms of the angles measured in each observation window and the full displacement curves are shown in Figure 14, where each motion is presented in separate columns.

Table 11 presents the excursion data for radial and ulnar deviations while Table 12 presents data for flexion and extension. Each table displays the results measured during the full waveform as well as the average of the data assessed during observation windows, where the number of windows is given by n. The first section of the table presents results for the upper excursion regions and lower excursion regions, and the statistical data that describe the histograms is presented after the excursion regions.

Table 13 and Table 14 display the average excursion data and histogram statistics for the full waveforms and average observation windows of four packers from Site 1. The average number of observation windows collected across the four packers (i.e., n Avg.) was 4.50 windows. The histograms for the three additional packers are shown in Appendix A.4.

The average results for excursion regions and histogram statistics for 18 subjects at Site 1 are shown in Table 15 and Table 16. The average number of observation windows collected for the 18 subjects at Site 1 (i.e., n Avg.) is 3.22 windows. The

individual excursion region and histogram data for each subject is included in Appendix A.5.

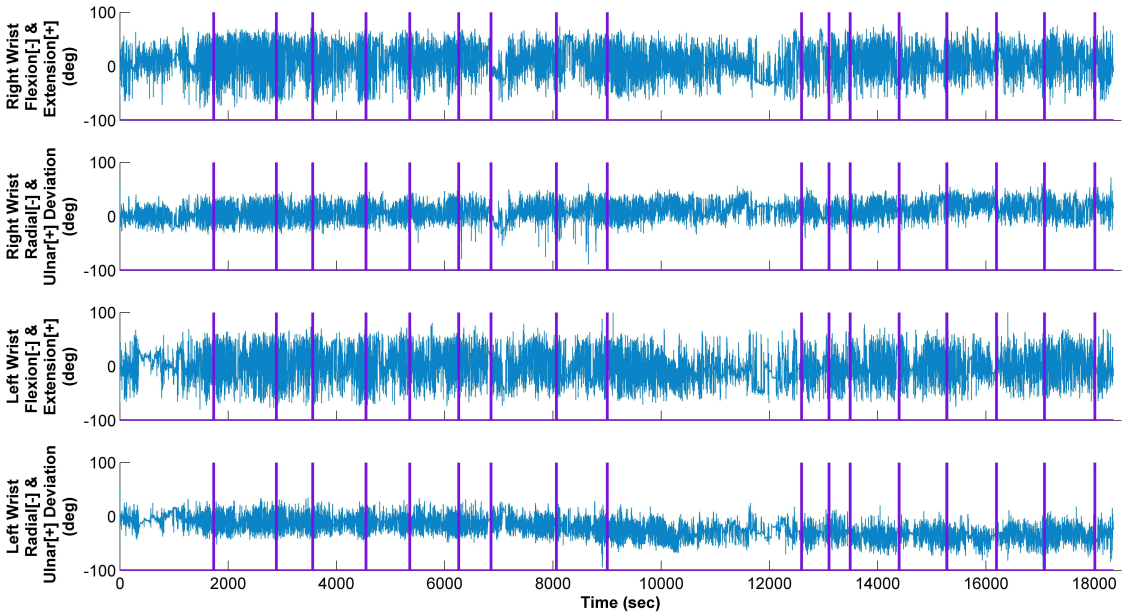


Figure 12: Full Displacement Curves during Packing Task for Five Hours

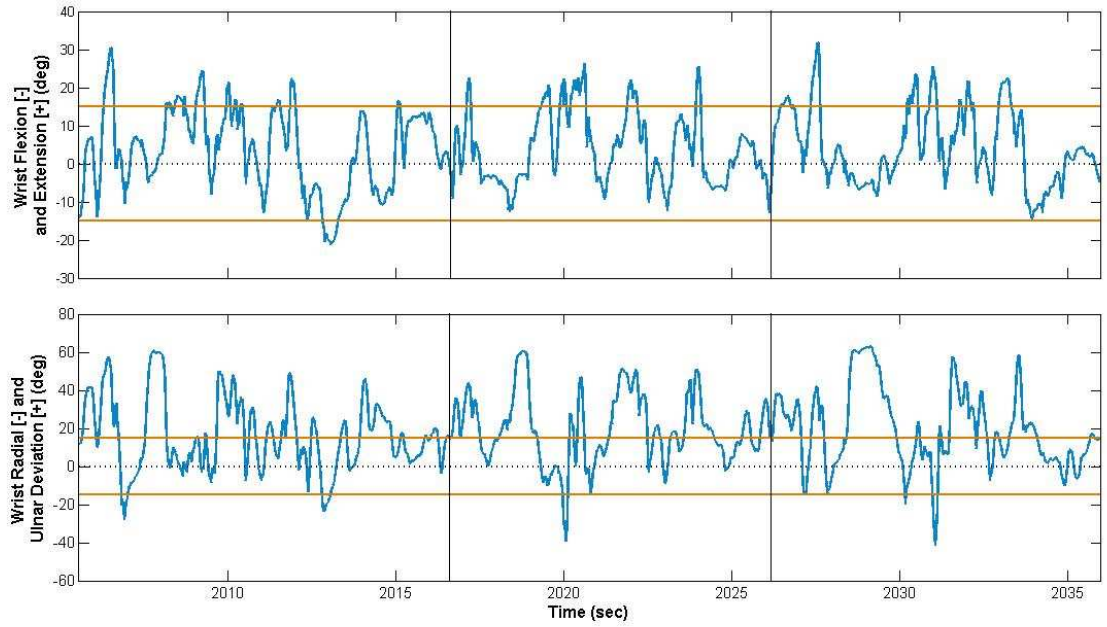


Figure 13: Right Wrist Joint Motion Repetition during Packing Task for Three Cycles

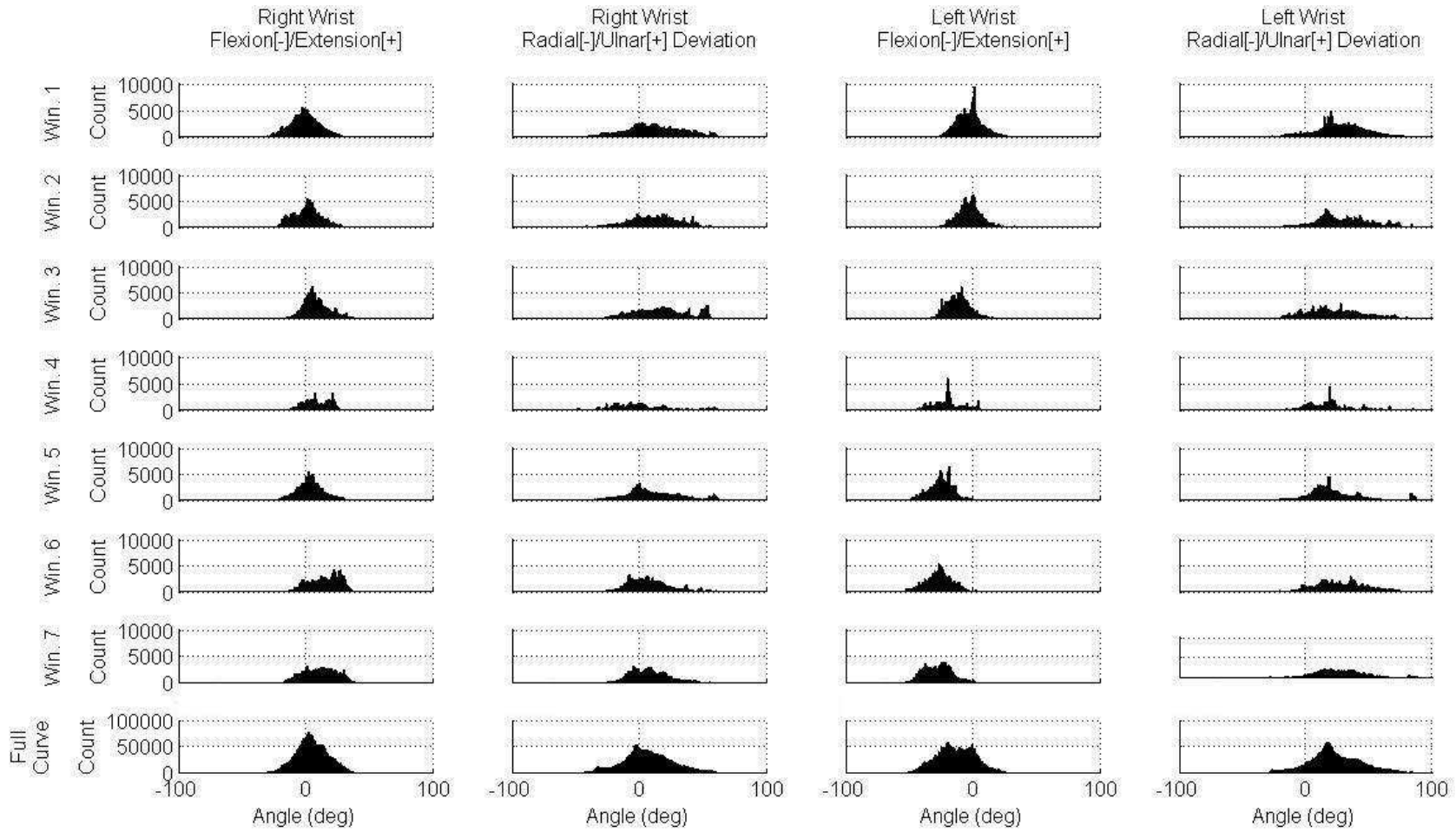


Figure 14: Histograms of Wrist Motion during Packing Task

Table 11: Wrist Motion Statistics of Select Packer for Radial/Ulnar Deviation

Subject 01		Full Waveform		Windows (n=7)			
		Right	Left	Right (Avg.)	Right (S.D.)	Left (Avg.)	Left (S.D.)
Ulnar Deviation (Upper Excursions)	Max. Excursion Time (sec)	56.30	227.21	25.76	11.37	27.82	7.75
	Max. Excursion Area (deg-sec)	2426.95	5839.39	843.59	500.77	1178.53	644.97
	Total Excursion Time (sec)	5878.93	11570.03	346.37	129.28	594.64	171.85
	Total Excursion Time (%)	32.03	63.03	5.42	5.68	9.16	9.94
	Total Excursion Area (deg-sec)	89616.46	234271.69	5996.94	2453.27	12927.67	4090.83
	Total Excursion Area (%)	28.12	49.18	33.54	5.77	51.36	3.11
Radial Deviation (Lower Excursions)	Max. Excursion Time (sec)	81.46	51.29	8.39	6.03	5.38	3.27
	Max. Excursion Area (deg-sec)	-1516.43	-570.36	-136.08	78.03	-63.92	69.12
	Total Excursion Time (sec)	2579.30	846.26	105.88	39.50	32.83	8.87
	Total Excursion Time (%)	14.05	4.61	1.66	1.91	0.48	0.52
	Total Excursion Area (deg-sec)	-34875.31	-7356.76	-1400.52	727.65	-299.31	121.91
	Total Excursion Area (%)	-10.94	-1.54	-8.51	4.99	-1.22	0.39
Radial[-]/Ulnar[+] Deviation Histogram Statistics	Mean (deg)	6.17	22.72	8.93	4.69	24.23	3.14
	Median (deg)	5.23	20.18	7.74	6.13	22.46	3.82
	Mode (deg)	-3.00	16.00	7.71	21.97	21.57	6.92
	Maximum (deg)	74.23	145.04	68.86	2.22	92.68	5.45
	Minimum (deg)	-80.75	-57.67	-69.64	6.95	-46.98	5.37
	Range (deg)	154.98	202.71	138.50	6.34	139.66	6.23
	Standard Deviation (deg)	14860.43	14261.14	729.86	173.26	748.00	136.97
	Skewness	1.00	1.53	0.88	0.31	1.42	0.94
	Kurtosis	2.77	4.58	2.73	0.77	6.28	6.51

Table 12: Wrist Motion Statistics of Select Packer for Flexion/Extension

Subject 01		Full Waveform		Windows (n=7)			
		Right	Left	Right (Avg.)	Right (S.D.)	Left (Avg.)	Left (S.D.)
Extension (Upper Excursions)	Max. Excursion Time (sec)	47.71	41.13	21.12	18.23	1.66	2.10
	Max. Excursion Area (deg-sec)	603.71	361.61	212.15	211.13	18.59	29.64
	Total Excursion Time (sec)	3759.43	594.61	222.46	146.92	18.52	28.13
	Total Excursion Time (%)	20.48	3.24	2.20	0.94	0.51	0.92
	Total Excursion Area (deg-sec)	29504.02	3505.22	1837.29	1601.32	122.95	195.15
	Total Excursion Area (%)	14.79	1.12	16.36	9.56	1.34	2.14
Flexion (Lower Excursions)	Max. Excursion Time (sec)	82.78	101.03	4.93	3.30	37.82	24.89
	Max. Excursion Area (deg-sec)	-976.39	-1756.66	-50.92	64.72	-563.33	471.25
	Total Excursion Time (sec)	1247.46	8814.63	47.46	50.28	477.48	316.29
	Total Excursion Time (%)	6.80	48.02	1.09	1.79	4.02	1.15
	Total Excursion Area (deg-sec)	-7605.45	-107682.03	-268.71	267.62	-6112.90	5467.47
	Total Excursion Area (%)	-3.81	-34.44	-2.99	2.63	-30.20	19.65
Flexion[-]/Extension[+] Histogram Statistics	Mean (deg)	4.45	-13.89	6.28	5.62	-16.93	11.21
	Median (deg)	3.92	-14.16	6.34	6.03	-16.86	11.10
	Mode (deg)	2.00	-20.00	5.00	8.14	-14.14	11.52
	Maximum (deg)	66.66	62.03	47.61	7.94	28.49	11.13
	Minimum (deg)	-93.78	-92.35	-44.44	22.34	-58.11	19.15
	Range (deg)	160.44	154.38	92.04	26.41	86.60	11.07
	Standard Deviation (deg)	21251.51	18428.68	1283.16	280.01	1473.33	338.06
	Skewness	1.54	1.04	1.00	0.61	1.47	0.73
	Kurtosis	4.10	2.50	3.25	1.79	5.29	4.86

Table 13: Wrist Motion Statistics of All Packers at Single Site for Radial/Ulnar Deviation

Subjects (n=4)		Full		Windows (n Avg.=4.50)			
		Right	Left	Right (Avg.)	Right (S.D.)	Left (Avg.)	Left (S.D.)
Ulnar Deviation (Upper Excursions)	Max. Excursion Time (sec)	111.58	128.09	31.85	14.61	36.78	15.04
	Max. Excursion Area (deg-sec)	2735.59	3610.31	760.67	386.64	853.82	463.85
	Total Excursion Time (sec)	6130.25	6922.19	361.13	68.45	376.90	107.02
	Total Excursion Time (%)	40.47	42.33	11.01	9.59	10.18	8.04
	Total Excursion Area (deg-sec)	94148.69	130329.49	5846.86	1613.54	6900.26	2374.81
	Total Excursion Area (%)	30.95	34.25	31.29	4.11	35.74	3.57
Radial Deviation (Lower Excursions)	Max. Excursion Time (sec)	65.36	44.31	18.11	12.64	6.91	2.87
	Max. Excursion Area (deg-sec)	-1372.16	-692.52	-301.22	324.02	-108.59	38.86
	Total Excursion Time (sec)	2094.64	2071.92	115.13	32.94	117.27	16.82
	Total Excursion Time (%)	14.44	15.22	3.15	2.61	3.72	3.38
	Total Excursion Area (deg-sec)	-23905.85	-24378.66	-1359.29	728.99	-1381.45	158.54
	Total Excursion Area (%)	-8.96	-9.06	-8.11	3.70	-7.63	0.76
Radial[-]/Ulnar[+] Deviation Histogram Statistics	Mean (deg)	9.21	10.63	10.33	2.64	12.11	2.09
	Median (deg)	8.57	8.35	9.61	3.41	9.21	2.98
	Mode (deg)	-1.00	3.50	9.97	12.24	11.14	10.73
	Maximum (deg)	70.62	86.81	63.85	2.30	67.36	4.74
	Minimum (deg)	-75.72	-65.20	-60.62	3.28	-55.05	3.58
	Range (deg)	146.34	152.02	124.48	4.11	122.40	6.70
	Standard Deviation (deg)	12827.55	12538.69	869.34	234.04	903.77	213.78
	Skewness	0.82	0.97	1.48	0.61	1.75	1.01
	Kurtosis	2.42	3.18	6.60	3.55	8.41	6.44

Table 14: Wrist Motion Statistics of All Packers at Single Site for Flexion/Extension

Subjects (n=4)		Full		Windows (n Avg.=4.50)			
		Right	Left	Right (Avg.)	Right (S.D.)	Left (Avg.)	Left (S.D.)
Extension (Upper Excursions)	Max. Excursion Time (sec)	55.54	58.11	11.81	8.38	12.83	7.94
	Max. Excursion Area (deg-sec)	451.30	543.05	81.11	59.25	139.30	128.02
	Total Excursion Time (sec)	2100.65	2465.10	107.67	60.07	146.32	29.38
	Total Excursion Time (%)	11.99	17.97	2.32	1.25	5.13	4.66
	Total Excursion Area (deg-sec)	14738.90	15815.50	689.30	483.06	1037.77	307.09
	Total Excursion Area (%)	8.24	8.84	7.50	3.24	8.47	1.95
Flexion (Lower Excursions)	Max. Excursion Time (sec)	59.80	45.35	8.15	3.27	15.32	10.74
	Max. Excursion Area (deg-sec)	-666.60	-584.20	-147.70	46.86	-185.18	146.19
	Total Excursion Time (sec)	1941.85	2739.19	136.24	26.24	148.41	96.55
	Total Excursion Time (%)	15.04	15.73	4.14	3.74	1.66	0.50
	Total Excursion Area (deg-sec)	-17520.64	-29895.45	-1365.84	270.19	-1671.25	1445.25
	Total Excursion Area (%)	-8.45	-11.00	-8.66	1.39	-9.45	5.74
Flexion[-]/Extension[+] Histogram Statistics	Mean (deg)	-0.08	1.04	0.61	2.18	0.22	3.57
	Median (deg)	0.07	0.80	1.23	2.40	-0.08	3.53
	Mode (deg)	0.25	-2.50	1.54	3.24	-0.10	4.74
	Maximum (deg)	57.69	68.44	35.34	4.73	31.87	4.04
	Minimum (deg)	-49.07	-51.55	-32.78	6.98	-35.02	7.26
	Range (deg)	106.76	119.99	68.13	9.30	66.89	5.55
	Standard Deviation (deg)	24305.46	21978.24	1805.19	444.87	1789.44	447.30
	Skewness	1.33	1.36	1.56	0.64	1.63	0.42
	Kurtosis	3.60	3.75	6.50	2.76	6.71	2.50

Table 15: Wrist Motion Statistics of Population from Site 1 for Radial/Ulnar Deviation

Subjects (n=18)		Full		Windows (n Avg.=3.22)			
		Right	Left	Right (Avg.)	Right (S.D.)	Left (Avg.)	Left (S.D.)
Ulnar Deviation (Upper Excursions)	Max. Excursion Time (sec)	146.91	144.74	44.00	22.09	58.15	29.89
	Max. Excursion Area (deg-sec)	3770.69	3911.16	1076.27	639.61	1457.69	853.02
	Total Excursion Time (sec)	4990.29	5544.11	414.49	76.90	451.25	88.19
	Total Excursion Time (%)	42.35	45.02	10.15	7.03	11.53	8.51
	Total Excursion Area (deg-sec)	78834.71	108605.13	6421.18	1779.01	8870.54	2330.81
	Total Excursion Area (%)	31.91	36.70	32.99	5.04	38.74	4.86
Radial Deviation (Lower Excursions)	Max. Excursion Time (sec)	84.77	66.39	13.94	13.40	18.23	9.67
	Max. Excursion Area (deg-sec)	-2179.54	-1746.45	-345.62	471.49	-338.04	246.56
	Total Excursion Time (sec)	1586.16	1434.48	85.82	37.36	89.91	30.54
	Total Excursion Time (%)	12.33	12.15	1.92	1.29	2.01	1.26
	Total Excursion Area (deg-sec)	-22231.83	-21246.16	-1191.93	829.56	-1139.21	527.59
	Total Excursion Area (%)	-9.19	-8.64	-6.93	4.18	-6.39	2.54
Radial[-]/Ulnar[+] Deviation Histogram Statistics	Mean (deg)	9.95	12.55	11.81	3.85	14.90	3.97
	Median (deg)	9.44	11.66	11.35	4.09	14.16	4.83
	Mode (deg)	3.67	13.17	9.32	9.66	11.26	13.67
	Maximum (deg)	75.59	85.17	65.49	3.73	70.44	4.57
	Minimum (deg)	-76.40	-70.17	-62.67	5.81	-57.18	4.13
	Range (deg)	151.99	155.35	128.16	7.73	127.62	6.82
	Standard Deviation (deg)	10811.19	10492.81	1036.36	203.11	1013.55	177.00
	Skewness	1.35	1.31	1.67	0.63	1.81	0.62
	Kurtosis	4.50	4.38	6.93	4.18	7.52	3.75

Table 16: Wrist Motion Statistics of Population from Site 1 for Flexion/Extension

Subjects (n=18)		Full		Windows (n Avg.=3.22)			
		Right	Left	Right (Avg.)	Right (S.D.)	Left (Avg.)	Left (S.D.)
Extension (Upper Excursions)	Max. Excursion Time (sec)	90.38	84.35	25.40	14.99	16.23	10.12
	Max. Excursion Area (deg-sec)	1073.97	862.24	283.68	147.10	128.33	113.08
	Total Excursion Time (sec)	2653.93	1853.48	201.26	49.05	111.87	41.69
	Total Excursion Time (%)	21.70	14.40	5.72	4.39	3.29	2.84
	Total Excursion Area (deg-sec)	24082.71	10280.90	1786.64	327.35	615.83	250.05
	Total Excursion Area (%)	12.10	6.78	11.17	2.19	5.32	2.19
Flexion (Lower Excursions)	Max. Excursion Time (sec)	61.52	70.78	15.29	8.64	25.46	9.65
	Max. Excursion Area (deg-sec)	-731.05	-1154.33	-179.48	128.18	-594.40	241.05
	Total Excursion Time (sec)	1316.52	1763.87	120.80	38.38	143.95	52.67
	Total Excursion Time (%)	12.39	14.71	2.79	1.91	2.14	0.69
	Total Excursion Area (deg-sec)	-10031.46	-19599.58	-989.10	428.51	-1915.93	798.86
	Total Excursion Area (%)	-6.80	-10.28	-7.09	2.80	-10.24	3.45
Flexion[-]/Extension[+] Histogram Statistics	Mean (deg)	3.44	-0.83	3.68	2.43	-1.79	3.03
	Median (deg)	3.80	-1.14	4.40	2.60	-1.92	3.19
	Mode (deg)	3.72	-1.72	5.29	3.72	0.30	4.90
	Maximum (deg)	62.30	69.02	37.59	3.47	32.96	5.18
	Minimum (deg)	-39.35	-50.12	-27.52	3.22	-37.94	5.62
	Range (deg)	101.65	119.14	65.12	5.26	70.90	8.39
	Standard Deviation (deg)	19990.87	19776.32	1979.78	324.05	1958.93	362.36
	Skewness	1.58	1.71	1.66	0.54	1.65	0.50
	Kurtosis	5.04	5.81	6.47	2.85	6.37	2.64

3.3.2. Site 2 and 3 Data

Subject 1 and Subject 2 represent two individuals doing identical tool assembly tasks at the same work site (Site 2). This particular assembly task is estimated to repeat approximately 200 times throughout one work day by one worker. Subjects 3, 4, and 5 all exemplify individual tasks taking place at Site 3, where Subject 3 used a small electric handheld grinder to grind machine parts, Subject 4 used a screwdriver to fasten different circuit boards together during and assembly process, and Subject 5 assembled switch components using a screwdriver and pliers.

Three cycles of repetitive actions in multiple assembly processes are shown in Figure 15, where patterns of motion for four different tasks, machine board grinding, tool assembly, circuit board fastening, and switch assembly, are displayed. Each cycle of motion is separated by vertical black lines. Movement thresholds for the wrist are indicated by orange horizontal lines, and the threshold values coincide with the thresholds of the PATH protocol, which were +/- 15° for wrist flexion/extension and +/- 15° radial/ulnar deviation. Data for task B (tool assembly) was collected from the Subject 1 at Site 2, whereas data for task A, C, and D were collected from the three subjects at Site 3.

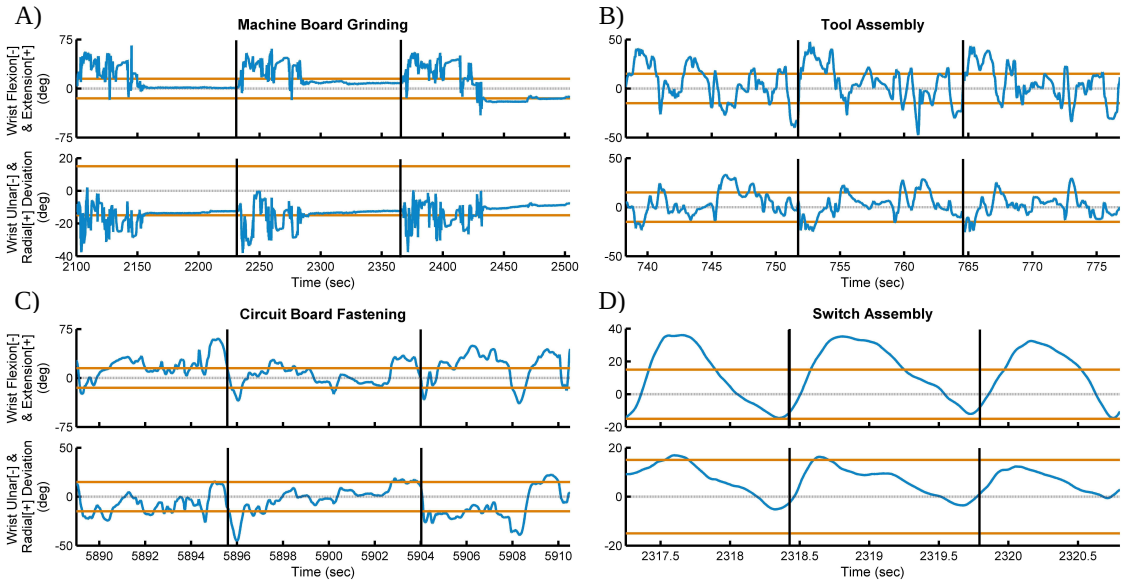


Figure 15: Right Wrist Joint Movement Repetition during Various Tasks for Three Cycles: A) Machine Board Grinding, B) Tool Assembly, C) Circuit Board Fastening, and D) Switch Assembly

For two subjects doing similar assembly tasks, an abbreviated selection of the mean joint movement statistics for six observation windows are presented in Figure 16 for the left and right wrist joints of Subject 1 and Subject 2. The direction of flexion and extension and radial and ulnar deviation are defined within the title of the figure and the left and right joint for each subject is displayed in a different color.

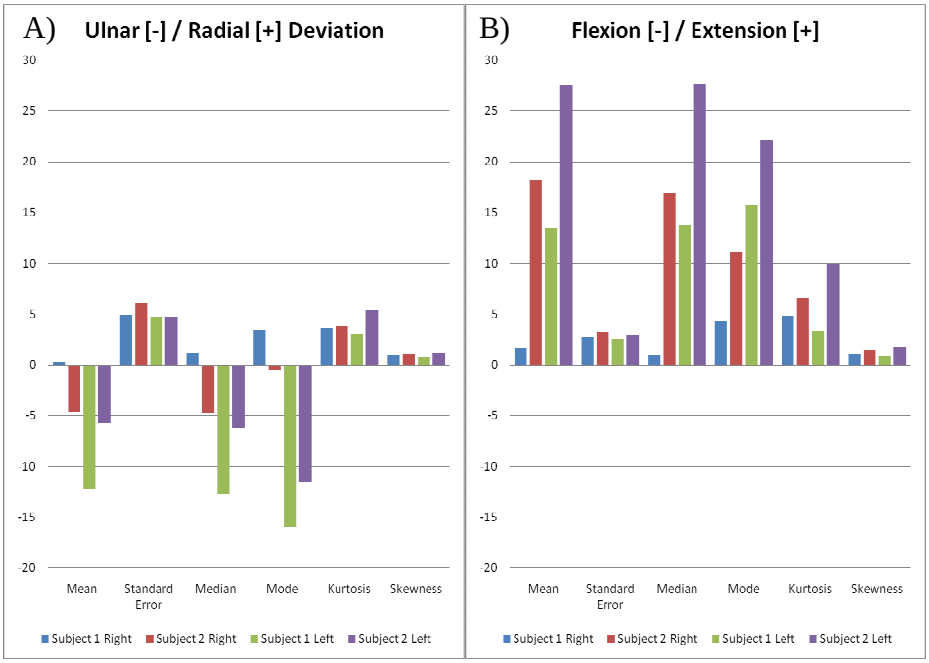


Figure 16: Angular Position Statistics for Wrists of Two Subjects during Identical Task: A) Ulnar / Radial Deviation B) Flexion / Extension

Table 17 displays the percentage of time exceeding either threshold value for the wrist joints of Subject 1 and Subject 2. Results from six observation windows for each subject are shown as measured by the data logger and compared with the PATH observations.

The average results for all six observation windows of the ratio of all the excursion regions to the total displacement curve area is displayed in Table 18 for both subjects performing identical tasks when exceeding the upper and lower threshold. Data for all individual windows of percent area is present in Appendix A.7.

Table 17: Percent Time Exceeding Movement Threshold for Identical Task

Total Time: 93 Minutes		Time (%) Exceeding Upper [+] Threshold from Data Logger	Time (%) Exceeding Lower [-] Threshold from Data Logger	Total Time (%) Exceeding Threshold from Observation	Total Time (%) Exceeding Threshold from Data Logger	Difference Between Totals (%)
Subject	**Wrist**					
1	**Right**	8.39	7.34	43.00	15.73	27.27
	Left	13.38	15.12	51.00	28.50	22.5
2	**Right**	8.05	1.82	22.00	9.87	12.13
	Left	0.57	13.11	13.00	13.68	-0.68

Table 18: Percent Area Exceeding Movement Threshold for Identical Task

Total Time: 93 Minutes		Flexion [-] / Extension [+] (%)		Radial [-] / Ulnar [+] Deviation (%)	
Abnormal Excursion	**Subject**	**Right Wrist**	**Left Wrist**	**Right Wrist**	**Left Wrist**
Upper Region [+]	**1**	19.24	38.40	4.82	0.19
	2	42.19	0.34	0.78	1.06
Lower Region [-]	**1**	-11.96	-3.50	-4.85	-20.17
	2	-0.83	-53.68	-6.20	-8.99

The average of angular position statistics, including mean, median, and mode, for three observation windows of the wrists during three different tasks is presented in Figure 17. Statistics for the left and right joints and the three subjects are identified in separate colors. In Appendix A.8, the movement histograms for all three windows and both movements of each wrist during three distinct tasks for all three windows are shown.

In Table 19, the average percentage of time exceeding either threshold value for both wrist joints during the three manufacturing tasks is shown for three observation windows. Percentage values measured by the data logger and estimated by the PATH observations are included.

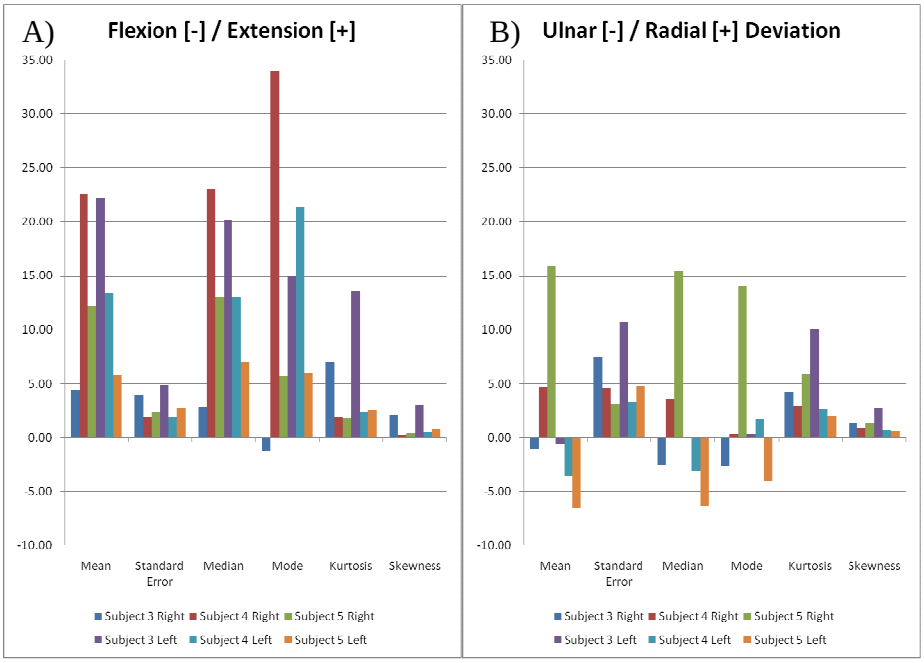


Figure 17: Angular Position Statistics for Wrists for Three Subjects during Three Different Tasks: A) Flexion/Extension B) Radial/Ulnar Deviation

Table 19: Percent Time Exceeding Movement Threshold for Different Tasks

Total Time: 47 Minutes		**Total Time (%) Exceeding Threshold from PATH Observation**	**Total Time (%) Exceeding Threshold from Data Logger**	**Difference Between Totals (%)**
Task	**Wrist**			
Machine Grinding	**Right**	34.00	25.38	8.62
	Left	26.67	27.46	-0.79
Circuit Board Fastening	**Right**	13.33	37.81	-24.48
	Left	13.67	39.27	-25.6
Assembling Switches	**Right**	23.33	13.09	10.24
	Left	17.67	14.59	3.08

For three observation windows, Table 20 presents the ratio of the sum of all the excursion regions to the total displacement curve area. Upper abnormal excursion regions exceed +15° and lower abnormal excursion regions exceed -15°.

Table 20: Percent Area Exceeding Movement Thresholds for Different Tasks

Total Time: 47 Minutes		**Flexion [-] / Extension [+] (%)**		**Radial [-] / Ulnar [+] Deviation (%)**	
Abnormal Excursion	**Task**	**Right Wrist**	**Left Wrist**	**Right Wrist**	**Left Wrist**
Upper Region [+]	**Machine Grinding**	23.36	47.68	1.81	0.43
	Circuit Board Fastening	51.45	40.71	12.80	7.99
	Assembling Switches	33.99	21.99	11.38	1.38
Lower Region [-]	**Machine Grinding**	9.86	0.32	0.49	1.08
	Circuit Board Fastening	2.41	7.70	0.58	18.63
	Assembling Switches	5.40	10.94	0.40	12.62

3.4 Validation of Shoulder Motion

The results for the left shoulder of two volunteers using the same electrogoniometer sensor with similar mounting positions during proprioception are presented below. The mean value for each region as measured by the electrogoniometer is shown in Figure 18, where the error bars show ±2° as defined by the manufacturer specifications. Figure 24 in Appendix A.6 shows the similar plots with maximum and minimum value bars instead of error bars.

The data measured by the sensor was translated into spherical coordinates via the following transformation equations assuming a radius of 100mm for visualization of the sensor performance.

$$x = r \cdot \cos(\theta) \cdot \cos(-\varphi + 90) \quad (1)$$

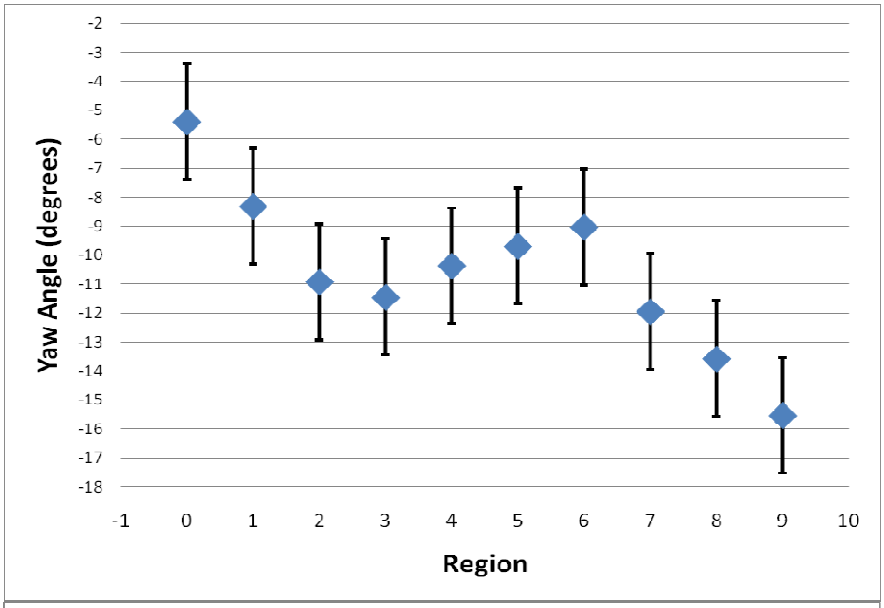
$$y = r \cdot \cos(\theta) \cdot \sin(-\varphi + 90) \quad (2)$$

$$z = r \cdot \sin(\theta) \quad (3)$$

where θ is the pitch output and φ is the yaw output of the sensor and the origin is considered to be the fixed block of the sensor mounted above the acromion. Figure 19A displays a three-dimensional plot of a sample trial translated to spherical coordinates while Figure 19B and Figure 19C show the planar views of the same plot.

The results from the Gaussian distributions and maximum likelihood estimator show accuracy ranging between 0% and 80% depending on the region, in Figure 20.

A)



B)

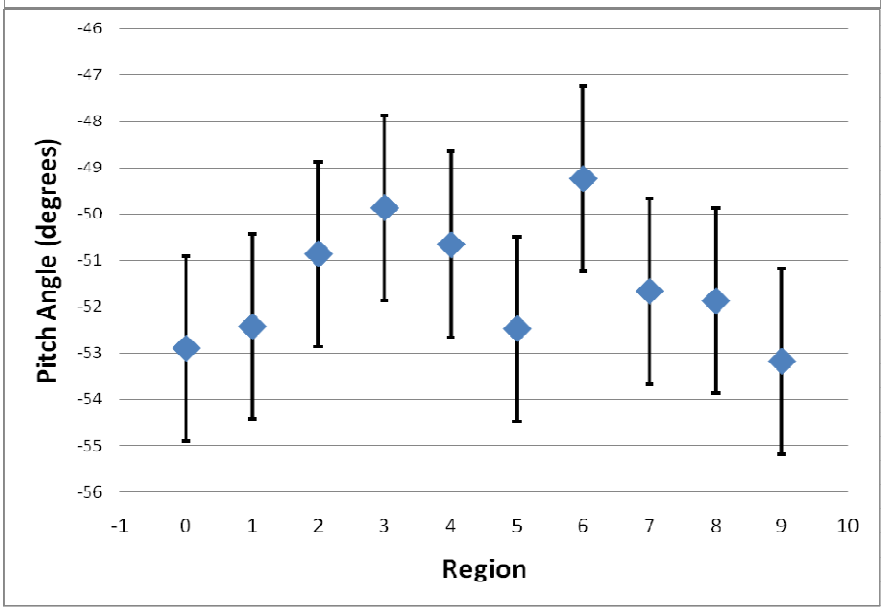
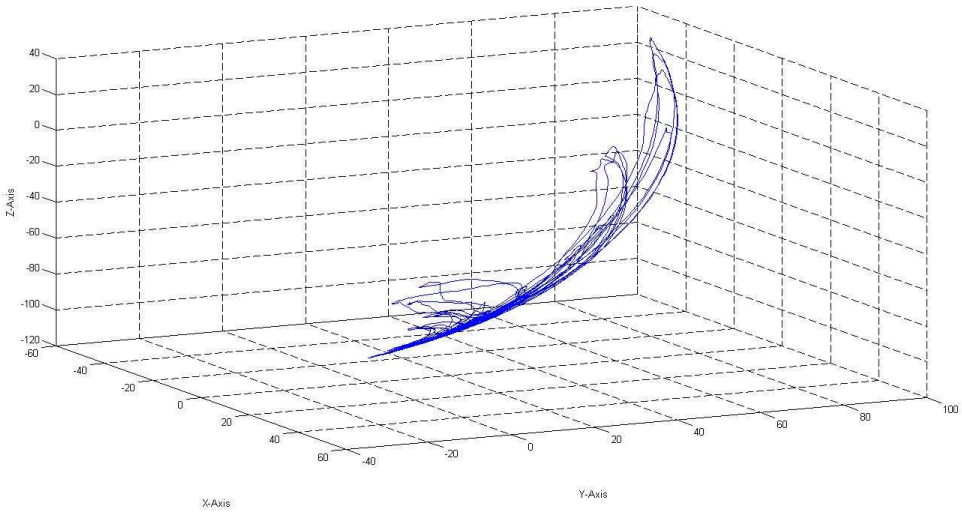
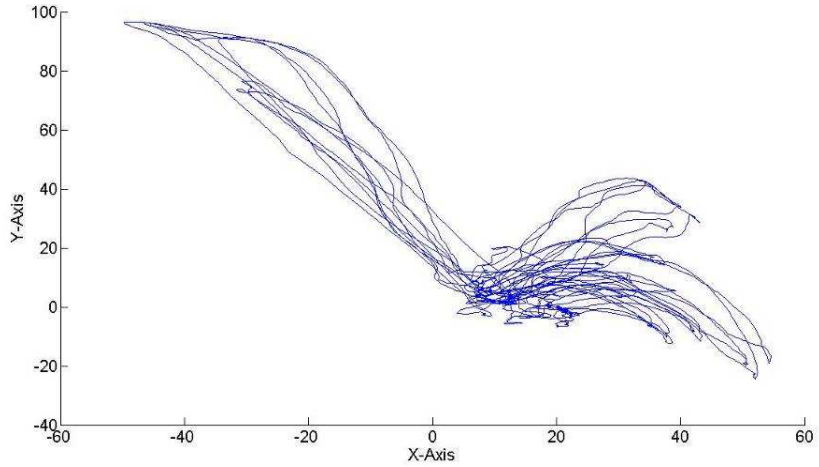


Figure 18: Mean Shoulder Electrogoniometer Results of 20 Trials with Region Definitons: A) Pitch Angle & B) Yaw Angle

A)



B)



C)

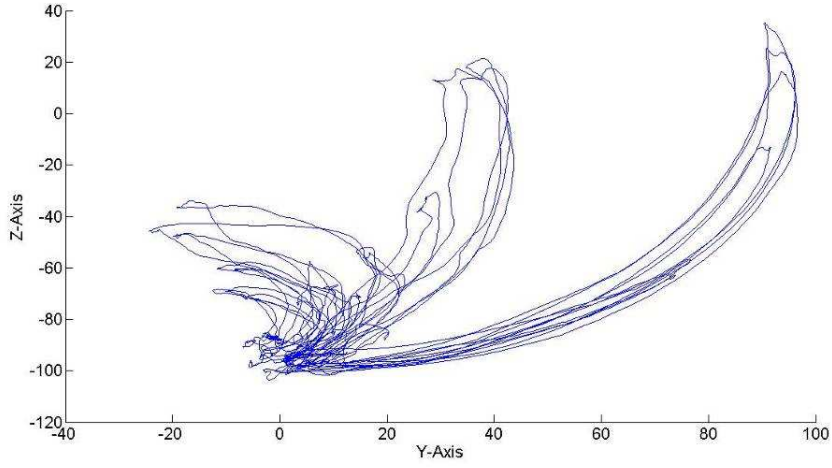


Figure 19: Plots of Shoulder Sensor Validation Test Motion Translated to Spherical Coordinates: A) Spherical Curve B) XY Planar View C) YZ Planar View

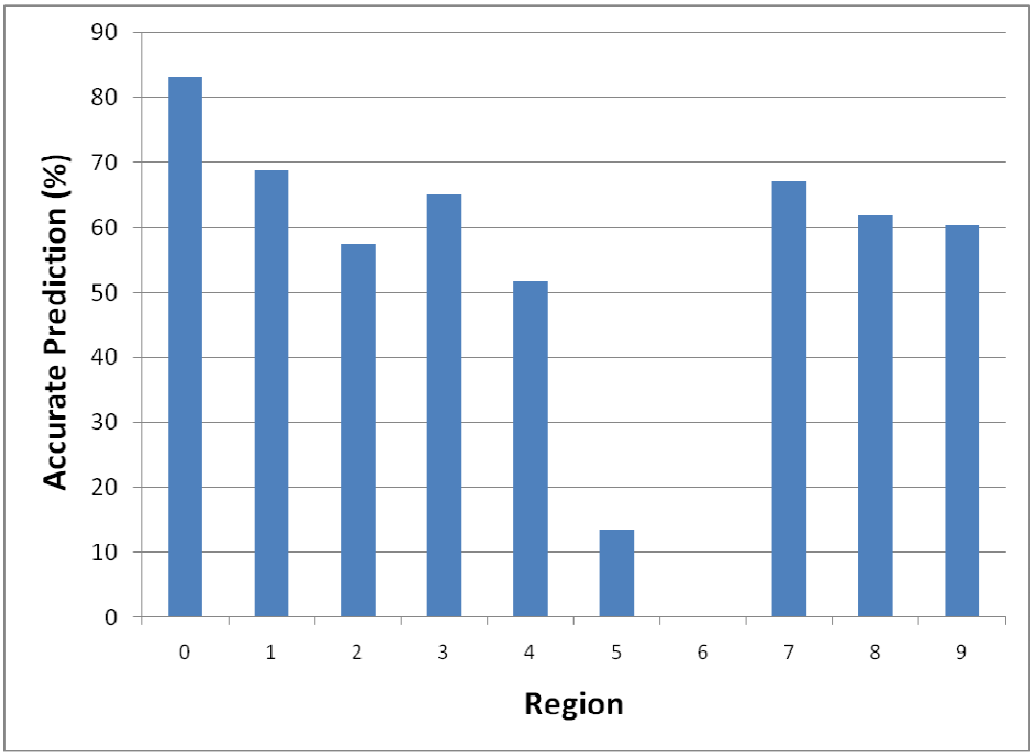


Figure 20: Percentage of Values with Accurate Region Prediction

4. Discussion

4.1 System Limitations

Based on the number of subjects collected and the number of sensors broken in the course of the field studies (Figure 7), the estimation of seven subject measurements per sensors excludes laboratory tests and does not capture how many hours were captured per wrist sensor. A decrease in the breakage of sensors occurs after April 2010, which coincides with the switch from small wrist electrogoniometers to large wrist electrogoniometers. Of the 34 sensors that have had to be replaced, only one sensor was a shoulder sensor which supports the hypothesis of breakage due to improper mounting and care. A second possible reason for wrist sensor breakage is calibration procedures and subject usage exceeding the manufacturer's recommended number of sensor cycles, which is more difficult to accurately estimate. While sensor breakage was a major resource issue due to the cost of the sensors, a stock of electrogoniometers was typically available to replace the broken sensor with a new functioning electrogoniometer.

As seen in Table 3, excluding the electrogoniometers, the most frequent system components to malfunction or break were the battery terminal connections, the cords connecting the sensors, and the instrumentation amplifiers. Re-soldering the battery terminal, which can be considered trivial in terms of time and cost, arises as a prominent issue in the field when a soldering iron is not readily available. While part breakage of the system throughout the studies is not significant, identifying the breakage of components, such as the cords and amplifiers, can only be determined in the laboratory either prior to or post data collection. If the component fails during mounting or motion capture, there is no indication until the data is processed.

The amount of time required for data processing also limits the system capabilities. Variations in data logging capture times present an obvious restriction due to size of the files. For a single channel file, the processing time can range from ten minutes, for a 15-minute observation window, to up to 3.5 hours for data logging capture times of five hours. An additional variable is the quantity of excursions regions and the size of each region which is unknown when initiating the data processing. The differences in excursion region can cause one channel of data to need an hour of processing time whereas another channel of data may take three hours. Regardless of the time limitations established by the Matlab data processing code, it may be possible to increase the efficiency of the process by using the multiple cores available in newer data processing computers. Parallel processing was found to be not viable due to the recursive nature of the analysis code.

4.2 Validation of Data Capture and Analysis Process for Wrist Motion

The validation results for wrist motion capture of the maximum range of motion match the manual goniometer measurements as seen in Table 4. A difference of less than 10 degrees is seen between the average peak motions measured by the electrogoniometers and manual goniometer. The program also correctly identifies three excursion regions per threshold. Deviation between the demonstrated and measured maximum range of motion for each joint motion can be explained by subject performance and/or errors commonly associated with manual goniometric measurements.

The resulting histograms from the validation test, especially for flexion and extension in Figure 9, demonstrate similarities to the histogram of a sinusoidal curve, which is to be expected from the sinusoidal nature of the displacement curve. The disparity between duration times for each maximum position and the changing frequency

at which each motion was performed causes the slight variations seen in the data histograms when compared to sine waves.

4.3 Long-Duration Wrist Motion

4.3.1 Individual, Task Description, and Site Comparisons (Site 1)

When analyzing the data logging output for an individual, the quantity of results is sizable but can be tailored for specific comparisons. The results shown for the selected packer represent the outputs for each subject and clearly demonstrate the amount of information than be garnered from the system and analysis process.

For data sets that do not include figures of the histograms, the statistical values presented in the tables can be used to interpret the shape of the distribution. The mode will indicate where the highest peak is located, and the median will indicate the center of the distribution. For a normal Gaussian distribution, the mean, median, and mode equal zero, while kurtosis equals three and the skewness equals zero. Kurtosis values greater than three indicate more outliers and therefore longer tails on frequency distributions. Kurtosis values less than three indicate fewer outliers, which yields a distribution with higher peaks. Positive skew values indicate distributions favoring values greater than zero and leaning toward the right, whereas negative skew values indicate distributions favoring negative values and leaning toward the left. These principles can be observed when comparing the results of the full waveform histograms in Figure 14 to the motion statistics found in Table 11 and Table 12.

In Figure 14, the patterns of shift in the position histograms as the windows progress are apparent. Flat distributions with large tales, seen for radial and ulnar deviation, instead of the more short-tailed kurtotic distribution, seen for flexion and extension, demonstrate more abnormal deviations. The shift of the peak of the histogram

away from or toward 0 degrees when progressing from window 1 to window 7 may be related to increasing fatigue.

The motion statistics for the selected packer support the hypothesis that a histogram mean closer to or exceeding the abnormal threshold values corresponds to larger total excursion areas as seen from ulnar deviation of the left wrist in Table 11 and flexion of the left wrist in Table 12. When comparing the results of total percent time of the excursion regions for either direction of motion, the average of the observation windows only represents approximately 10 to 20 percent of the full waveform values. The difference is most likely due to the arbitrary selection of windows during the day long data collection session. This disparity, however, is not true for the total percent area exceeding the abnormal thresholds, which is overestimated by 15 percent for every motion except flexion.

The selected packer shows results that are higher the total excursion time and area percentage results of all packers for radial and ulnar deviation of the left wrist and lower for flexion extension of the left wrist. For the right wrist, the flexion results are the only larger values when compared against the average packer. The cumulative assessment of these statistics between an individual and a task grouping of multiple subjects can yield insight into individual preferences while performing similar tasks.

When comparing the results of all the packers (Table 13 and Table 14) against the site population data (Table 15 and Table 16), the packers demonstrate similar total percent excursion areas (i.e., ±2%) for every motion except extension of the right wrist in the full waveforms. The upper excursion regions also demonstrate larger total excursion time percentages for the packer.

4.3.2 Identical Task (Site 2)

While the results from the full displacement curves versus the observation window curves shown in the results of the Site 1 comparisons demonstrate that only a small percentage of motions measured during the full waveforms are represented in the observation windows, abbreviated data comparing measurements during the observation windows allow for comparisons between the electrogoniometer data logging method and the PATH method.

From Figure 16, a clear comparison can be made between two subjects completing similar work tasks. Wrist flexion and extension for Subject 2 shows an average angular position that is 10º greater than for Subject 1 during the same task, which indicates more extreme flexion and extension positions for Subject 2. Subject 1 shows a mean position of approximately 0º with the right wrist versus ulnar deviation of 10º for the left wrist when examining radial and ulnar deviation whereas the right and left wrist for Subject 2 show a mean position of 5º ulnar deviation. The results for Subject 2 indicate more symmetrical motion patterns than Subject 1.

Table 17 demonstrates a difference of greater than 10% occurs when comparing the observational data and electrogoniometer data, with only the exception of the left wrist for Subject 2. Despite this disparity, both data sets demonstrate larger excursion durations for Subject 1, which indicates that Subject 1 has a greater preference for extreme flexion and extension and radial and ulnar deviation.

For Subject 1, the percent area for flexion and extension of both wrists is notably higher in the upper region indicating the preference of extension, whereas Subject 2 demonstrates joint deviations exceeding the thresholds with the right wrist for both planes of movement. The percentage area calculations in Table 18 show a large area percentage

for extension of the right and left wrist for Subject 1 but only a large area percentage during extension of the right wrist for Subject 2. Also, ulnar deviation of both wrists is more prevalent for both subjects, which may indicate the job task demands wrist postures with large ulnar deviations regardless of subject preference.

4.3.3 Different Tasks (Site 3)

For flexion and extension motions, the angles for the wrist are greatest for the right wrist during circuit assembly and for the left wrist during machine grinding. The switch assembly task shows large values of radial and ulnar deviation motion for both wrists. The differences in the motion may indicate a pattern of performance specific to each task.

The PATH observations shown in Table 19 appear to overestimate, by 5% on average, very fast repetitions, as seen in assembling switches, and very slow repetitions, as seen in machine grinding. For repetitions that are in between, as seen in circuit board fastening, PATH observations appear to underestimate by 25%. The results of percent time exceeding the threshold indicate that different conclusions can be reached based on the method of classifying motion because of the opposing patterns in PATH observation versus data logging.

In Table 20, circuit board fastening demonstrates the largest percentage of upper excursion regions for extension, radial, and ulnar deviations of the right wrist whereas assembling switches demonstrates the largest percentage of lower excursion regions for flexion and extension. The results indicate a preference for extension and radial deviation of the right wrist when fastening circuit boards versus flexion and ulnar deviation of the left wrist when assembling switches. Differences in dominant hands will play a role when examining the intensity results but were not provided for these subjects.

4.4 Shoulder Motion Validation

There is a large region of overlap between all the regions seen in Figure 18 and Figure 24 (Appendix A.6) that demonstrates the difficulty in discerning which region a particular point falls using any of the statistical methods. In both the yaw and pitch sensor channels, a 1° region exists where the measured angle overlaps more than 6 of the possible 10 regions. The results indicate that the maximum percentage of accurate predictions is approximately 80% for any region, and the regions with the lowest accuracy for prediction are the regions of medium abduction and adduction, which are Regions 4, 5, and 6. At the values between the extreme regions, the cross-talk of the two sensors channels may be less relevant as a source of error.

The spherical transformations of the sensor output reveal that distinctions within the sensor behavior are clearly observed in both planar views. Processing the spherical data with a similar maximum likelihood estimator does not increase the viability of this method, because the overlap between sensor results is too large to accurately distinguish the regions. Despite the position of 90° abduction and 0° flexion expected to be easily interpreted by the sensor, the XY planar plot demonstrates that the sensor estimates the motion to be approximately 15° greater.

Repeating this test methodology with fewer regions and more subjects may yield better results. Since the selected method for analyzing shoulder position is not based on the particular subject but instead a calculated translation that ignores error caused by abnormal placement of sensors or sensor slippage (e.g., due to perspiration in the course of a capture session), a method using information from the calibration procedure performed by the subject may be more valuable.

A second analysis of the data accounting for a rotation of the coordinate system of the sensor may also yield more insight into the behavior of the shoulder electrogoniometer. While the sensor is placed to be in a straight line at 0° flexion and 90° abduction, human anatomy requires the sensor to be tilted approximately 45° from the transverse anatomical plane. Subtracting this rotation from the sensor measurements and accounting for the cross-talk between the channels may result in an accurate depiction of shoulder movement.

4.5 Improving System Accuracy

The accuracy of this method of data capture is closely related to the precision of sensor placement and calibration of the sensor on the subject. Issues known to affect the accuracy include but are not limited to charge of the batteries, proper formatting of the SD cards, connecting the correct sensors to the pre-assigned channels, and ensuring that the cables are connected. A different calibration technique that aims to capture particular postures may yield more accurate measurements for repetition, but this method would require a more thorough understanding of each task being observed.

4.6 Future Electrogoniometer Data Logging System Directions

The final data analysis routines will run on all subjects who have undergone electrogoniometer data logging, which to date is 238 subjects, but only results regarding select subjects from the NIOSH 5R01OH008929 study population have been presented (see Section 2.3). After the cohort of data is analyzed, classification of normal and abnormal human performance patterns can be determined to yield predictive models of behavior and disease.

In order to calculate velocity and acceleration, time derivatives of the positional data must be taken. Exploration of angular velocity and angular acceleration data for both

the wrist and the shoulder may yield insight into fatigue and repetition during a task or through the course of the day.

The time frequency of reoccurrence for each movement signature is unique to the task and ranges from over a minute to approximately one second in Figure 15. The highest frequency task is the switch assembly and the lowest frequency task is machine grinding. This phenomenon occurs because of the differences between tasks as well as the difference between how individuals perform the tasks. The patterns of repetitive motion during different tasks shown in Figure 15 demonstrate that each task has a unique pattern of motion and that variation occurs within the selected cycles. While visual analysis of a longer waveform can identify repetition, wavelet analysis and decomposition can provide more insightful and accurate measurement into the repetitive motions within the full waveforms. A major limitation of identifying repetitious movements using wavelet analysis is knowledge of the repeating signal (mother wavelet) for identification before the analysis is conducted. Once the base signal is defined, the signature can be scaled and shifted for detection within the data.

5. Conclusions

With the increasing occurrence of musculoskeletal injuries and the cost associated with the diseases across occupations, information regarding the onset and progression of upper extremity human movement disorders is valuable. While short duration field tests and laboratory optoelectronic motion capture methods exist, predictions based solely on those results have not yielded significant insight into musculoskeletal disease occurrence. An electrogoniometer and custom-built data logger system has been developed in order to monitor long-duration human movements in real-world settings beyond the laboratory.

Field usage has found the electrogoniometer data logging system to be a viable method of motion capture that is only limited by the life span of the expensive wrist sensors, which can be extended through proper placement and handling. Large scale comparison in human performance between subjects, tasks, and a full site demonstrate significant differences in movement patterns, which may lead to estimation of musculoskeletal risk for each subject or each task. Interpretation of data from using the electrogoniometer on the shoulder has had limited efficacy to date, but may yield better results with further validation using a second form of motion capture (e.g., optoelectronic methods).

The data that have been collected can ultimately be used to create an extensive database of normal and abnormal wrist and shoulder movements, as defined by established thresholds, to better understand the cumulative effects of repetitive joint motions. By standardizing movement thresholds and normalizing data against pre-defined intervals of time, long-duration joint movements of subjects can be quantitatively characterized and compared in greater detail. Investigations into angular acceleration may

provide additional insight into performance and possibly reveal quantifiable symptoms of fatigue beyond the evidence seen in progressive frequency distributions.

Using the quantitative results of the electrogoniometer data logging system along with information from industrial ergonomists, hygienists, and designers, workplace design, worker training, and/or tool selection can be modified to reduce the risk of joint degeneration. The efficient and long term use of this system can lead to adaptable models of human performance and, ultimately, minimize the biomechanical risks associated with various occupations that have high incidence of musculoskeletal disorders.

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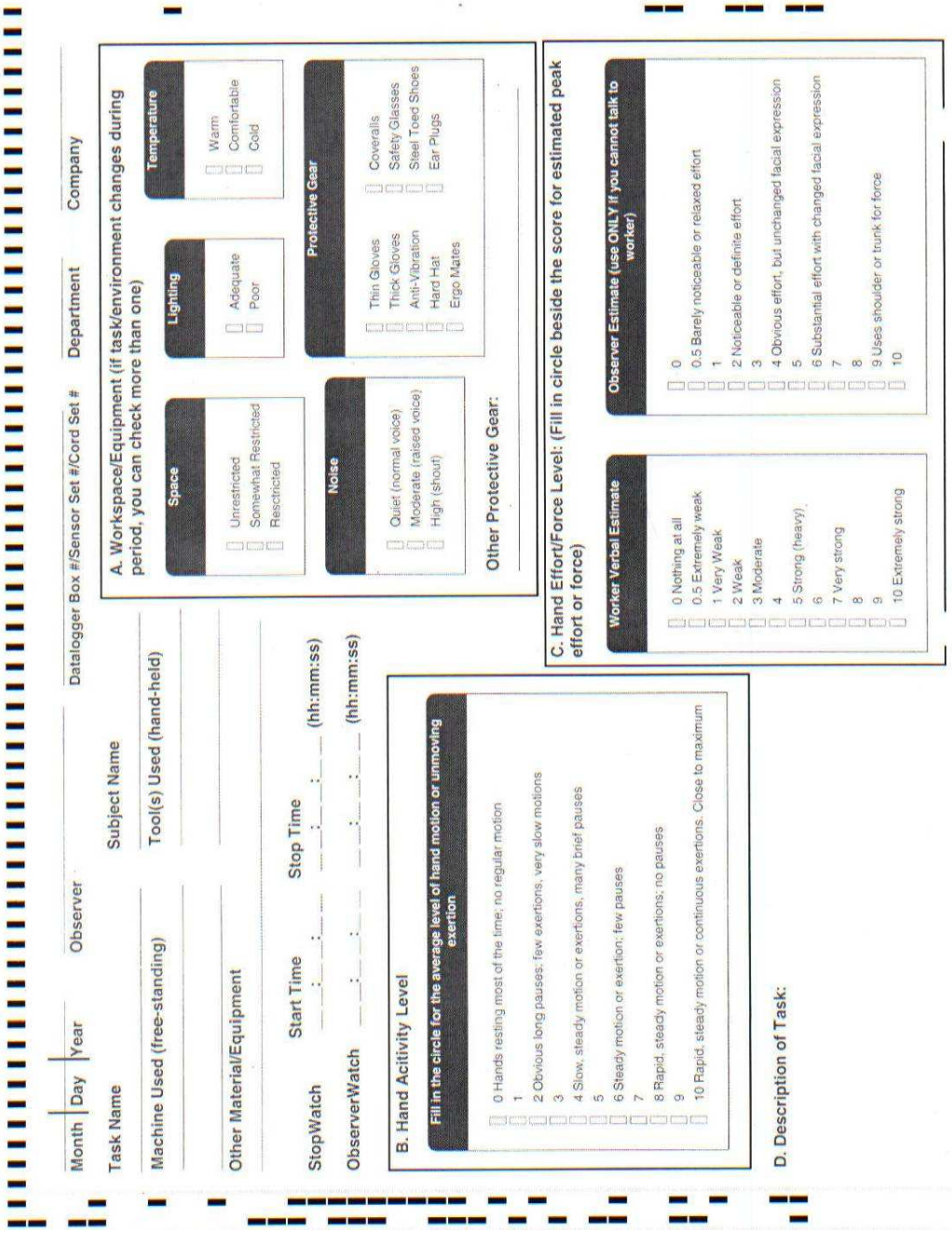
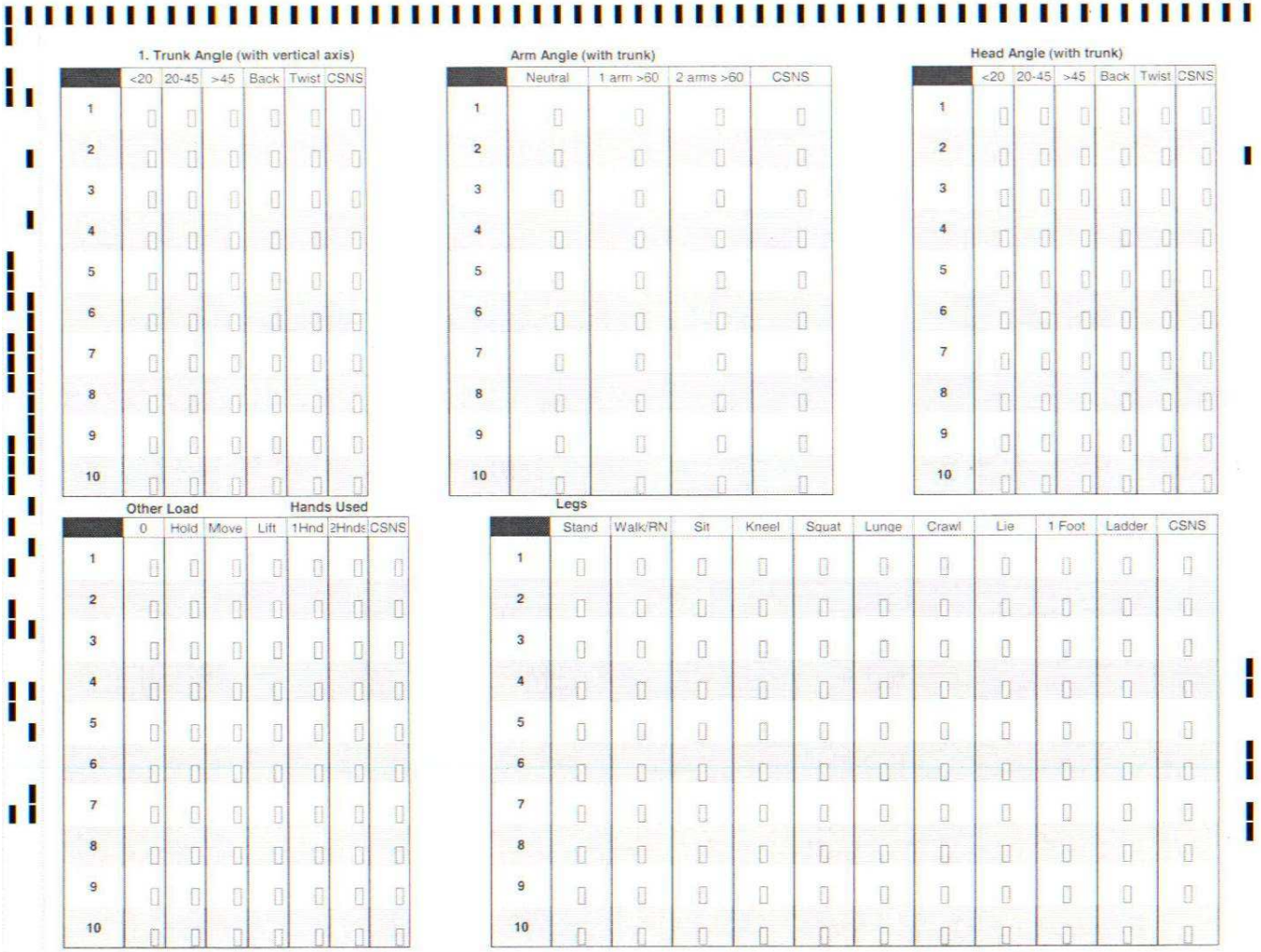
A.1 Mock Electrogoniometer Data Logging System Log Sheet

Page 1 / 1	**First Name:** John	**Last Name:** Doe
Date: 12 / 31 / 2010	**Site: UCONN Health Center**	**Subject #** 01
Study Participant ☒ **Yes** ☐ **No**	**Survey** ☒ **Yes** ☐ **No**	**Physical** ☒ **Yes** ☐ **No**
Job Title: Technician		**Dept. #** 999
Box # 7	**Sensor Set #** 6	**Cord Set #** 5
Sensor Mounted by: Jane Doe	**PATH Observation by:** Jane Doe	

Clock	**Timer**	**PATH**	**Task**	**Memo**
			Box On Test	
			Box Off Test	File 1
9:00 AM	0:00:00		Box On	
	0:00:30	X	Start Calibration	
	0:02:30	X	End Calibration	Followed Protocol – 24 PATH Presses
9:03 AM	0:03:00		Box Off	File 2
9:04 AM	0:00:00		Box On	
9:06 AM	0:02:10	X	Start Work	Blending truck door panels using large
			grinding wheel.	Lifts panel, tapes over identification
			number, blends	edges. When completed, lifts door onto
			finished rack.	Replaced grinding wheel ~ 20 min.
	0:40:55	X	Start PATH	*Window 1* – Blended 2 door panels
9:44 AM	0:56:25	X	End PATH	
10:11 AM	1:10:16	X	Coffee Break	
10:32 AM	1:26:32	X	Return to Work	Continue blending truck door panels.
	1:31:07	X	Loose wires.	Added extra tape to left wrist sensor
10:43 AM	1:38:43	X	Start PATH	*Window 2* – Blended 1 door panel and
10:59 AM	1:55:13	X	End PATH	replaced grinding wheel.
11:29 AM	2:27:21		Box Off	
11:30 AM	0:00:00		Box On	
	0:00:35	X	Start Calibration	
	0:02:40	X	End Calibration	Followed Protocol – 24 PATH Presses
11:34 AM	0:03:10		Box Off	File 3
				2 PATH Windows – 3 Data Files

A.2 Sample PATH Form





1. Trunk Angle (with vertical axis)

	<20	20-45	>45	Back	Twist	CSNS
1						
2						
3						
4						
5						
6						
7						
8						
9						
10						

Arm Angle (with trunk)

	Neutral	1 arm >60	2 arms >60	CSNS
1				
2				
3				
4				
5				
6				
7				
8				
9				
10				

Head Angle (with trunk)

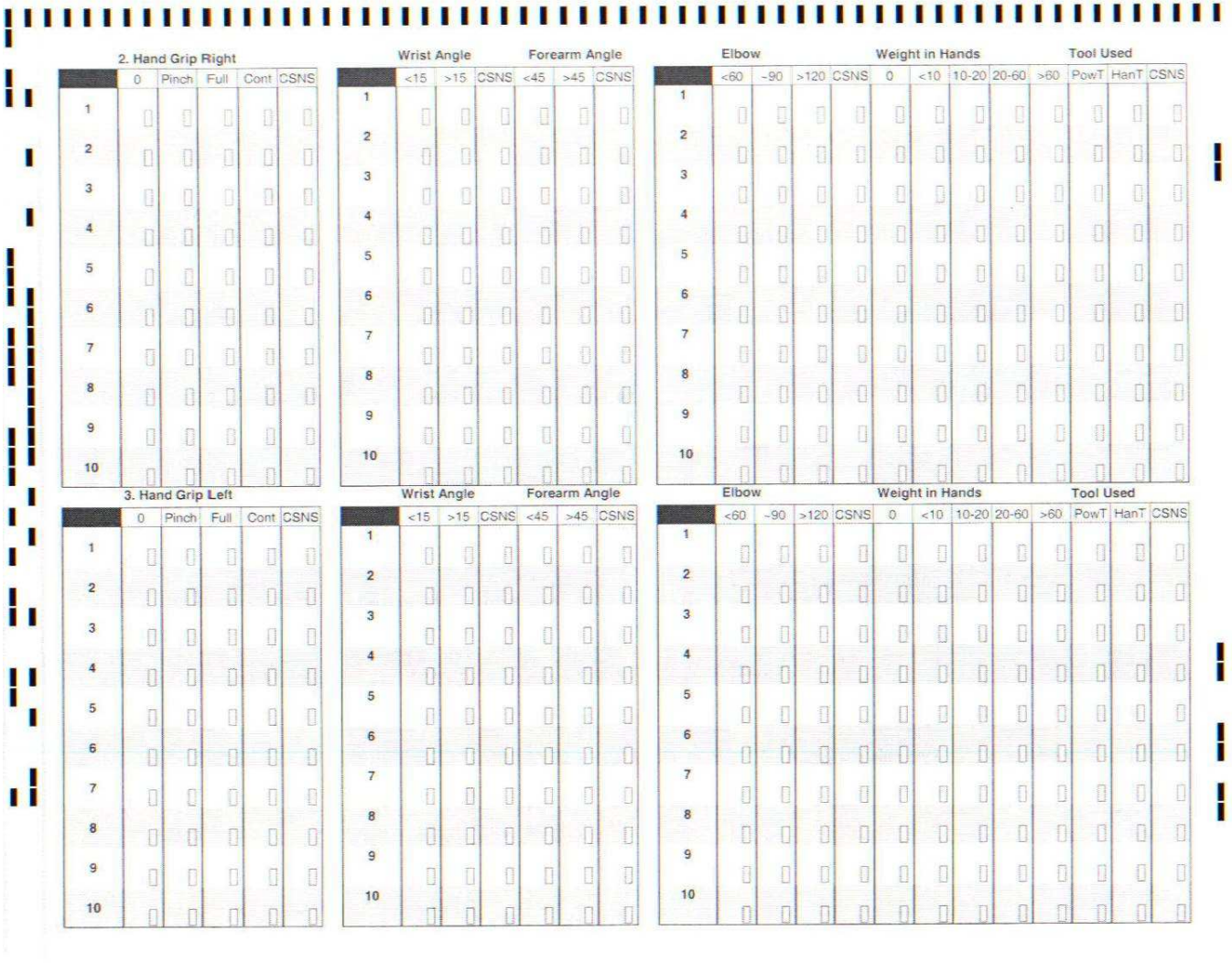
	<20	20-45	>45	Back	Twist	CSNS
1						
2						
3						
4						
5						
6						
7						
8						
9						
10						

Other Load / Hands Used

	0	Hold	Move	Lift	1Hnd	2Hnds	CSNS
1							
2							
3							
4							
5							
6							
7							
8							
9							
10							

Legs

	Stand	Walk/RN	Sit	Kneel	Squat	Lunge	Crawl	Lie	1 Foot	Ladder	CSNS
1											
2											
3											
4											
5											
6											
7											
8											
9											
10											


2. Hand Grip Right
0
Pinch
Full
Cont
CSNS
Wrist Angle
<15
>15
CSNS
Forearm Angle
<45
>45
CSNS
Elbow
<60
~90
>120
CSNS
Weight in Hands
0
<10
10-20
20-60
>60
Tool Used
PowT
HanT
CSNS
3. Hand Grip Left
1
2
3
4
5
6
7
8
9
10

A.3 MATLAB Code

```
function
[Fs,neutral,UT,LT,UTarray,LTarray,AngStat,AngOverall]=EGDLdatanalysisFULL(input
filedirectory,filenumber,channelnumber,outputdirectory,UT,LT,neutral)
%example
[Fs,neutral,UT,LT,UTarray,LTarray,AngStat,AngOverall]=EGDLdatanalysisFULL('C:\
My Documents',5,2,'C:\My Documents\Output',15,-15,9.5)

% Function: EGDLdatanalysisFULL - Analyzes a full of electrogoniometer data
% logger displacement curve file to determine upper and lower excursion
% regions and histogram information. Saves 5 additional files.

% Inputs:
% inputfiledirectory=Directory Where Input Files are Located
% filenumber=Number of File to be Analyzed
% channelnumber=Number of Channel to be Analyzed
% outputdirectory=Directory to Store Output Files
% UT=Upper Threshold Angle
% LT=Lower Threshold Angle
% neutral=Angle Response from Calibration during Neutral Mounting Position

% Outputs:
% Fs=Measured Sampling Rate
% neutral=Angle Response from Calibration during Neutral Mounting Position
% UT=Upper Threshold Angle
% LT=Lower Threshold Angle
% UTarray=Upper Threshold Excursion Region Full Data
% LTarray=Lower Threshold Excursion Region Full Data
% AngStat=Histogram Statistics of Data
% AngOverall=Angle Occurence Data to Generate Histograms
% Figures: thresholdplot=Plot of Channel Data with Thresholds, histogram=Histogram
Plot
% Files: UTstat.txt=Upper Threshold Statistics, LTstat.txt=Lower Threshold Statistics,
histstat.txt=Histogram Statistics

close all
tic
%% Read In File
if filenumber<10

datafilename=[inputfiledirectory,'\0000000',num2str(filenumber),'_rCH',num2str(channel
number),'_ANG.txt'];
else

datafilename=[inputfiledirectory,'\000000',num2str(filenumber),'_rCH',num2str(channeln
umber),'_ANG.txt'];
```

```
end
fid=fopen(datafilename);
datao=fscanf(fid,'%g %g',[2 inf]);
fclose(fid);
datao=datao';
Fs=1/(datao(2,1)-datao(1,1)); %Hz
data=[datao(:,1),datao(:,2)-neutral]; % Reset Data to Neutral Position
%% Overall Calculations
AMax=max(data(:,2)); %Maximum Value of Data
AMin=min(data(:,2)); %Minimum Value of Data
Time=max(data(:,1)); %Total Time of Data
TArea=trapz(data(:,1),abs(data(:,2))); %Total absolute Area under Data Curve Based on
Defined Neutral as 0
%% Establish & Plot Data with Thresholds
figure('Name','Data Plot')
set(1,'tag','Data Plot');
UTp=UT*ones(length(data),1);
LTp=LT*ones(length(data),1);
neutralp=zeros(length(data),1);
plot(data(:,1),data(:,2))
hold on
plot(data(:,1),UTp,'r','LineWidth',3);
plot(data(:,1),LTp,'r','LineWidth',3);
plot(data(:,1),neutralp,'k--','LineWidth',3);
xlabel('Time (sec)')
ylabel('Angle (deg)')
hgsave([outputdirectory,'\F',num2str(filenumber),'CH',num2str(channelnumber),'threshol
dplot'])
%% Upper Excursion Regions
UTd=[]; %Upper Excursion Region Data
UTt=[]; %Upper Excursion Region Time
for a=1:length(data) %Identify Data above Upper Threshold
   if data(a,2)>=UT
      UTd=[UTd;data(a,2)];
      UTt=[UTt;data(a,1)];
   end
end
if isempty(UTt)==1
   UTarray='No Upper Threshold Excursion Regions';
   UTstat=0;
else
UTstart=1; %Upper Excursion Region Start Time
UTend=[]; %Upper Excursion Region End Time
for b=1:length(UTt)-1 %Identify Upper Threshold Excursion Region Start and Stop Time
Indicies
   if (UTt(b+1,1)-UTt(b,1))>1/(Fs-1)
```

```
        UTstart=[UTstart,b+1];
        UTend=[UTend,b];
    end
end
UTend=[UTend,length(UTt)];

delind=[];
for b=1:length(UTstart) %Identify indices to be deleted because start and stop times are
equivalent
    if UTstart(b)==UTend(b)
        delind=[delind,b];
    end
end
c=length(delind); %Delete indices because start and stop times are equivalent
for b=1:c
    UTstart(delind(c))=[];
    UTend(delind(c))=[];
    c=c-1;
end

UTr=[]; %Upper Threshold Excursion Region
UTET=[]; %Upper Threshold Excursion Region Time
UTArea=[]; %Upper Threshold Excursion Region Area
UTPeak=[]; %Upper Threshold Excursion Region Peak
UTst=[]; %Upper Threshold Excursion Region Start Time
UTtr=[]; %Upper Threshold Excursion Region Time Ratio
UTar=[]; %Upper Threshold Excursion Region Area Ratio
numerr=0;
for c=1:length(UTstart)
    UTr=[UTr;c];
    UTst=[UTst;UTt(UTstart(1,c))];
    UTET=[UTET;UTt(UTend(1,c))-UTt(UTstart(1,c))];
    if isscalar(UTt(UTstart(1,c):UTend(1,c)))
        numerr=numerr+1;
    else

UTArea=[UTArea;trapz(UTt(UTstart(1,c):UTend(1,c)),UTd(UTstart(1,c):UTend(1,c))-
UT)];
    end
    UTPeak=[UTPeak;max(UTd(UTstart(1,c):UTend(1,c)))+neutral];
    UTtr=[UTtr;(UTt(UTend(1,c))-UTt(UTstart(1,c)))/Time*100];
    UTar=[UTar;trapz(UTt(UTstart(1,c):UTend(1,c)),UTd(UTstart(1,c):UTend(1,c))-
UT)/TArea*100];
end
```

```
UTstat=[sum(UTET),sum(UTArea),0,sum(UTtr),sum(UTar);mean(UTET),mean(UTAre
a),mean(UTPeak),0,0;max(UTET),max(UTArea),max(UTPeak),0,0;min(UTET),min(UT
Area),min(UTPeak),0,0];
UTheader={'Region','Start Time (sec)','Event Time (sec)','Area (degree sec)','Peak
(degree)','Time Ratio (%)','Area Ratio (%)'};
UTtot={'Total',length(UTr),sum(UTET),sum(UTArea),'',sum(UTtr),sum(UTar);'Average'
,'',mean(UTET),mean(UTArea),mean(UTPeak),mean(UTtr),mean(UTar);'Maximum','',m
ax(UTET),max(UTArea),max(UTPeak),max(UTtr),max(UTar);'Minimum','',min(UTET),
min(UTArea),min(UTPeak),min(UTtr),min(UTar);'Total
Time','',max(data(:,1)),'','','';'Total Curve Area','','',TArea,'','',};
UTarray={};
for d=1:length(UTstart)
   UTarray(d,1)={UTr(d)};
   UTarray(d,2)={UTst(d)};
   UTarray(d,3)={UTET(d)};
   UTarray(d,4)={UTArea(d)};
   UTarray(d,5)={UTPeak(d)};
   UTarray(d,6)={UTtr(d)};
   UTarray(d,7)={UTar(d)};
end
UTarray=[UTheader;UTarray;UTtot];
end
%% Lower Excursion Regions
LTd=[]; %Lower Excursion Region Data
LTt=[]; %Lower Excursion Region Time
for a=1:length(data) %Identify Data below Lower Threshold
   if data(a,2)<=LT
      LTd=[LTd;data(a,2)];
      LTt=[LTt;data(a,1)];
   end
end

if isempty(LTt)==1
   LTarray='No Lower Threshold Excursion Regions';
   LTstat=0;
else
LTstart=1; %Lower Excursion Region Start Time
LTend=[]; %Lower Excursion Region Stop Time
for b=1:length(LTt)-1 %Identify Lower Threshold Excursion Region Start and Stop Time
   if LTt(b+1,1)-LTt(b,1)>1/(Fs-1)
      LTstart=[LTstart,b+1];
      LTend=[LTend,b];
   end
end
LTend=[LTend,length(LTt)];
```

```
delind=[]; %Identify indices to be deleted because start and stop times are equivalent
for b=1:length(LTstart)
   if LTstart(b)==LTend(b)
      delind=[delind,b];
   end
end
c=length(delind); %Delete indices because start and stop times are equivalent
for b=1:c
   LTstart(delind(c))=[];
   LTend(delind(c))=[];
   c=c-1;
end

LTr=[]; %Lower Threshold Excursion Region
LTET=[]; %Lower Threshold Excursion Region Time
LTArea=[]; %Lower Threshold Excursion Region Area
LTPeak=[]; %Lower Threshold Excursion Region Peak
LTst=[]; %Lower Threshold Excursion Region Start Time
LTtr=[]; %Lower Threshold Excursion Region Time Ratio
LTar=[]; %Lower Threshold Excursion Region Area Ratio
for c=1:length(LTstart)
   LTr=[LTr;c];
   LTst=[LTst;LTt(LTstart(1,c))];
   LTET=[LTET;LTt(LTend(1,c))-LTt(LTstart(1,c))];
   LTArea=[LTArea;trapz(LTt(LTstart(1,c):LTend(1,c)),LTd(LTstart(1,c):LTend(1,c))-
LT)];
   LTPeak=[LTPeak;min(LTd(LTstart(1,c):LTend(1,c)))+neutral];
   LTtr=[LTtr;(LTt(LTend(1,c))-LTt(LTstart(1,c)))/Time*100];
   LTar=[LTar;trapz(LTt(LTstart(1,c):LTend(1,c)),LTd(LTstart(1,c):LTend(1,c))-
LT)/TArea*100];
end
LTstat=[sum(LTET),sum(LTArea),0,sum(LTtr),sum(LTar);mean(LTET),mean(LTArea),
mean(LTPeak),0,0;max(LTET),max(LTArea),max(LTPeak),0,0;min(LTET),min(LTArea
),min(LTPeak),0,0];
LTheader={'Region','Start Time (sec)','Event Time (sec)','Area (degree sec)','Peak
(degree)','Time Ratio (%)','Area Ratio (%)'};
LTtot={'Total',length(LTr),sum(LTET),sum(LTArea),'',sum(LTtr),sum(LTar);'Average','
',mean(LTET),mean(LTArea),mean(LTPeak),mean(LTtr),mean(LTar);'Maximum','',max(
LTET),max(LTArea),max(LTPeak),max(LTtr),max(LTar);'Minimum','',min(LTET),min(
LTArea),min(LTPeak),min(LTtr),min(LTar);'Total Time','',max(data(:,1)),'','','';'Total
Curve Area','','',TArea,'','',''};
LTarray={};
for d=1:length(LTstart)
   LTarray(d,1)={LTr(d)};
   LTarray(d,2)={LTst(d)};
   LTarray(d,3)={LTET(d)};
```

```
    LTarray(d,4)={LTArea(d)};
    LTarray(d,5)={LTPeak(d)};
    LTarray(d,6)={LTtr(d)};
    LTarray(d,7)={LTar(d)};
end
LTarray=[LTheader;LTarray;LTtot];
end

%% Histogram Calculations
figure('Name','Histogram')
[AFreq,Ang]=hist(data(:,2),floor(AMin):1:floor(AMax));
hist(data(:,2),floor(AMin):1:floor(AMax));
set(2,'tag','Histogram');
ylabel('Number of Occurences')
xlabel('Angle (degrees)')
xlim([floor(AMin)-.5 floor(AMax)+.5])
hgsave([outputdirectory,'\F',num2str(filenumber),'CH',num2str(channelnumber),'histogra
m'])
AngOverall=cell(length(Ang)+1,2);
AngOverall(1,1)={'Angle (degrees)'};
AngOverall(1,2)={'Number of Occurences'};
modeD={};
moded=[];
for d=1:length(Ang)
    if AFreq(d)==max(AFreq)
        modeD=[modeD,Ang(d)];
        moded=[moded,Ang(d)];
    end
    AngOverall(d+1,1)={Ang(d)};
    AngOverall(d+1,2)={AFreq(d)};
end
AngStat={'Mean',sum(data(:,2))/length(data(:,2));'Standard
Error',std(AFreq)/sqrt(length(data(:,2)));'Median',median(sort(data(:,2)));'Mode',modeD;'
Standard Deviation',std(AFreq);'Sample
Variance',var(AFreq);'Kurtosis',kurtosis(AFreq);'Skewness',skewness(AFreq);'Range',A
Max-
AMin;'Minimum',AMin;'Maximum',AMax;'Sum',sum(data(:,2));'Count',length(data(:,2))
};
%% Write Data to File
fid=fopen([outputdirectory,'\F',num2str(filenumber),'CH',num2str(channelnumber),'UTst
at.txt'],'at');
fprintf(fid,'%6.2f\t%6.2f\t%6.2f\t%6.2f\t%6.2f\n',UTstat');
fclose(fid);

fid=fopen([outputdirectory,'\F',num2str(filenumber),'CH',num2str(channelnumber),'LTsta
t.txt'],'at');
```

```
fprintf(fid,'%6.2f\t%6.2f\t%6.2f\t%6.2f\t%6.2f\n',LTstat');
fclose(fid);

histstat=[Fs;neutral;UT;LT;sum(data(:,2))/length(data(:,2));std(AFreq)/sqrt(length(data(:,
2)));median(sort(data(:,2)));moded(1);std(AFreq);var(AFreq);kurtosis(AFreq);skewness(
AFreq);AMax-
AMin;AMin;AMax;sum(data(:,2));length(data(:,2));max(data(:,1));TArea];
fid=fopen([outputdirectory,'\F',num2str(filenumber),'CH',num2str(channelnumber),'histst
at.txt'],'at');
fprintf(fid,'%12.2f\n',histstat);
fclose(fid);

subjnum=inputfiledirectory(length(inputfiledirectory)-3:length(inputfiledirectory));

runtime=toc;
disp(['The running of EGDLdatanalysis.m for subject ',num2str(subjnum),' file
',num2str(filenumber),' channel ',num2str(channelnumber),' full data run required
',num2str(runtime),' seconds.'])
```

A.4 Wrist Motion Histograms of Additional Packer Subjects (Site 1)

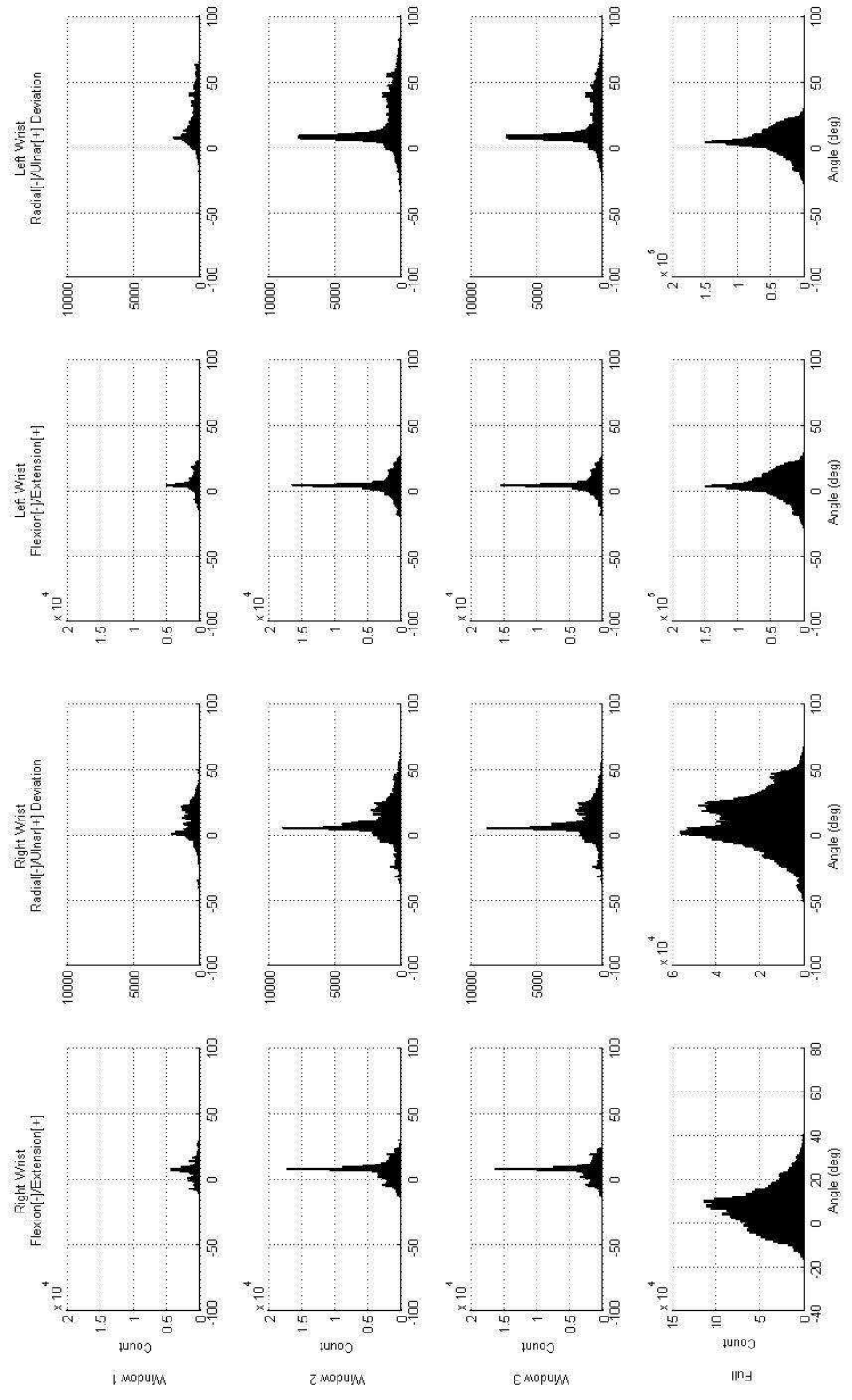


Figure 21: Wrist Motion Histograms for Packer #2 (Subject 02)

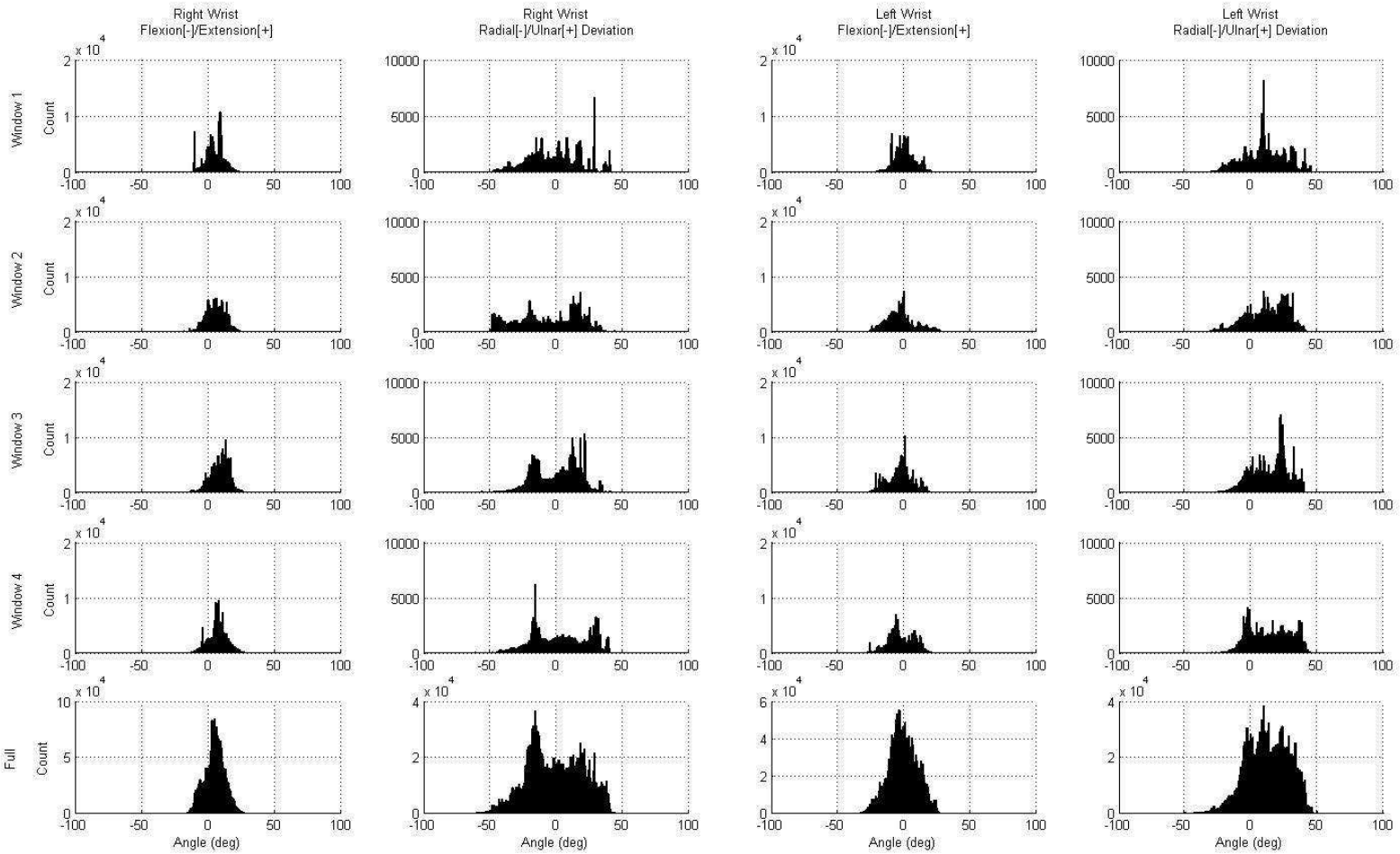


Figure 22: Wrist Motion Histograms for Packer #3 (Subject 08)

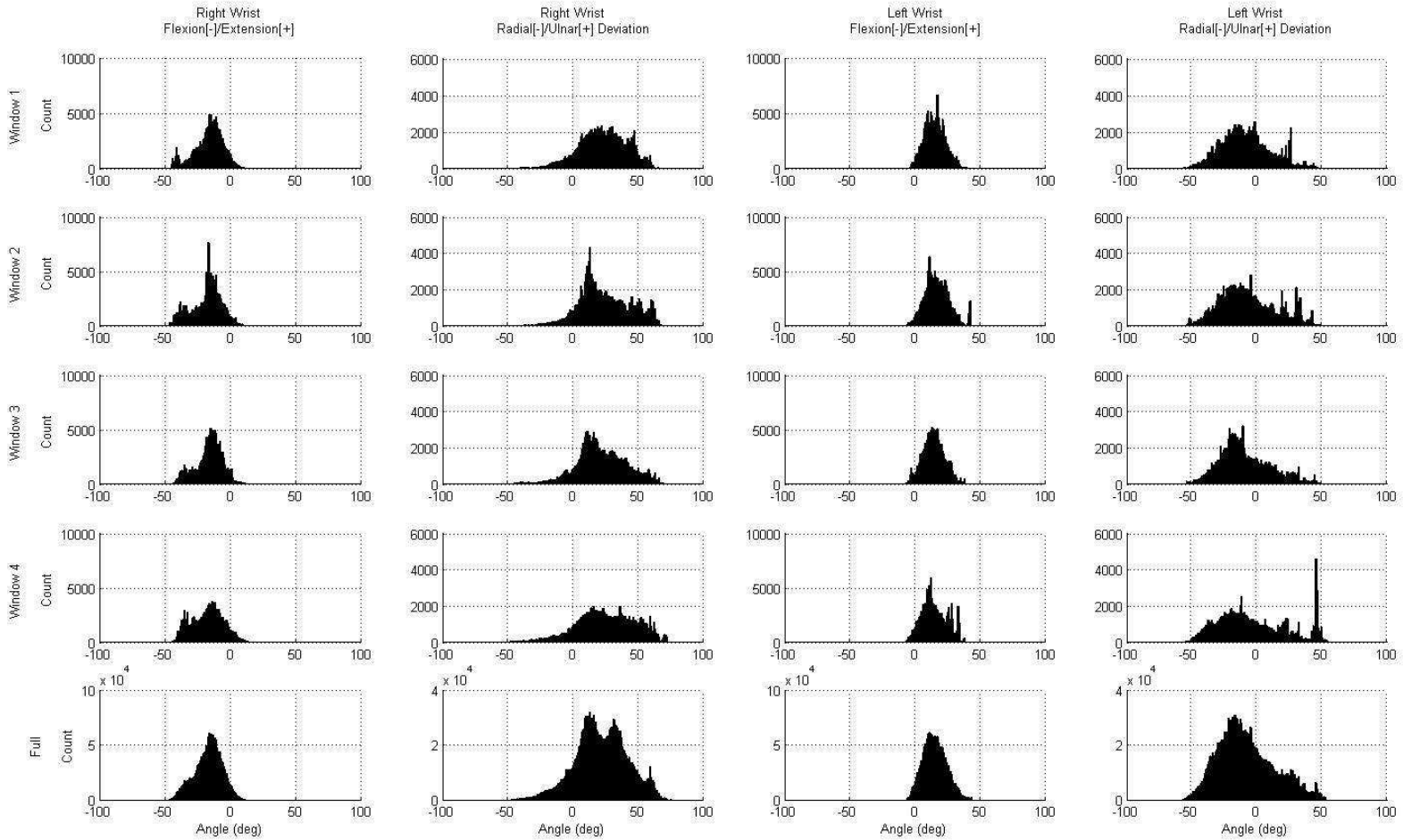


Figure 23: Wrist Motion Histograms for Packer #4 (Subject 09)

A.5 Full Subject Data for Site 1

Subject	Job Description	Total Data Logging Time (H:MM:SS)	Observation Windows
01	Packer	5:05:35	7
02	Packer	5:19:51	3
03	Back Tender	3:25:30	3
04	Material Operator	4:37:35	3
05	Machine Operator	5:05:00	5
06	Material Handler	4:56:00	2
07	Machine Operator	2:26:09	2
08	Packer	3:08:30	4
09	Packer	3:23:02	4
10	Machine Operator	1:55:46	3
11	Machine Helper	2:15:46	3
12	Material Operator	2:58:21	3
13	Machine Operator	3:53:40	2
14	Machine Operator	2:43:00	4
15	Technical Assistant	2:14:45	1
16	Quality Manager	2:18:30	3
17	Research Director	2:22:00	3
18	Machine Superintendent	1:47:53	3

Subject 02		Full Waveform		Windows (n=3)			
		Right	Left	Right (Avg.)	Right (S.D.)	Left (Avg.)	Left (S.D.)
Ulnar Deviation (Upper Excursions)	Max. Excursion Time (sec)	93.86	135.01	19.75	2.14	31.85	13.72
	Max. Excursion Area (deg-sec)	3404.80	5496.97	270.97	67.55	985.39	378.32
	Total Excursion Time (sec)	8033.74	9291.70	238.50	84.35	305.64	99.76
	Total Excursion Time (%)	40.85	47.25	11.25	6.34	14.80	9.05
	Total Excursion Area (deg-sec)	110893.24	201892.31	2881.76	1266.32	7221.33	2910.17
	Total Excursion Area (%)	32.25	45.25	27.68	1.21	47.45	0.76
Radial Deviation (Lower Excursions)	Max. Excursion Time (sec)	68.70	53.15	17.87	10.73	2.99	0.66
	Max. Excursion Area (deg-sec)	-1307.91	-975.23	-164.06	38.24	-71.69	17.67
	Total Excursion Time (sec)	1917.34	1645.42	44.21	21.79	19.67	8.98
	Total Excursion Time (%)	9.75	8.37	1.83	0.56	0.85	0.33
	Total Excursion Area (deg-sec)	-19655.80	-18353.16	-445.87	169.33	-225.23	87.86
	Total Excursion Area (%)	-5.72	-4.11	-4.37	0.31	-1.49	0.01
Radial[-]/Ulnar[+] Deviation Histogram Statistics	Mean (deg)	10.05	16.48	9.71	0.30	18.86	0.64
	Median (deg)	9.54	13.22	7.86	1.12	11.59	3.13
	Mode (deg)	2.00	6.00	3.67	2.31	7.00	0.00
	Maximum (deg)	79.37	87.78	72.19	1.44	81.68	7.75
	Minimum (deg)	-67.93	-64.62	-51.49	3.74	-56.59	0.39
	Range (deg)	147.30	152.40	123.68	5.18	138.27	8.14
	Standard Deviation (deg)	17016.11	14759.32	985.79	450.76	940.73	477.84
	Skewness	0.86	1.15	2.74	1.13	3.26	1.44
	Kurtosis	2.35	4.24	13.63	8.18	16.27	9.04

Subject 02		Full Waveform		Windows (n=3)			
		Right	Left	Right (Avg.)	Right (S.D.)	Left (Avg.)	Left (S.D.)
Extension (Upper Excursions)	Max. Excursion Time (sec)	145.97	31.95	16.54	4.72	6.51	1.83
	Max. Excursion Area (deg-sec)	1071.30	169.23	78.66	12.27	33.97	0.91
	Total Excursion Time (sec)	3608.23	2535.42	92.59	32.98	73.80	14.77
	Total Excursion Time (%)	18.35	12.89	4.36	2.46	3.90	2.96
	Total Excursion Area (deg-sec)	25654.67	10010.36	530.88	149.04	304.74	95.36
	Total Excursion Area (%)	13.69	5.92	9.02	2.03	5.96	0.37
Flexion (Lower Excursions)	Max. Excursion Time (sec)	1.85	40.08	0.69	0.65	3.25	1.80
	Max. Excursion Area (deg-sec)	-8.73	-262.82	-2.56	3.35	-28.30	13.20
	Total Excursion Time (sec)	42.91	1072.41	1.79	1.57	17.91	10.29
	Total Excursion Time (%)	0.22	5.45	0.05	0.04	0.70	0.15
	Total Excursion Area (deg-sec)	-89.69	-5859.47	-4.14	4.68	-92.77	48.33
	Total Excursion Area (%)	-0.05	-3.47	-0.05	0.05	-1.70	0.42
Flexion[-]/Extension[+] Histogram Statistics	Mean (deg)	7.08	3.65	6.84	0.26	4.45	0.65
	Median (deg)	6.97	3.95	7.40	0.44	4.16	0.39
	Mode (deg)	10.00	3.00	7.67	0.58	4.00	0.00
	Maximum (deg)	61.93	60.95	47.34	6.14	29.85	1.29
	Minimum (deg)	-24.42	-49.95	-19.33	2.87	-37.34	3.44
	Range (deg)	86.35	110.90	66.67	4.15	67.20	2.15
	Standard Deviation (deg)	33784.92	32661.71	2078.91	1008.96	2126.13	1039.31
	Skewness	1.12	1.90	3.24	0.75	3.28	0.55
	Kurtosis	2.96	6.31	15.88	5.66	15.05	3.44

Subject 03		Full Waveform		Windows (n=3)			
		Right	Left	Right (Avg.)	Right (S.D.)	Left (Avg.)	Left (S.D.)
Ulnar Deviation (Upper Excursions)	Max. Excursion Time (sec)	339.37	164.61	41.55	14.44	27.47	9.71
	Max. Excursion Area (deg-sec)	12891.20	4256.34	1122.66	175.72	664.85	261.85
	Total Excursion Time (sec)	5154.61	4723.48	381.29	88.25	338.17	45.29
	Total Excursion Time (%)	41.75	38.26	5.15	3.48	4.43	2.51
	Total Excursion Area (deg-sec)	86751.20	85690.96	6765.81	1840.15	6383.64	855.76
	Total Excursion Area (%)	35.28	36.29	35.79	5.86	36.69	2.05
Radial Deviation (Lower Excursions)	Max. Excursion Time (sec)	84.96	36.92	31.56	48.33	8.45	7.16
	Max. Excursion Area (deg-sec)	-2997.63	-954.18	-894.78	1434.77	-228.64	184.97
	Total Excursion Time (sec)	1305.36	1143.71	101.74	42.03	80.41	24.98
	Total Excursion Time (%)	10.57	9.26	1.16	0.32	0.98	0.38
	Total Excursion Area (deg-sec)	-21996.71	-15507.63	-1775.68	1279.15	-1271.57	590.28
	Total Excursion Area (%)	-8.95	-6.57	-9.56	6.52	-7.29	3.14
Radial[-]/Ulnar[+] Deviation Histogram Statistics	Mean (deg)	11.10	11.82	10.91	4.32	11.29	1.55
	Median (deg)	10.36	9.91	9.11	3.78	8.20	1.25
	Mode (deg)	4.00	6.00	5.33	2.08	5.00	1.00
	Maximum (deg)	82.53	89.44	79.32	3.94	84.70	4.37
	Minimum (deg)	-86.86	-75.61	-79.56	7.79	-66.77	7.08
	Range (deg)	169.39	165.04	158.88	4.64	151.46	2.99
	Standard Deviation (deg)	9818.11	10747.71	805.59	74.77	906.50	72.25
	Skewness	1.17	1.62	1.61	0.10	2.28	0.04
	Kurtosis	3.15	5.18	5.42	0.53	9.17	0.93

Subject 03		Full Waveform		Windows (n=3)			
		Right	Left	Right (Avg.)	Right (S.D.)	Left (Avg.)	Left (S.D.)
Extension (Upper Excursions)	Max. Excursion Time (sec)	92.46	38.02	22.52	8.78	7.13	5.51
	Max. Excursion Area (deg-sec)	1092.68	198.23	179.13	26.02	81.30	85.83
	Total Excursion Time (sec)	2090.52	1031.60	164.35	30.46	64.35	10.39
	Total Excursion Time (%)	16.93	8.36	2.11	1.04	0.78	0.21
	Total Excursion Area (deg-sec)	13650.37	5739.50	1037.39	84.20	394.42	94.33
	Total Excursion Area (%)	11.41	5.80	11.93	1.63	5.33	1.48
Flexion (Lower Excursions)	Max. Excursion Time (sec)	36.69	66.78	4.38	3.19	20.60	6.44
	Max. Excursion Area (deg-sec)	-76.05	-694.08	-22.15	12.92	-141.54	101.16
	Total Excursion Time (sec)	411.61	904.65	22.26	7.97	85.84	11.13
	Total Excursion Time (%)	3.33	7.33	0.27	0.09	1.12	0.64
	Total Excursion Area (deg-sec)	-913.93	-4776.39	-76.62	29.53	-419.26	171.97
	Total Excursion Area (%)	-0.76	-4.83	-0.87	0.31	-5.58	2.19
Flexion[-]/Extension[+] Histogram Statistics	Mean (deg)	4.94	0.39	6.10	0.33	-0.72	0.34
	Median (deg)	5.21	1.00	5.78	0.66	0.07	0.30
	Mode (deg)	5.00	2.00	4.33	1.15	1.33	0.58
	Maximum (deg)	60.19	57.88	43.48	3.28	37.48	2.34
	Minimum (deg)	-29.04	-34.70	-26.51	1.44	-33.75	0.82
	Range (deg)	89.22	92.58	69.99	3.09	71.24	2.60
	Standard Deviation (deg)	19170.26	20979.90	1729.31	213.75	1684.23	140.44
	Skewness	1.21	1.69	1.42	0.31	1.61	0.26
	Kurtosis	3.71	5.53	4.44	1.44	5.57	1.50

Subject 04		Full Waveform		Windows (n=3)			
		Right	Left	Right (Avg.)	Right (S.D.)	Left (Avg.)	Left (S.D.)
Ulnar Deviation (Upper Excursions)	Max. Excursion Time (sec)	121.47	144.44	4.93	1.78	18.95	6.98
	Max. Excursion Area (deg-sec)	2335.91	3522.97	120.75	20.90	370.65	150.60
	Total Excursion Time (sec)	2758.10	6780.23	94.86	21.48	412.04	44.77
	Total Excursion Time (%)	16.54	40.65	3.53	3.14	15.54	14.69
	Total Excursion Area (deg-sec)	47373.57	151167.82	1210.31	256.20	7285.08	870.95
	Total Excursion Area (%)	15.37	41.81	10.44	2.78	39.86	2.16
Radial Deviation (Lower Excursions)	Max. Excursion Time (sec)	68.47	60.93	10.65	5.46	7.52	6.47
	Max. Excursion Area (deg-sec)	-1660.60	-1293.01	-199.33	125.46	-82.13	70.42
	Total Excursion Time (sec)	5376.08	1935.34	191.74	79.79	61.44	34.22
	Total Excursion Time (%)	32.23	11.60	5.59	3.95	1.65	1.02
	Total Excursion Area (deg-sec)	-76864.58	-20978.44	-2217.57	1596.17	-532.75	195.00
	Total Excursion Area (%)	-24.93	-5.80	-17.62	9.47	-2.93	1.14
Radial[-]/Ulnar[+] Deviation Histogram Statistics	Mean (deg)	-5.27	13.37	-3.83	3.50	14.13	2.68
	Median (deg)	-6.95	10.58	-3.94	2.20	12.08	2.60
	Mode (deg)	-7.00	11.00	-2.67	3.21	2.33	8.50
	Maximum (deg)	77.13	93.23	72.86	1.28	87.59	0.75
	Minimum (deg)	-74.09	-60.82	-69.94	0.66	-58.40	2.39
	Range (deg)	151.22	154.06	142.80	1.65	145.99	3.04
	Standard Deviation (deg)	13220.97	12098.63	1034.69	137.91	805.60	62.18
	Skewness	1.07	1.01	1.56	0.21	1.31	0.63
	Kurtosis	3.03	3.09	4.36	0.77	4.88	3.81

Subject 04		Full Waveform		Windows (n=3)			
		Right	Left	Right (Avg.)	Right (S.D.)	Left (Avg.)	Left (S.D.)
Extension (Upper Excursions)	Max. Excursion Time (sec)	261.62	214.57	140.49	37.41	46.30	14.52
	Max. Excursion Area (deg-sec)	5105.25	1416.54	2628.86	857.17	192.12	114.64
	Total Excursion Time (sec)	14454.20	11517.78	860.35	20.74	545.98	36.22
	Total Excursion Time (%)	86.67	69.06	31.50	29.69	19.30	17.47
	Total Excursion Area (deg-sec)	194672.86	56037.70	14071.14	802.61	2310.49	62.30
	Total Excursion Area (%)	44.83	19.29	50.87	0.99	15.44	0.49
Flexion (Lower Excursions)	Max. Excursion Time (sec)	0.00	0.00	0.00	0.00	0.00	0.00
	Max. Excursion Area (deg-sec)	0.00	0.00	0.00	0.00	0.00	0.00
	Total Excursion Time (sec)	0.00	0.00	0.00	0.00	0.00	0.00
	Total Excursion Time (%)	0.00	0.00	0.00	0.00	0.00	0.00
	Total Excursion Area (deg-sec)	0.00	0.00	0.00	0.00	0.00	0.00
	Total Excursion Area (%)	0.00	0.00	0.00	0.00	0.00	0.00
Flexion[-]/Extension[+] Histogram Statistics	Mean (deg)	26.03	17.42	29.78	0.67	16.12	0.21
	Median (deg)	26.73	17.54	32.23	0.45	16.13	0.36
	Mode (deg)	32.00	18.00	34.00	0.00	18.33	1.53
	Maximum (deg)	77.68	79.84	48.49	0.95	34.27	0.20
	Minimum (deg)	-11.49	2.56	-3.09	0.56	3.77	1.05
	Range (deg)	89.17	77.28	51.59	1.19	30.50	1.21
	Standard Deviation (deg)	29520.38	48524.29	2320.06	174.59	3372.00	178.73
	Skewness	1.09	2.09	1.45	0.06	0.65	0.35
	Kurtosis	2.70	6.58	4.18	0.15	2.29	0.92

Subject 05		Full Waveform		Windows (n=5)			
		Right	Left	Right (Avg.)	Right (S.D.)	Left (Avg.)	Left (S.D.)
Ulnar Deviation (Upper Excursions)	Max. Excursion Time (sec)	73.58	89.97	25.12	9.68	40.99	28.95
	Max. Excursion Area (deg-sec)	2794.64	3240.83	794.05	211.92	890.52	154.80
	Total Excursion Time (sec)	7398.68	8235.54	388.50	68.78	479.96	79.37
	Total Excursion Time (%)	40.04	44.57	9.77	10.03	11.48	11.46
	Total Excursion Area (deg-sec)	151591.15	194656.24	7659.10	1845.64	10793.53	1453.05
	Total Excursion Area (%)	39.49	46.60	38.87	7.79	48.73	1.53
Radial Deviation (Lower Excursions)	Max. Excursion Time (sec)	109.43	51.18	31.54	43.12	11.93	8.69
	Max. Excursion Area (deg-sec)	-4385.36	-2426.11	-1066.79	1846.40	-268.99	268.50
	Total Excursion Time (sec)	1927.61	1179.19	103.88	62.19	60.74	53.62
	Total Excursion Time (%)	10.43	6.38	2.10	1.64	1.12	0.79
	Total Excursion Area (deg-sec)	-34673.95	-21340.92	-2104.06	2335.46	-763.92	643.24
	Total Excursion Area (%)	-9.03	-5.11	-10.00	10.16	-3.32	2.57
Radial[-]/Ulnar[+] Deviation Histogram Statistics	Mean (deg)	11.85	17.35	11.97	5.77	20.03	2.02
	Median (deg)	8.82	11.55	11.35	3.50	16.35	3.33
	Mode (deg)	4.00	6.00	6.80	8.53	11.40	7.96
	Maximum (deg)	94.16	138.45	85.77	9.27	92.06	6.62
	Minimum (deg)	-73.24	-67.28	-64.50	5.76	-53.34	5.59
	Range (deg)	167.40	205.73	150.28	12.73	145.40	8.14
	Standard Deviation (deg)	14320.70	16088.74	664.81	69.38	759.15	155.00
	Skewness	1.49	2.67	1.06	0.37	1.82	0.49
	Kurtosis	4.71	10.91	3.54	1.24	6.99	2.32

Subject 05		Full Waveform		Windows (n=5)			
		Right	Left	Right (Avg.)	Right (S.D.)	Left (Avg.)	Left (S.D.)
Extension (Upper Excursions)	Max. Excursion Time (sec)	31.81	60.93	14.87	11.54	5.29	3.63
	Max. Excursion Area (deg-sec)	182.57	186.66	99.80	60.18	29.84	17.64
	Total Excursion Time (sec)	1658.14	1261.75	120.06	48.23	43.46	24.45
	Total Excursion Time (%)	8.97	6.83	2.87	3.19	1.05	1.34
	Total Excursion Area (deg-sec)	7800.73	3637.44	569.05	220.78	154.72	99.59
	Total Excursion Area (%)	5.62	3.07	7.37	1.99	2.55	1.51
Flexion (Lower Excursions)	Max. Excursion Time (sec)	26.99	71.44	3.42	2.29	4.72	2.67
	Max. Excursion Area (deg-sec)	-129.92	-560.00	-22.91	17.40	-23.96	11.68
	Total Excursion Time (sec)	579.53	774.08	20.70	5.18	39.76	9.95
	Total Excursion Time (%)	3.14	4.19	0.41	0.29	0.94	0.87
	Total Excursion Area (deg-sec)	-1903.26	-3616.96	-76.77	27.97	-156.00	62.11
	Total Excursion Area (%)	-1.37	-3.06	-1.07	0.55	-2.64	0.91
Flexion[-]/Extension[+] Histogram Statistics	Mean (deg)	3.00	0.83	4.58	1.70	-0.24	1.09
	Median (deg)	3.22	0.93	4.69	2.01	-0.17	1.25
	Mode (deg)	3.00	1.00	4.80	4.60	-0.40	2.70
	Maximum (deg)	61.18	59.77	34.57	2.51	29.62	2.58
	Minimum (deg)	-32.05	-42.54	-25.91	0.71	-31.16	1.63
	Range (deg)	93.22	102.31	60.48	2.86	60.78	3.38
	Standard Deviation (deg)	34648.19	38500.85	1708.90	146.51	1968.27	281.04
	Skewness	1.89	2.90	1.11	0.59	1.69	0.39
	Kurtosis	6.16	12.46	3.57	2.02	5.93	1.68

Subject 06		Full Waveform		Windows (n=2)			
		Right	Left	Right (Avg.)	Right (S.D.)	Left (Avg.)	Left (S.D.)
Ulnar Deviation (Upper Excursions)	Max. Excursion Time (sec)	119.76	117.53	58.34	30.00	70.51	13.41
	Max. Excursion Area (deg-sec)	4085.06	2747.90	1686.34	360.89	1333.78	641.09
	Total Excursion Time (sec)	12154.90	11669.16	668.84	162.56	652.97	129.92
	Total Excursion Time (%)	66.61	63.95	5.14	1.10	5.07	1.32
	Total Excursion Area (deg-sec)	203100.22	203119.43	12578.76	1893.45	10851.79	3166.12
	Total Excursion Area (%)	44.88	44.95	51.56	0.35	44.60	6.03
Radial Deviation (Lower Excursions)	Max. Excursion Time (sec)	66.99	35.60	1.36	0.04	25.11	11.05
	Max. Excursion Area (deg-sec)	-1215.38	-1748.24	-30.09	9.00	-1276.90	736.49
	Total Excursion Time (sec)	905.53	1155.03	12.36	2.33	44.57	9.51
	Total Excursion Time (%)	4.96	6.33	0.11	0.06	0.38	0.24
	Total Excursion Area (deg-sec)	-11617.25	-19326.30	-110.45	32.39	-1447.25	832.08
	Total Excursion Area (%)	-2.57	-4.28	-0.47	0.21	-6.37	4.47
Radial[-]/Ulnar[+] Deviation Histogram Statistics	Mean (deg)	21.22	19.44	26.90	2.13	22.06	4.30
	Median (deg)	23.42	24.18	27.26	1.96	26.01	5.78
	Mode (deg)	29.00	34.00	20.50	12.02	14.00	12.73
	Maximum (deg)	75.16	70.71	68.43	3.88	62.10	4.21
	Minimum (deg)	-67.03	-74.31	-48.45	15.90	-72.93	0.61
	Range (deg)	142.19	145.02	116.87	19.78	135.03	4.81
	Standard Deviation (deg)	17239.40	16683.74	938.69	292.43	997.24	202.54
	Skewness	1.08	1.00	1.13	0.48	1.48	0.16
	Kurtosis	2.80	2.72	3.84	1.97	4.18	0.11

Subject 06		Full Waveform		Windows (n=2)			
		Right	Left	Right (Avg.)	Right (S.D.)	Left (Avg.)	Left (S.D.)
Extension (Upper Excursions)	Max. Excursion Time (sec)	50.74	13.89	4.01	1.10	5.61	7.41
	Max. Excursion Area (deg-sec)	694.56	79.35	7.59	1.27	41.39	56.85
	Total Excursion Time (sec)	997.64	305.61	17.28	12.50	28.16	38.90
	Total Excursion Time (%)	5.47	1.67	0.12	0.04	0.30	0.42
	Total Excursion Area (deg-sec)	3842.15	885.77	36.63	17.30	150.78	210.07
	Total Excursion Area (%)	2.13	0.56	0.44	0.22	2.23	3.11
Flexion (Lower Excursions)	Max. Excursion Time (sec)	64.22	60.14	27.37	8.96	42.58	27.24
	Max. Excursion Area (deg-sec)	-284.67	-612.55	-177.96	108.42	-350.32	395.34
	Total Excursion Time (sec)	2893.17	2667.69	179.20	72.15	110.76	53.94
	Total Excursion Time (%)	15.85	14.62	1.59	1.24	0.81	0.04
	Total Excursion Area (deg-sec)	-13916.11	-25402.84	-988.51	621.24	-903.11	679.10
	Total Excursion Area (%)	-7.73	-15.99	-11.39	6.77	-12.75	9.17
Flexion[-]/Extension[+] Histogram Statistics	Mean (deg)	-2.94	-4.64	-5.48	5.18	-2.54	4.33
	Median (deg)	-3.58	-3.22	-5.14	4.83	-1.06	2.74
	Mode (deg)	-5.00	1.00	2.50	7.78	-3.50	3.54
	Maximum (deg)	43.96	45.59	26.91	5.54	22.84	2.87
	Minimum (deg)	-41.63	-53.98	-33.27	0.87	-46.21	4.64
	Range (deg)	85.60	99.57	60.17	6.42	69.05	1.77
	Standard Deviation (deg)	25668.83	29759.70	1393.53	14.34	1704.28	357.31
	Skewness	0.44	1.39	0.52	0.43	1.29	0.30
	Kurtosis	1.54	3.49	2.46	0.32	3.65	0.85

Subject 07		Full Waveform		Windows (n=2)			
		Right	Left	Right (Avg.)	Right (S.D.)	Left (Avg.)	Left (S.D.)
Ulnar Deviation (Upper Excursions)	Max. Excursion Time (sec)	173.44	305.38	106.92	101.00	128.30	83.46
	Max. Excursion Area (deg-sec)	7205.82	9787.36	4145.95	4615.49	3689.54	3674.13
	Total Excursion Time (sec)	4198.47	3841.70	529.31	145.37	592.01	96.39
	Total Excursion Time (%)	47.83	43.76	16.29	9.53	17.89	8.71
	Total Excursion Area (deg-sec)	101007.48	93600.40	14378.44	9719.86	14437.32	7232.44
	Total Excursion Area (%)	47.72	40.45	51.03	18.61	51.86	11.77
Radial Deviation (Lower Excursions)	Max. Excursion Time (sec)	137.75	145.01	4.66	2.72	17.37	17.38
	Max. Excursion Area (deg-sec)	-3701.32	-3573.09	-88.15	66.47	-397.09	439.93
	Total Excursion Time (sec)	815.73	1961.62	60.91	49.28	58.25	15.46
	Total Excursion Time (%)	9.29	22.35	1.55	0.84	1.64	0.12
	Total Excursion Area (deg-sec)	-11388.90	-33400.27	-716.37	636.16	-724.71	186.29
	Total Excursion Area (%)	-5.38	-14.44	-3.35	3.59	-2.71	0.09
Radial[-]/Ulnar[+] Deviation Histogram Statistics	Mean (deg)	15.21	10.45	21.73	14.26	23.58	9.41
	Median (deg)	12.71	7.59	26.17	21.10	29.84	16.50
	Mode (deg)	-5.00	44.00	25.00	46.67	35.50	9.19
	Maximum (deg)	77.67	87.26	70.62	5.00	69.76	5.18
	Minimum (deg)	-73.11	-57.62	-63.00	2.33	-53.22	4.63
	Range (deg)	150.77	144.88	133.61	7.33	122.97	9.81
	Standard Deviation (deg)	7346.83	6066.41	950.33	307.63	1107.98	412.62
	Skewness	1.67	0.65	1.68	1.54	2.32	1.51
	Kurtosis	6.57	2.61	6.78	6.52	11.12	7.42

Subject 07		Full Waveform		Windows (n=2)			
		Right	Left	Right (Avg.)	Right (S.D.)	Left (Avg.)	Left (S.D.)
Extension (Upper Excursions)	Max. Excursion Time (sec)	98.03	324.76	4.74	0.03	16.13	17.95
	Max. Excursion Area (deg-sec)	1362.13	4422.87	50.89	18.70	199.29	250.52
	Total Excursion Time (sec)	810.17	1374.12	72.83	21.92	66.68	23.90
	Total Excursion Time (%)	9.23	15.65	2.04	0.08	1.84	0.04
	Total Excursion Area (deg-sec)	6992.16	10977.48	475.18	139.31	426.01	66.92
	Total Excursion Area (%)	9.18	11.93	5.54	2.13	5.65	1.58
Flexion (Lower Excursions)	Max. Excursion Time (sec)	83.76	129.97	10.20	2.81	17.88	16.31
	Max. Excursion Area (deg-sec)	-1033.79	-1575.57	-81.54	72.03	-184.14	180.98
	Total Excursion Time (sec)	706.13	1304.19	59.49	17.20	73.07	15.32
	Total Excursion Time (%)	8.04	14.86	1.66	0.08	2.08	0.28
	Total Excursion Area (deg-sec)	-4902.23	-8398.27	-295.66	14.48	-522.32	5.99
	Total Excursion Area (%)	-6.43	-9.12	-3.41	0.49	-6.87	0.94
Flexion[-]/Extension[+] Histogram Statistics	Mean (deg)	2.00	-0.55	3.41	3.93	-1.78	1.80
	Median (deg)	2.27	-2.16	5.25	6.22	-2.89	1.78
	Mode (deg)	2.00	-2.00	7.00	5.66	-3.50	2.12
	Maximum (deg)	54.22	137.83	39.95	0.25	35.44	0.27
	Minimum (deg)	-35.20	-45.48	-30.90	0.22	-40.75	1.97
	Range (deg)	89.42	183.31	70.84	0.46	76.20	2.24
	Standard Deviation (deg)	15741.73	11499.15	2264.52	943.35	2238.16	878.76
	Skewness	2.10	3.40	2.57	1.87	2.78	1.75
	Kurtosis	7.50	16.63	11.96	11.13	13.56	11.62

Subject 08		Full Waveform		Windows (n=4)			
		Right	Left	Right (Avg.)	Right (S.D.)	Left (Avg.)	Left (S.D.)
Ulnar Deviation (Upper Excursions)	Max. Excursion Time (sec)	75.65	82.81	40.35	24.99	40.00	15.65
	Max. Excursion Area (deg-sec)	1422.70	1443.17	550.89	391.17	499.51	184.24
	Total Excursion Time (sec)	3159.13	4843.76	269.92	34.79	433.79	98.45
	Total Excursion Time (%)	27.90	42.77	8.41	8.73	11.84	9.37
	Total Excursion Area (deg-sec)	33094.66	57995.80	2573.72	1057.78	4907.82	920.57
	Total Excursion Area (%)	16.19	31.27	15.01	6.36	30.81	3.87
Radial Deviation (Lower Excursions)	Max. Excursion Time (sec)	87.70	24.22	43.18	32.90	6.55	5.25
	Max. Excursion Area (deg-sec)	-2497.31	-361.06	-854.42	1154.92	-69.68	30.64
	Total Excursion Time (sec)	3350.78	574.14	275.77	60.48	44.20	23.06
	Total Excursion Time (%)	29.59	5.07	8.12	7.18	1.90	2.66
	Total Excursion Area (deg-sec)	-35234.32	-5409.14	-3167.90	1864.26	-376.25	142.63
	Total Excursion Area (%)	-17.24	-2.92	-17.82	8.91	-2.43	1.09
Radial[-]/Ulnar[+] Deviation Histogram Statistics	Mean (deg)	-0.80	11.58	-0.45	3.86	11.92	1.77
	Median (deg)	-1.60	11.57	0.78	4.04	12.78	3.03
	Mode (deg)	-16.00	9.00	13.00	19.88	9.25	10.21
	Maximum (deg)	51.77	58.60	43.02	2.39	44.51	2.29
	Minimum (deg)	-87.85	-64.47	-67.42	1.14	-56.44	7.16
	Range (deg)	139.62	123.08	110.44	1.43	100.95	9.37
	Standard Deviation (deg)	9242.08	11611.65	986.09	204.22	1179.18	180.38
	Skewness	0.63	0.61	1.60	0.57	1.49	1.04
	Kurtosis	2.37	1.78	7.51	3.97	6.94	6.37

Subject 08		Full Waveform		Windows (n=4)			
		Right	Left	Right (Avg.)	Right (S.D.)	Left (Avg.)	Left (S.D.)
Extension (Upper Excursions)	Max. Excursion Time (sec)	28.08	45.31	9.47	10.42	7.65	5.86
	Max. Excursion Area (deg-sec)	129.98	227.44	33.56	13.49	39.34	52.91
	Total Excursion Time (sec)	1032.97	885.63	115.52	60.21	43.80	23.04
	Total Excursion Time (%)	9.12	7.82	2.73	1.59	1.44	1.46
	Total Excursion Area (deg-sec)	3795.51	3593.70	388.95	181.79	166.03	165.61
	Total Excursion Area (%)	4.46	3.62	4.64	1.36	2.13	1.98
Flexion (Lower Excursions)	Max. Excursion Time (sec)	2.61	40.28	1.44	1.38	20.20	16.29
	Max. Excursion Area (deg-sec)	-6.43	-317.31	-3.10	2.59	-149.11	100.30
	Total Excursion Time (sec)	22.59	1069.73	1.74	1.55	98.25	59.60
	Total Excursion Time (%)	0.20	9.45	0.04	0.03	1.92	0.69
	Total Excursion Area (deg-sec)	-43.76	-6040.29	-3.37	2.79	-479.32	265.20
	Total Excursion Area (%)	-0.05	-6.09	-0.05	0.04	-5.88	2.91
Flexion[-]/Extension[+] Histogram Statistics	Mean (deg)	4.92	-0.75	6.49	1.92	-1.96	1.40
	Median (deg)	5.16	-1.15	6.93	2.23	-2.19	1.57
	Mode (deg)	5.00	-4.00	9.00	2.94	-3.50	4.80
	Maximum (deg)	59.83	60.90	31.70	3.01	26.45	2.24
	Minimum (deg)	-26.28	-53.68	-19.71	1.34	-36.90	5.00
	Range (deg)	86.11	114.59	51.41	3.78	63.36	6.79
	Standard Deviation (deg)	23293.71	16392.47	2417.02	259.36	1857.97	272.04
	Skewness	1.56	1.27	1.17	0.53	1.30	0.32
	Kurtosis	4.40	3.26	3.58	1.67	4.40	1.47

Subject 09		Full Waveform		Windows (n=4)			
		Right	Left	Right (Avg.)	Right (S.D.)	Left (Avg.)	Left (S.D.)
Ulnar Deviation (Upper Excursions)	Max. Excursion Time (sec)	220.52	67.32	41.53	19.93	47.47	23.03
	Max. Excursion Area (deg-sec)	3687.92	1661.69	1377.25	587.05	751.86	647.88
	Total Excursion Time (sec)	7449.19	1983.27	589.72	25.37	173.53	58.00
	Total Excursion Time (%)	61.08	16.26	18.97	17.59	4.91	3.80
	Total Excursion Area (deg-sec)	142990.39	27158.17	11935.01	1676.78	2544.24	1577.66
	Total Excursion Area (%)	47.22	11.31	48.96	3.12	13.33	6.55
Radial Deviation (Lower Excursions)	Max. Excursion Time (sec)	23.56	48.58	2.99	0.89	12.72	2.28
	Max. Excursion Area (deg-sec)	-166.97	-863.42	-50.33	24.87	-229.07	38.00
	Total Excursion Time (sec)	531.12	5221.86	34.64	10.00	372.37	26.39
	Total Excursion Time (%)	4.35	42.81	0.97	0.78	11.65	10.01
	Total Excursion Area (deg-sec)	-5857.96	-66395.57	-422.89	154.71	-4625.01	281.77
	Total Excursion Area (%)	-1.93	-27.65	-1.75	0.61	-25.38	1.53
Radial[-]/Ulnar[+] Deviation Histogram Statistics	Mean (deg)	21.43	-8.25	23.11	1.70	-6.57	2.80
	Median (deg)	21.12	-11.58	22.05	2.35	-10.00	1.94
	Mode (deg)	13.00	-17.00	15.50	4.80	6.75	25.77
	Maximum (deg)	77.09	55.83	71.35	3.17	50.56	3.46
	Minimum (deg)	-66.35	-74.04	-53.95	1.29	-60.18	1.42
	Range (deg)	143.44	129.87	125.30	3.50	110.73	3.05
	Standard Deviation (deg)	10191.59	9522.66	775.62	107.90	747.17	59.94
	Skewness	0.78	0.58	0.69	0.42	0.85	0.60
	Kurtosis	2.18	2.12	2.56	1.28	4.17	3.85

Subject 09		Full Waveform		Windows (n=4)			
		Right	Left	Right (Avg.)	Right (S.D.)	Left (Avg.)	Left (S.D.)
Extension (Upper Excursions)	Max. Excursion Time (sec)	0.39	114.04	0.12	0.14	35.51	21.98
	Max. Excursion Area (deg-sec)	0.22	1413.93	0.07	0.09	465.29	428.62
	Total Excursion Time (sec)	1.95	5844.72	0.13	0.16	449.17	51.59
	Total Excursion Time (%)	0.02	47.92	0.01	0.01	14.66	13.31
	Total Excursion Area (deg-sec)	1.41	46152.71	0.07	0.09	3557.36	772.24
	Total Excursion Area (%)	0.00	24.70	0.00	0.00	24.43	3.32
Flexion (Lower Excursions)	Max. Excursion Time (sec)	151.95	0.00	25.57	7.77	0.00	0.00
	Max. Excursion Area (deg-sec)	-1674.84	0.00	-534.21	116.77	0.00	0.00
	Total Excursion Time (sec)	6454.43	0.00	493.98	51.55	0.00	0.00
	Total Excursion Time (%)	52.92	0.00	15.40	13.13	0.00	0.00
	Total Excursion Area (deg-sec)	-62343.64	0.00	-5187.15	805.67	0.00	0.00
	Total Excursion Area (%)	-29.88	0.00	-31.57	2.84	0.00	0.00
Flexion[-]/Extension[+] Histogram Statistics	Mean (deg)	-16.76	15.14	-17.16	0.91	15.32	1.04
	Median (deg)	-15.79	14.55	-15.76	0.91	14.56	1.05
	Mode (deg)	-16.00	11.00	-15.50	1.29	13.25	2.63
	Maximum (deg)	42.35	89.87	14.72	1.82	42.67	1.52
	Minimum (deg)	-51.78	-10.23	-47.66	1.36	-7.74	1.47
	Range (deg)	94.13	100.09	62.38	2.86	50.41	2.20
	Standard Deviation (deg)	18891.68	20430.11	1441.69	231.14	1700.33	139.78
	Skewness	1.10	1.21	0.85	0.67	0.48	0.08
	Kurtosis	2.93	2.92	3.28	1.94	2.12	0.22

Subject 10		Full Waveform		Windows (n=3)			
		Right	Left	Right (Avg.)	Right (S.D.)	Left (Avg.)	Left (S.D.)
Ulnar Deviation (Upper Excursions)	Max. Excursion Time (sec)	85.36	43.61	52.64	30.54	18.65	8.39
	Max. Excursion Area (deg-sec)	2053.59	1588.58	1160.20	862.97	460.09	275.75
	Total Excursion Time (sec)	2088.17	1875.40	277.52	102.74	245.17	72.01
	Total Excursion Time (%)	30.02	26.96	7.32	2.08	6.39	0.81
	Total Excursion Area (deg-sec)	31429.87	27006.07	4087.70	1869.07	3403.51	1062.25
	Total Excursion Area (%)	30.57	26.99	32.98	4.73	28.66	3.17
Radial Deviation (Lower Excursions)	Max. Excursion Time (sec)	37.87	35.09	4.63	0.27	16.76	16.96
	Max. Excursion Area (deg-sec)	-1137.46	-1200.58	-155.01	74.67	-234.68	147.85
	Total Excursion Time (sec)	651.36	679.61	46.90	4.66	73.43	21.09
	Total Excursion Time (%)	9.36	9.77	1.37	0.75	2.07	0.89
	Total Excursion Area (deg-sec)	-8966.19	-9664.83	-762.86	65.56	-948.87	311.67
	Total Excursion Area (%)	-8.72	-9.66	-6.77	2.24	-8.49	3.39
Radial[-]/Ulnar[+] Deviation Histogram Statistics	Mean (deg)	6.50	6.02	8.98	2.50	7.46	1.32
	Median (deg)	1.96	3.65	6.54	4.12	5.96	2.55
	Mode (deg)	-2.00	0.00	-2.33	1.53	-0.33	2.08
	Maximum (deg)	66.19	70.12	58.18	4.31	65.79	2.71
	Minimum (deg)	-82.70	-75.24	-80.61	1.97	-64.17	4.89
	Range (deg)	148.89	145.36	138.78	3.66	129.96	3.35
	Standard Deviation (deg)	8232.69	7507.35	1027.23	517.31	849.62	355.25
	Skewness	3.21	2.10	3.77	2.90	2.36	0.95
	Kurtosis	16.29	7.52	28.11	34.04	10.72	7.02

Subject 10		Full Waveform		Windows (n=3)			
		Right	Left	Right (Avg.)	Right (S.D.)	Left (Avg.)	Left (S.D.)
Extension (Upper Excursions)	Max. Excursion Time (sec)	53.38	11.59	20.04	30.18	3.42	2.22
	Max. Excursion Area (deg-sec)	303.55	111.77	117.02	168.99	21.38	24.68
	Total Excursion Time (sec)	241.29	200.84	42.85	27.87	17.19	10.96
	Total Excursion Time (%)	3.47	2.89	1.07	0.40	0.49	0.31
	Total Excursion Area (deg-sec)	1194.35	1044.63	236.07	180.28	71.36	55.68
	Total Excursion Area (%)	2.25	2.12	3.63	1.84	1.42	0.97
Flexion (Lower Excursions)	Max. Excursion Time (sec)	34.28	22.43	24.69	12.63	12.11	10.48
	Max. Excursion Area (deg-sec)	-184.71	-188.22	-139.31	64.97	-82.29	97.65
	Total Excursion Time (sec)	950.71	420.35	92.70	28.28	62.76	36.42
	Total Excursion Time (%)	13.67	6.04	2.52	0.86	1.49	0.33
	Total Excursion Area (deg-sec)	-3969.55	-1908.52	-405.72	106.07	-308.43	235.82
	Total Excursion Area (%)	-7.47	-3.87	-6.96	2.29	-5.14	2.80
Flexion[-]/Extension[+] Histogram Statistics	Mean (deg)	-2.43	-2.22	-1.59	0.50	-3.05	2.31
	Median (deg)	-0.23	-2.11	0.67	0.63	-3.32	2.68
	Mode (deg)	2.00	-8.00	2.00	1.00	-5.00	4.36
	Maximum (deg)	55.88	61.10	39.32	5.79	27.82	2.28
	Minimum (deg)	-39.50	-36.31	-33.47	5.67	-32.26	3.20
	Range (deg)	95.38	97.41	72.79	6.98	60.09	0.92
	Standard Deviation (deg)	13979.64	13002.24	1697.89	675.30	1779.20	624.87
	Skewness	2.80	1.64	3.18	1.26	1.99	0.70
	Kurtosis	12.39	4.47	17.18	11.78	7.87	4.38

Subject 11		Full Waveform		Windows (n=3)			
		Right	Left	Right (Avg.)	Right (S.D.)	Left (Avg.)	Left (S.D.)
Ulnar Deviation (Upper Excursions)	Max. Excursion Time (sec)	91.36	93.00	21.46	7.44	51.56	38.80
	Max. Excursion Area (deg-sec)	2332.78	2461.55	665.15	260.12	1290.19	903.84
	Total Excursion Time (sec)	3130.09	4620.54	340.67	40.10	586.31	64.96
	Total Excursion Time (%)	38.38	56.66	10.58	5.60	20.08	15.31
	Total Excursion Area (deg-sec)	46775.47	95278.23	5275.55	112.27	12734.11	2212.60
	Total Excursion Area (%)	35.06	50.34	34.91	1.03	53.12	2.45
Radial Deviation (Lower Excursions)	Max. Excursion Time (sec)	14.25	5.72	5.22	0.95	1.87	0.70
	Max. Excursion Area (deg-sec)	-251.84	-56.40	-80.10	59.17	-20.53	9.52
	Total Excursion Time (sec)	309.34	90.75	38.64	10.22	8.17	2.26
	Total Excursion Time (%)	3.79	1.11	1.22	0.81	0.24	0.11
	Total Excursion Area (deg-sec)	-2962.11	-770.71	-424.59	283.93	-69.18	35.50
	Total Excursion Area (%)	-2.22	-0.41	-2.78	1.77	-0.30	0.17
Radial[-]/Ulnar[+] Deviation Histogram Statistics	Mean (deg)	11.30	22.07	11.09	0.65	24.84	3.80
	Median (deg)	9.20	19.18	8.93	1.27	23.48	5.38
	Mode (deg)	-8.00	5.00	-4.67	7.57	15.00	20.88
	Maximum (deg)	77.86	99.06	68.68	4.27	84.93	5.00
	Minimum (deg)	-73.41	-53.77	-59.31	4.95	-43.62	2.98
	Range (deg)	151.28	152.83	127.99	7.86	128.55	4.55
	Standard Deviation (deg)	7734.60	7669.78	919.27	34.56	906.72	63.48
	Skewness	0.95	1.25	1.06	0.24	1.44	0.80
	Kurtosis	2.38	3.76	3.14	0.80	6.32	5.17

Subject 11		Full Waveform		Windows (n=3)			
		Right	Left	Right (Avg.)	Right (S.D.)	Left (Avg.)	Left (S.D.)
Extension (Upper Excursions)	Max. Excursion Time (sec)	61.60	56.62	40.57	11.50	3.77	1.40
	Max. Excursion Area (deg-sec)	942.24	1732.76	440.63	183.53	30.91	17.63
	Total Excursion Time (sec)	5722.85	1649.85	704.15	41.52	45.51	21.02
	Total Excursion Time (%)	70.17	20.23	22.41	13.32	1.42	1.02
	Total Excursion Area (deg-sec)	46858.86	11613.16	5901.71	378.78	218.63	184.26
	Total Excursion Area (%)	30.06	14.27	31.51	1.84	3.39	2.56
Flexion (Lower Excursions)	Max. Excursion Time (sec)	3.98	16.80	0.26	0.32	4.60	3.03
	Max. Excursion Area (deg-sec)	-8.93	-141.13	-0.73	1.21	-15.19	7.57
	Total Excursion Time (sec)	4.73	377.79	0.26	0.32	46.64	10.75
	Total Excursion Time (%)	0.06	4.63	0.01	0.01	1.57	1.24
	Total Excursion Area (deg-sec)	-11.06	-1487.32	-0.73	1.21	-162.36	73.86
	Total Excursion Area (%)	-0.01	-1.83	0.00	0.01	-2.58	0.92
Flexion[-]/Extension[+] Histogram Statistics	Mean (deg)	18.64	3.55	20.00	0.70	-1.13	0.40
	Median (deg)	18.43	0.40	19.42	0.30	-2.00	0.73
	Mode (deg)	17.00	-3.00	17.67	2.52	-3.00	1.00
	Maximum (deg)	70.17	54.65	51.92	6.88	35.99	11.33
	Minimum (deg)	-21.27	-36.33	-17.46	3.30	-28.07	2.90
	Range (deg)	91.45	90.98	69.39	10.14	64.06	14.22
	Standard Deviation (deg)	15141.35	13136.02	1973.64	260.48	2205.86	525.39
	Skewness	1.77	1.85	1.64	0.39	2.15	0.84
	Kurtosis	5.44	7.00	5.52	1.71	8.56	4.32

Subject 12		Full Waveform		Windows (n=3)			
		Right	Left	Right (Avg.)	Right (S.D.)	Left (Avg.)	Left (S.D.)
Ulnar Deviation (Upper Excursions)	Max. Excursion Time (sec)	131.15	118.11	47.94	10.45	84.37	22.84
	Max. Excursion Area (deg-sec)	2022.43	3986.19	1095.08	232.98	3227.00	771.76
	Total Excursion Time (sec)	3991.59	8110.93	357.32	28.63	788.47	72.63
	Total Excursion Time (%)	34.14	69.38	4.76	1.62	10.52	3.71
	Total Excursion Area (deg-sec)	44634.44	197992.06	4326.47	723.84	21442.95	2232.11
	Total Excursion Area (%)	22.54	55.99	24.71	5.88	59.30	3.55
Radial Deviation (Lower Excursions)	Max. Excursion Time (sec)	128.32	69.28	17.47	16.57	5.24	2.17
	Max. Excursion Area (deg-sec)	-2358.43	-971.56	-202.16	155.25	-61.07	48.20
	Total Excursion Time (sec)	1809.98	408.46	150.06	93.79	34.00	27.83
	Total Excursion Time (%)	15.48	3.49	2.04	1.26	0.43	0.34
	Total Excursion Area (deg-sec)	-24189.95	-3221.51	-1688.79	1127.47	-246.55	154.79
	Total Excursion Area (%)	-12.22	-0.91	-9.17	5.13	-0.70	0.47
Radial[-]/Ulnar[+] Deviation Histogram Statistics	Mean (deg)	4.88	27.44	5.37	4.14	31.42	5.79
	Median (deg)	5.77	25.94	4.17	4.26	28.86	5.74
	Mode (deg)	-2.00	17.00	22.67	28.31	18.00	31.05
	Maximum (deg)	100.26	115.79	52.82	4.17	89.56	5.22
	Minimum (deg)	-84.28	-72.39	-63.30	3.88	-43.56	11.00
	Range (deg)	184.55	188.18	116.12	7.34	133.13	16.18
	Standard Deviation (deg)	9412.37	8075.57	978.00	32.84	800.36	56.74
	Skewness	0.93	0.75	0.70	0.13	0.76	0.54
	Kurtosis	2.26	2.20	2.58	0.71	3.24	1.36

Subject 12		Full Waveform		Windows (n=3)			
		Right	Left	Right (Avg.)	Right (S.D.)	Left (Avg.)	Left (S.D.)
Extension (Upper Excursions)	Max. Excursion Time (sec)	123.12	37.65	21.48	6.39	4.91	5.14
	Max. Excursion Area (deg-sec)	2804.64	283.95	251.97	223.60	96.32	122.81
	Total Excursion Time (sec)	2998.28	272.91	214.84	54.50	22.65	35.15
	Total Excursion Time (%)	25.65	2.33	2.73	0.40	0.41	0.67
	Total Excursion Area (deg-sec)	33261.88	1973.82	1436.87	134.00	139.28	123.45
	Total Excursion Area (%)	23.36	0.92	12.64	0.62	0.65	0.60
Flexion (Lower Excursions)	Max. Excursion Time (sec)	44.48	105.55	13.85	11.48	54.60	31.65
	Max. Excursion Area (deg-sec)	-262.28	-6232.95	-44.44	31.00	-2228.83	2757.16
	Total Excursion Time (sec)	356.80	5574.10	35.94	25.05	557.95	215.73
	Total Excursion Time (%)	3.05	47.68	0.49	0.42	6.81	0.47
	Total Excursion Area (deg-sec)	-1597.44	-76155.94	-117.27	95.53	-8812.73	6657.59
	Total Excursion Area (%)	-1.12	-35.66	-1.03	0.89	-37.06	14.72
Flexion[-]/Extension[+] Histogram Statistics	Mean (deg)	8.78	-15.76	7.32	1.88	-17.63	9.25
	Median (deg)	7.77	-14.31	7.77	2.27	-16.39	6.67
	Mode (deg)	6.00	-10.00	7.33	2.31	-18.00	8.00
	Maximum (deg)	125.20	108.56	41.58	1.93	47.26	42.23
	Minimum (deg)	-100.71	-145.16	-29.76	4.02	-77.08	40.01
	Range (deg)	225.91	253.71	71.34	3.47	124.34	82.08
	Standard Deviation (deg)	12852.96	11227.62	2043.67	231.18	1239.96	290.69
	Skewness	2.50	2.51	1.65	0.19	1.30	0.74
	Kurtosis	8.46	8.54	5.41	0.84	4.50	2.08

Subject 13		Full Waveform		Windows (n=2)			
		Right	Left	Right (Avg.)	Right (S.D.)	Left (Avg.)	Left (S.D.)
Ulnar Deviation (Upper Excursions)	Max. Excursion Time (sec)	210.27	74.32	27.99	20.01	50.60	36.51
	Max. Excursion Area (deg-sec)	5480.14	2348.21	838.49	509.05	1759.74	926.14
	Total Excursion Time (sec)	4720.44	5001.04	345.89	42.77	471.41	86.10
	Total Excursion Time (%)	33.63	35.62	3.21	0.41	4.34	0.30
	Total Excursion Area (deg-sec)	84021.13	89914.94	5200.14	138.44	9446.73	1971.33
	Total Excursion Area (%)	30.23	26.22	33.28	0.64	39.90	10.37
Radial Deviation (Lower Excursions)	Max. Excursion Time (sec)	155.60	215.42	9.24	0.65	34.45	36.38
	Max. Excursion Area (deg-sec)	-3297.57	-6626.66	-226.49	115.51	-1031.88	1328.90
	Total Excursion Time (sec)	2919.91	3510.33	76.36	24.85	132.89	105.50
	Total Excursion Time (%)	20.80	25.01	0.75	0.41	1.38	1.31
	Total Excursion Area (deg-sec)	-38815.40	-86964.68	-1057.83	97.62	-2593.51	2562.76
	Total Excursion Area (%)	-13.97	-25.36	-6.79	0.93	-10.61	10.20
Radial[-]/Ulnar[+] Deviation Histogram Statistics	Mean (deg)	5.49	2.68	8.65	1.51	13.35	8.17
	Median (deg)	3.63	5.95	4.94	2.43	14.85	8.34
	Mode (deg)	1.00	6.00	-2.50	4.95	-2.50	62.93
	Maximum (deg)	69.82	66.20	66.16	1.25	64.21	2.81
	Minimum (deg)	-72.64	-79.07	-66.72	8.38	-71.09	0.56
	Range (deg)	142.45	145.27	132.87	7.13	135.29	3.38
	Standard Deviation (deg)	10367.29	8786.95	1101.02	56.58	796.80	118.05
	Skewness	1.00	0.65	2.30	0.35	1.46	0.12
	Kurtosis	3.92	2.48	8.99	1.82	5.63	0.53

Subject 13		Full Waveform		Windows (n=2)			
		Right	Left	Right (Avg.)	Right (S.D.)	Left (Avg.)	Left (S.D.)
Extension (Upper Excursions)	Max. Excursion Time (sec)	93.55	70.63	43.47	58.41	29.12	10.05
	Max. Excursion Area (deg-sec)	1452.76	415.43	274.11	371.60	162.11	123.45
	Total Excursion Time (sec)	2082.02	1675.93	105.66	101.45	113.73	60.05
	Total Excursion Time (%)	14.83	11.94	1.12	1.21	1.00	0.30
	Total Excursion Area (deg-sec)	20466.22	6409.52	723.66	750.02	453.75	270.88
	Total Excursion Area (%)	11.88	5.01	6.08	6.43	5.14	2.75
Flexion (Lower Excursions)	Max. Excursion Time (sec)	94.16	128.53	31.39	15.73	7.57	1.36
	Max. Excursion Area (deg-sec)	-1500.35	-761.88	-574.79	338.05	-33.88	1.12
	Total Excursion Time (sec)	2383.04	1224.82	223.31	128.88	84.22	19.69
	Total Excursion Time (%)	16.98	8.72	1.95	0.69	0.82	0.38
	Total Excursion Area (deg-sec)	-21049.79	-6322.01	-2205.94	1606.03	-432.36	57.06
	Total Excursion Area (%)	-12.22	-4.94	-17.74	12.28	-5.03	1.03
Flexion[-]/Extension[+] Histogram Statistics	Mean (deg)	0.06	0.15	-2.73	6.67	0.64	2.24
	Median (deg)	1.99	-0.57	-0.26	6.49	0.16	1.77
	Mode (deg)	5.00	-1.00	5.00	0.00	5.50	9.19
	Maximum (deg)	53.18	62.76	41.34	1.30	28.03	2.72
	Minimum (deg)	-40.54	-51.83	-35.97	0.35	-37.74	2.91
	Range (deg)	93.72	114.59	77.32	0.95	65.77	0.18
	Standard Deviation (deg)	17627.07	19939.20	1663.42	10.94	1720.72	318.95
	Skewness	1.78	1.30	2.35	0.18	1.61	0.73
	Kurtosis	7.17	3.74	9.97	2.03	6.96	3.82

Subject 14		Full Waveform		Windows (n=4)			
		Right	Left	Right (Avg.)	Right (S.D.)	Left (Avg.)	Left (S.D.)
Ulnar Deviation (Upper Excursions)	Max. Excursion Time (sec)	132.77	103.44	46.88	34.36	34.63	20.20
	Max. Excursion Area (deg-sec)	2836.70	5249.99	1064.65	756.41	853.73	424.74
	Total Excursion Time (sec)	2438.04	2033.87	254.72	105.99	192.14	54.21
	Total Excursion Time (%)	24.90	20.77	9.63	12.44	7.05	8.09
	Total Excursion Area (deg-sec)	43874.37	36865.40	4550.53	2114.70	3459.40	1489.16
	Total Excursion Area (%)	23.77	20.28	26.40	13.17	21.38	10.55
Radial Deviation (Lower Excursions)	Max. Excursion Time (sec)	123.90	89.85	37.31	60.25	39.56	23.10
	Max. Excursion Area (deg-sec)	-6315.03	-5405.21	-1727.49	3178.39	-805.08	732.04
	Total Excursion Time (sec)	1875.56	2150.32	159.32	120.30	212.42	78.81
	Total Excursion Time (%)	19.15	21.96	3.55	1.86	5.23	3.04
	Total Excursion Area (deg-sec)	-36112.51	-44136.07	-3423.91	4183.93	-3326.11	2378.09
	Total Excursion Area (%)	-19.57	-24.28	-16.85	18.33	-19.15	12.23
Radial[-]/Ulnar[+] Deviation Histogram Statistics	Mean (deg)	0.49	-2.48	1.04	10.42	-1.52	5.42
	Median (deg)	-2.63	-4.46	-1.74	6.35	-4.84	1.63
	Mode (deg)	-8.00	-6.00	-9.00	0.82	-2.00	8.04
	Maximum (deg)	86.70	84.68	67.32	10.14	65.17	9.71
	Minimum (deg)	-95.20	-96.66	-74.69	3.69	-69.55	3.64
	Range (deg)	181.90	181.34	142.01	12.83	134.72	11.10
	Standard Deviation (deg)	8075.16	8678.73	1014.32	88.12	1062.47	139.42
	Skewness	2.00	2.40	2.35	0.53	2.64	0.56
	Kurtosis	7.17	9.22	9.25	3.37	11.66	4.21

Subject 14		Full Waveform		Windows (n=4)			
		Right	Left	Right (Avg.)	Right (S.D.)	Left (Avg.)	Left (S.D.)
Extension (Upper Excursions)	Max. Excursion Time (sec)	3.94	109.25	1.75	1.69	35.58	51.46
	Max. Excursion Area (deg-sec)	12.51	1060.81	6.53	5.68	290.96	533.29
	Total Excursion Time (sec)	52.00	1375.72	6.71	8.78	160.48	211.36
	Total Excursion Time (%)	0.53	14.05	0.42	0.77	2.21	1.85
	Total Excursion Area (deg-sec)	117.49	7658.40	15.14	17.86	958.64	1533.83
	Total Excursion Area (%)	0.09	8.78	0.13	0.17	7.77	10.54
Flexion (Lower Excursions)	Max. Excursion Time (sec)	134.13	32.84	41.46	25.10	7.84	5.27
	Max. Excursion Area (deg-sec)	-3422.88	-171.89	-589.95	661.48	-86.14	57.83
	Total Excursion Time (sec)	3346.12	780.82	292.51	92.10	70.46	46.14
	Total Excursion Time (%)	34.17	7.97	7.58	5.34	1.98	1.55
	Total Excursion Area (deg-sec)	-30777.41	-4064.93	-2425.88	1659.44	-377.64	243.80
	Total Excursion Area (%)	-23.52	-4.66	-18.45	9.43	-4.66	2.78
Flexion[-]/Extension[+] Histogram Statistics	Mean (deg)	-11.76	0.78	-11.67	2.88	1.24	6.02
	Median (deg)	-10.26	-0.92	-10.32	1.60	2.46	8.64
	Mode (deg)	-9.00	-2.00	-14.00	9.49	4.00	12.68
	Maximum (deg)	48.01	65.75	23.42	3.09	30.30	4.13
	Minimum (deg)	-44.24	-37.64	-37.72	3.45	-34.97	2.75
	Range (deg)	92.25	103.39	61.14	4.22	65.28	5.87
	Standard Deviation (deg)	16084.94	15917.56	2293.98	89.94	2189.74	621.83
	Skewness	1.66	2.32	2.18	0.55	2.44	0.73
	Kurtosis	5.61	9.75	8.37	3.75	10.68	4.26

Subject 15		Full Waveform		Windows (n=1)			
		Right	Left	Right (Avg.)	Right (S.D.)	Left (Avg.)	Left (S.D.)
Ulnar Deviation (Upper Excursions)	Max. Excursion Time (sec)	129.79	140.70	38.84	0.00	15.67	0.00
	Max. Excursion Area (deg-sec)	2612.28	884.70	608.11	0.00	62.38	0.00
	Total Excursion Time (sec)	3856.49	792.01	551.53	0.00	21.83	0.00
	Total Excursion Time (%)	47.64	9.78	7.06	0.00	0.28	0.00
	Total Excursion Area (deg-sec)	48120.35	3473.85	6843.06	0.00	114.23	0.00
	Total Excursion Area (%)	27.25	4.28	33.75	0.00	1.07	0.00
Radial Deviation (Lower Excursions)	Max. Excursion Time (sec)	219.61	87.62	10.96	0.00	90.10	0.00
	Max. Excursion Area (deg-sec)	-3926.91	-818.52	-206.46	0.00	-841.67	0.00
	Total Excursion Time (sec)	1445.35	1350.61	87.89	0.00	216.60	0.00
	Total Excursion Time (%)	17.86	16.69	1.12	0.00	2.77	0.00
	Total Excursion Area (deg-sec)	-27063.78	-7309.76	-1305.48	0.00	-1545.75	0.00
	Total Excursion Area (%)	-15.33	-9.00	-6.44	0.00	-14.48	0.00
Radial[-]/Ulnar[+] Deviation Histogram Statistics	Mean (deg)	8.46	-3.72	14.29	0.00	-8.63	0.00
	Median (deg)	14.36	-4.20	18.71	0.00	-9.11	0.00
	Mode (deg)	4.00	-1.00	19.00	0.00	-9.00	0.00
	Maximum (deg)	71.83	37.32	59.06	0.00	37.32	0.00
	Minimum (deg)	-75.85	-71.78	-75.85	0.00	-41.06	0.00
	Range (deg)	147.68	109.10	134.91	0.00	78.38	0.00
	Standard Deviation (deg)	7597.94	11815.06	948.36	0.00	1623.47	0.00
	Skewness	1.22	1.32	1.72	0.00	1.29	0.00
	Kurtosis	3.64	3.53	5.66	0.00	3.59	0.00

Subject 15		Full Waveform		Windows (n=1)			
		Right	Left	Right (Avg.)	Right (S.D.)	Left (Avg.)	Left (S.D.)
Extension (Upper Excursions)	Max. Excursion Time (sec)	348.78	150.33	11.23	0.00	23.53	0.00
	Max. Excursion Area (deg-sec)	2311.24	2361.13	113.05	0.00	349.34	0.00
	Total Excursion Time (sec)	2792.42	494.40	184.23	0.00	66.65	0.00
	Total Excursion Time (%)	34.50	6.11	2.36	0.00	0.85	0.00
	Total Excursion Area (deg-sec)	18516.07	6846.73	1189.68	0.00	841.33	0.00
	Total Excursion Area (%)	17.57	3.37	11.63	0.00	3.01	0.00
Flexion (Lower Excursions)	Max. Excursion Time (sec)	0.10	344.07	0.07	0.00	187.54	0.00
	Max. Excursion Area (deg-sec)	-0.19	-6413.57	-0.09	0.00	-6594.93	0.00
	Total Excursion Time (sec)	0.37	5142.66	0.07	0.00	645.97	0.00
	Total Excursion Time (%)	0.00	63.53	0.00	0.00	8.27	0.00
	Total Excursion Area (deg-sec)	-0.52	-93999.50	-0.09	0.00	-14772.88	0.00
	Total Excursion Area (%)	0.00	-46.22	0.00	0.00	-52.89	0.00
Flexion[-]/Extension[+] Histogram Statistics	Mean (deg)	12.90	-19.91	10.56	0.00	-24.89	0.00
	Median (deg)	11.74	-21.92	9.80	0.00	-26.81	0.00
	Mode (deg)	6.00	-18.00	8.00	0.00	2.00	0.00
	Maximum (deg)	65.54	67.56	45.24	0.00	67.56	0.00
	Minimum (deg)	-17.56	-89.33	-17.04	0.00	-78.88	0.00
	Range (deg)	83.11	156.89	62.29	0.00	146.44	0.00
	Standard Deviation (deg)	17681.84	6741.92	2422.31	0.00	808.16	0.00
	Skewness	1.41	0.89	1.65	0.00	1.39	0.00
	Kurtosis	3.57	2.74	4.40	0.00	4.52	0.00

Subject 16		Full Waveform		Windows (n=3)			
		Right	Left	Right (Avg.)	Right (S.D.)	Left (Avg.)	Left (S.D.)
Ulnar Deviation (Upper Excursions)	Max. Excursion Time (sec)	87.18	217.25	39.99	21.68	121.54	23.51
	Max. Excursion Area (deg-sec)	1073.70	4308.25	578.62	456.96	2528.01	484.45
	Total Excursion Time (sec)	3312.44	6591.99	445.94	160.87	764.14	137.23
	Total Excursion Time (%)	40.45	80.50	20.35	20.45	33.13	31.96
	Total Excursion Area (deg-sec)	24396.78	120576.97	3197.73	771.57	14038.14	3033.02
	Total Excursion Area (%)	19.85	51.31	21.95	2.07	52.10	3.60
Radial Deviation (Lower Excursions)	Max. Excursion Time (sec)	59.07	35.10	5.62	6.74	3.08	3.12
	Max. Excursion Area (deg-sec)	-907.27	-408.67	-43.65	36.11	-64.39	58.44
	Total Excursion Time (sec)	381.14	244.28	23.71	24.84	10.60	7.79
	Total Excursion Time (%)	4.65	2.98	0.49	0.17	0.25	0.02
	Total Excursion Area (deg-sec)	-4096.58	-2414.82	-153.45	121.17	-139.12	97.72
	Total Excursion Area (%)	-3.33	-1.03	-1.15	1.03	-0.57	0.48
Radial[-]/Ulnar[+] Deviation Histogram Statistics	Mean (deg)	10.54	26.48	12.77	5.32	27.72	5.00
	Median (deg)	12.80	30.94	12.91	5.21	30.76	5.03
	Mode (deg)	16.00	38.00	15.67	0.58	35.33	1.15
	Maximum (deg)	55.69	72.39	45.42	2.00	66.83	2.87
	Minimum (deg)	-67.51	-63.64	-45.65	11.08	-49.60	3.25
	Range (deg)	123.20	136.03	91.07	9.37	116.43	4.40
	Standard Deviation (deg)	11286.18	11012.73	1652.50	459.51	1549.07	350.25
	Skewness	1.63	2.09	1.62	0.66	2.55	0.56
	Kurtosis	4.77	6.45	5.31	2.05	9.84	2.84

Subject 16		Full Waveform		Windows (n=3)			
		Right	Left	Right (Avg.)	Right (S.D.)	Left (Avg.)	Left (S.D.)
Extension (Upper Excursions)	Max. Excursion Time (sec)	55.42	49.21	28.22	11.53	27.69	20.37
	Max. Excursion Area (deg-sec)	476.88	303.93	266.94	171.15	83.12	74.64
	Total Excursion Time (sec)	3045.86	1111.65	330.17	48.27	106.60	51.09
	Total Excursion Time (%)	37.19	13.57	13.36	12.55	5.56	7.12
	Total Excursion Area (deg-sec)	15269.37	3018.70	1739.77	136.99	283.59	184.92
	Total Excursion Area (%)	14.42	4.45	14.41	1.46	4.15	2.44
Flexion (Lower Excursions)	Max. Excursion Time (sec)	0.00	3.56	0.00	0.00	1.41	1.04
	Max. Excursion Area (deg-sec)	0.00	-27.05	0.00	0.00	-6.90	5.42
	Total Excursion Time (sec)	0.00	60.77	0.00	0.00	5.62	6.63
	Total Excursion Time (%)	0.00	0.74	0.00	0.00	0.21	0.18
	Total Excursion Area (deg-sec)	0.00	-266.37	0.00	0.00	-22.59	23.41
	Total Excursion Area (%)	0.00	-0.39	0.00	0.00	-0.36	0.40
Flexion[-]/Extension[+] Histogram Statistics	Mean (deg)	12.75	5.19	13.06	0.82	5.18	1.98
	Median (deg)	12.66	5.33	12.43	1.56	4.16	1.90
	Mode (deg)	10.00	2.00	12.00	4.36	11.33	8.33
	Maximum (deg)	77.66	61.47	43.13	5.66	25.59	1.24
	Minimum (deg)	-9.86	-32.20	-5.97	1.88	-24.68	5.97
	Range (deg)	87.52	93.66	49.10	4.77	50.26	5.74
	Standard Deviation (deg)	17855.41	14841.08	2581.31	258.59	2408.58	131.03
	Skewness	1.63	1.14	1.37	0.40	1.26	0.34
	Kurtosis	4.28	2.76	4.12	1.28	3.91	1.48

Subject 17		Full Waveform		Windows (n=3)			
		Right	Left	Right (Avg.)	Right (S.D.)	Left (Avg.)	Left (S.D.)
Ulnar Deviation (Upper Excursions)	Max. Excursion Time (sec)	223.43	91.79	41.50	9.22	33.62	14.38
	Max. Excursion Area (deg-sec)	5170.53	2292.48	770.99	131.51	998.73	708.61
	Total Excursion Time (sec)	4971.36	3029.18	576.44	87.14	383.13	114.53
	Total Excursion Time (%)	59.32	36.15	16.89	11.99	13.88	14.59
	Total Excursion Area (deg-sec)	61147.40	42753.48	5578.45	1925.54	4823.69	792.07
	Total Excursion Area (%)	35.37	27.09	29.30	4.98	27.83	6.34
Radial Deviation (Lower Excursions)	Max. Excursion Time (sec)	25.21	128.41	7.14	4.55	32.88	21.23
	Max. Excursion Area (deg-sec)	-655.08	-2795.16	-77.32	62.36	-257.91	168.25
	Total Excursion Time (sec)	366.29	1633.92	27.20	23.19	146.02	89.27
	Total Excursion Time (%)	4.37	19.50	0.76	0.54	3.03	0.68
	Total Excursion Area (deg-sec)	-4236.16	-18325.36	-249.13	223.20	-1240.21	714.06
	Total Excursion Area (%)	-2.45	-11.61	-1.21	0.83	-6.92	3.50
Radial[-]/Ulnar[+] Deviation Histogram Statistics	Mean (deg)	17.38	5.97	16.32	0.95	8.12	4.96
	Median (deg)	17.27	6.70	16.06	0.64	8.93	6.71
	Mode (deg)	17.00	27.00	12.67	5.86	8.67	24.58
	Maximum (deg)	73.45	74.93	71.01	4.16	59.78	5.77
	Minimum (deg)	-76.80	-90.94	-60.86	8.66	-70.89	8.89
	Range (deg)	150.25	165.87	131.87	9.97	130.67	13.17
	Standard Deviation (deg)	9849.18	6450.21	1549.77	398.98	1099.92	130.41
	Skewness	1.94	0.75	2.26	0.97	1.75	0.56
	Kurtosis	6.12	2.02	8.13	5.72	7.12	3.20

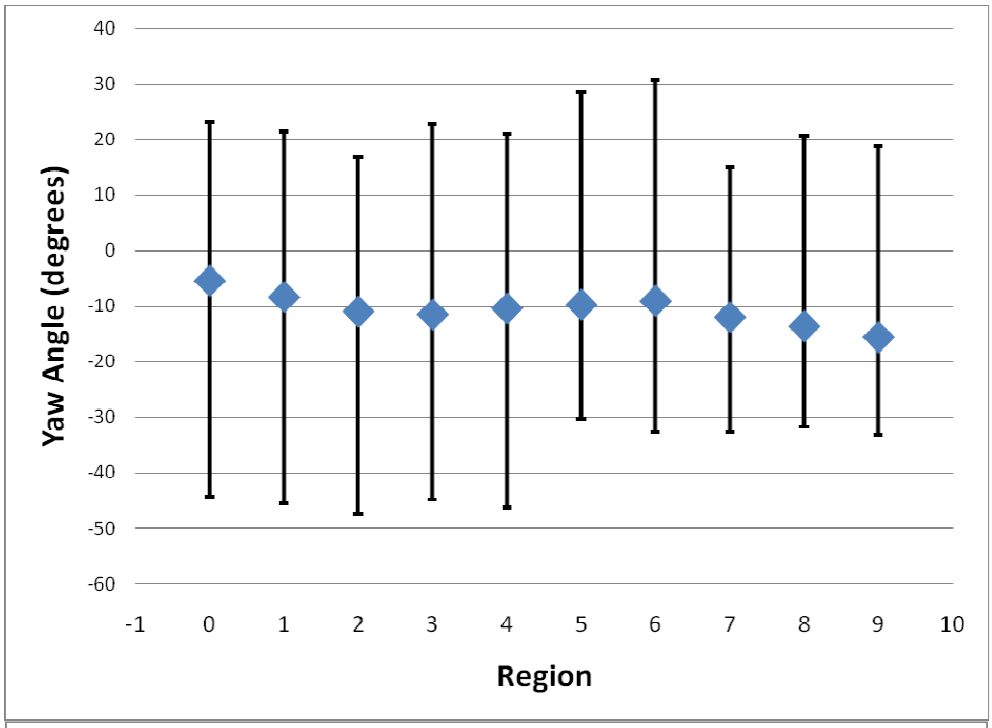
Subject 17		Full Waveform		Windows (n=3)			
		Right	Left	Right (Avg.)	Right (S.D.)	Left (Avg.)	Left (S.D.)
Extension (Upper Excursions)	Max. Excursion Time (sec)	118.97	148.11	56.60	57.81	32.41	10.72
	Max. Excursion Area (deg-sec)	689.69	773.96	345.30	322.85	174.69	101.46
	Total Excursion Time (sec)	2390.45	1229.52	368.47	226.31	146.96	109.38
	Total Excursion Time (%)	28.52	14.67	11.53	11.36	3.43	1.68
	Total Excursion Area (deg-sec)	11696.17	5950.36	1970.01	1098.02	530.86	386.33
	Total Excursion Area (%)	11.85	7.18	14.85	7.22	5.11	3.65
Flexion (Lower Excursions)	Max. Excursion Time (sec)	224.34	41.99	25.45	40.57	13.89	11.97
	Max. Excursion Area (deg-sec)	-1338.43	-116.24	-119.74	199.54	-75.89	38.50
	Total Excursion Time (sec)	513.91	702.87	52.27	86.68	90.54	40.70
	Total Excursion Time (%)	6.13	8.39	1.04	1.59	2.86	2.34
	Total Excursion Area (deg-sec)	-2621.46	-3156.94	-262.42	446.39	-451.72	231.14
	Total Excursion Area (%)	-2.66	-3.81	-2.21	3.75	-4.20	1.61
Flexion[-]/Extension[+] Histogram Statistics	Mean (deg)	7.67	2.09	9.70	7.69	1.23	5.41
	Median (deg)	8.66	3.20	11.08	7.54	1.02	8.10
	Mode (deg)	7.00	6.00	13.67	6.81	4.00	9.17
	Maximum (deg)	61.19	54.51	48.46	2.94	30.61	1.67
	Minimum (deg)	-36.76	-53.13	-20.28	4.24	-44.53	3.49
	Range (deg)	97.95	107.65	68.73	6.37	75.14	5.07
	Standard Deviation (deg)	13657.63	11462.12	2200.68	394.70	1758.56	241.05
	Skewness	1.33	1.00	1.73	0.50	1.18	0.06
	Kurtosis	3.65	2.77	6.19	3.12	3.62	0.57

Subject 18		Full Waveform		Windows (n=3)			
		Right	Left	Right (Avg.)	Right (S.D.)	Left (Avg.)	Left (S.D.)
Ulnar Deviation (Upper Excursions)	Max. Excursion Time (sec)	279.16	388.88	110.57	48.53	202.76	170.75
	Max. Excursion Area (deg-sec)	4035.27	9284.36	1679.15	1371.52	4694.02	4121.19
	Total Excursion Time (sec)	5130.79	4800.12	803.52	55.82	687.05	161.89
	Total Excursion Time (%)	79.19	74.08	19.01	6.24	16.72	7.49
	Total Excursion Area (deg-sec)	68206.67	91478.55	10541.83	2357.34	12854.48	6084.51
	Total Excursion Area (%)	43.23	51.07	43.61	6.44	49.30	9.56
Radial Deviation (Lower Excursions)	Max. Excursion Time (sec)	33.05	21.68	1.15	0.93	6.12	8.16
	Max. Excursion Area (deg-sec)	-933.24	-388.56	-18.54	27.17	-79.37	89.19
	Total Excursion Time (sec)	83.16	89.71	3.56	3.32	9.69	12.05
	Total Excursion Time (%)	1.28	1.38	0.10	0.12	0.19	0.18
	Total Excursion Area (deg-sec)	-1565.55	-1554.93	-27.49	33.99	-130.48	160.97
	Total Excursion Area (%)	-0.99	-0.87	-0.12	0.16	-0.65	0.87
Radial[-]/Ulnar[+] Deviation Histogram Statistics	Mean (deg)	23.15	26.41	25.15	3.28	25.99	8.62
	Median (deg)	24.98	28.89	25.45	3.18	26.66	10.13
	Mode (deg)	27.00	36.00	21.33	2.89	26.67	13.01
	Maximum (deg)	69.69	86.24	57.73	4.24	68.74	8.16
	Minimum (deg)	-69.65	-63.21	-33.20	16.38	-50.86	4.55
	Range (deg)	139.34	149.45	90.94	18.40	119.60	11.10
	Standard Deviation (deg)	8789.80	7034.28	1592.64	249.90	1363.85	212.61
	Skewness	1.69	1.47	1.25	0.49	2.03	0.27
	Kurtosis	4.51	4.35	3.32	1.51	7.20	2.72

Subject 18		Full Waveform		Windows (n=3)			
		Right	Left	Right (Avg.)	Right (S.D.)	Left (Avg.)	Left (S.D.)
Extension (Upper Excursions)	Max. Excursion Time (sec)	11.28	0.37	0.00	0.00	0.00	0.00
	Max. Excursion Area (deg-sec)	95.59	0.80	0.00	0.00	0.00	0.00
	Total Excursion Time (sec)	32.33	0.51	0.00	0.00	0.00	0.00
	Total Excursion Time (%)	0.50	0.01	0.00	0.00	0.00	0.00
	Total Excursion Area (deg-sec)	194.49	0.93	0.00	0.00	0.00	0.00
	Total Excursion Area (%)	0.17	0.00	0.00	0.00	0.00	0.00
Flexion (Lower Excursions)	Max. Excursion Time (sec)	121.03	68.53	60.11	19.31	21.76	13.33
	Max. Excursion Area (deg-sec)	-2250.35	-945.96	-866.25	612.74	-134.49	99.75
	Total Excursion Time (sec)	3783.92	858.02	650.75	122.11	123.96	95.57
	Total Excursion Time (%)	58.40	13.24	16.19	8.86	2.86	2.10
	Total Excursion Area (deg-sec)	-28821.01	-3654.66	-5484.76	2024.59	-460.29	156.61
	Total Excursion Area (%)	-25.24	-6.65	-29.83	8.14	-6.73	1.73
Flexion[-]/Extension[+] Histogram Statistics	Mean (deg)	-17.35	-6.37	-19.17	2.13	-5.54	4.83
	Median (deg)	-16.53	-6.98	-19.11	2.56	-5.64	6.36
	Mode (deg)	-15.00	-7.00	-15.33	8.33	-7.33	6.11
	Maximum (deg)	36.55	51.36	7.54	3.45	13.02	3.19
	Minimum (deg)	-52.16	-39.83	-46.95	3.42	-36.49	0.81
	Range (deg)	88.71	91.19	54.49	6.50	49.51	3.50
	Standard Deviation (deg)	12983.63	12529.06	2122.13	639.68	3025.29	143.22
	Skewness	1.57	1.25	0.85	0.42	1.90	0.06
	Kurtosis	4.23	3.12	2.66	0.69	6.18	0.07

A.6 Shoulder Test Results with Maximum and Minimum Value Bars

A)



B)

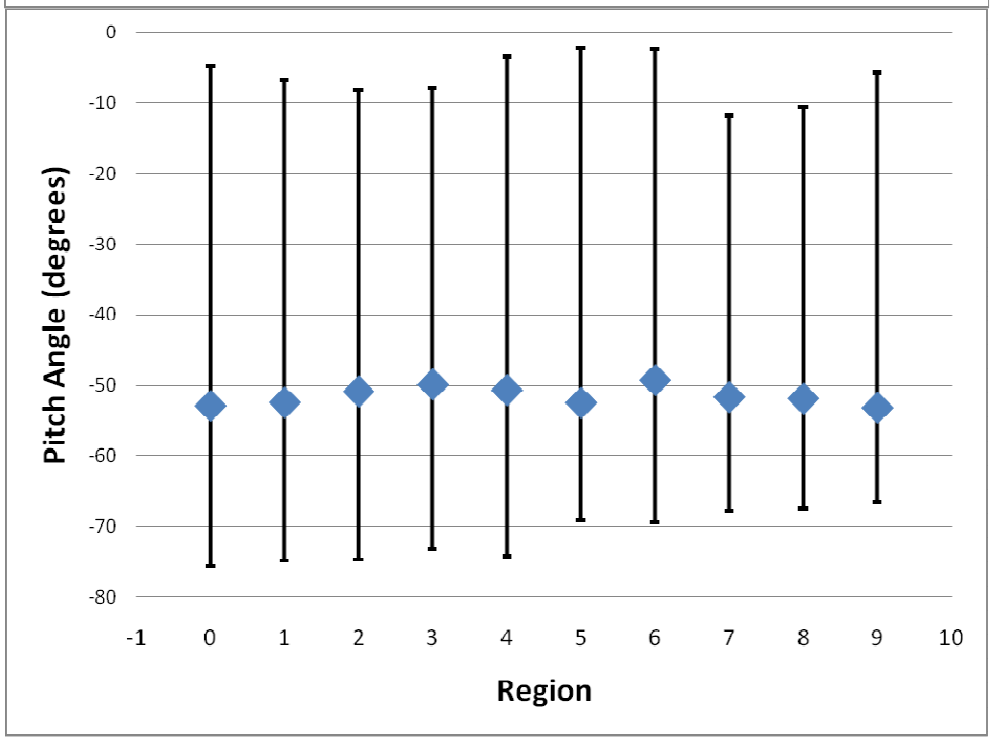


Figure 24. Average Results for Shoulder Validation Test with 20 Trials: A) Yaw Angle of Sensor for Each Region , B) Pitch Angle of Sensor for Each Region

A.7 Task Percent Area Charts for Wrist Motion at Site 2

Subject 1 Percent Area								
	Extension		Ulnar Deviation		Flexion		Radial Deviation	
Window/Wrist	Right	Left	Right	Left	Right	Left	Right	Left
1	13.75	38.92	5.24	0.01	-16.28	-2.70	-2.08	-24.54
2	29.23	38.99	4.22	0.02	-8.47	-4.01	-5.02	-23.72
3	18.41	38.67	4.84	0.35	-11.10	-3.09	-1.53	-15.31
4	15.47	36.78	3.15	0.66	-13.36	-2.59	-2.08	-17.17
5	14.20	30.79	0.81	0.07	-15.00	-2.79	-16.55	-22.18
6	24.37	46.24	10.63	0.02	-7.52	-5.84	-1.81	-18.10
Average	19.24	38.40	4.82	0.19	-11.96	-3.50	-4.85	-20.17

Subject 2 Percent Area								
	Extension		Ulnar Deviation		Flexion		Radial Deviation	
Window/Wrist	Right	Left	Right	Left	Right	Left	Right	Left
1	46.09	0.06	0.03	0.00	-0.30	-56.22	-9.98	-21.43
2	39.77	1.23	3.50	3.44	-2.21	-46.75	-6.07	-5.28
3	44.05	0.21	0.84	1.56	-0.83	-54.81	-5.74	-6.92
4	48.17	0.17	0.17	0.59	-0.34	-54.10	-5.37	-7.78
5	39.87	0.20	0.16	0.74	-0.86	-56.21	-4.24	-5.86
6	35.17	0.15	0.00	0.05	-0.45	-53.96	-5.82	-6.65
Average	42.19	0.34	0.78	1.06	-0.83	-53.68	-6.20	-8.99

A.8 Wrist Motion Histograms for Site 3

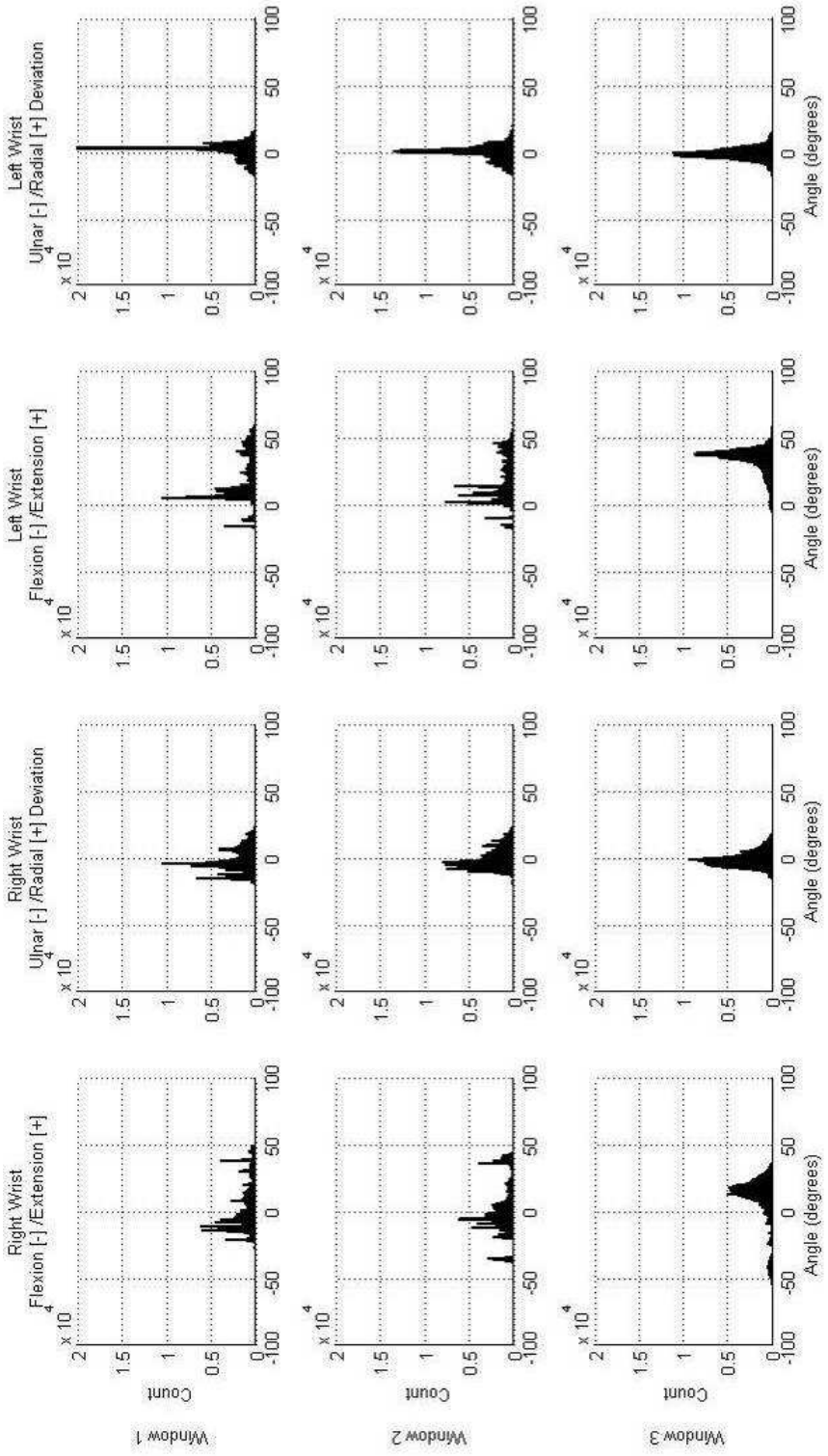


Figure 25: Machine Grinding Movement Histograms

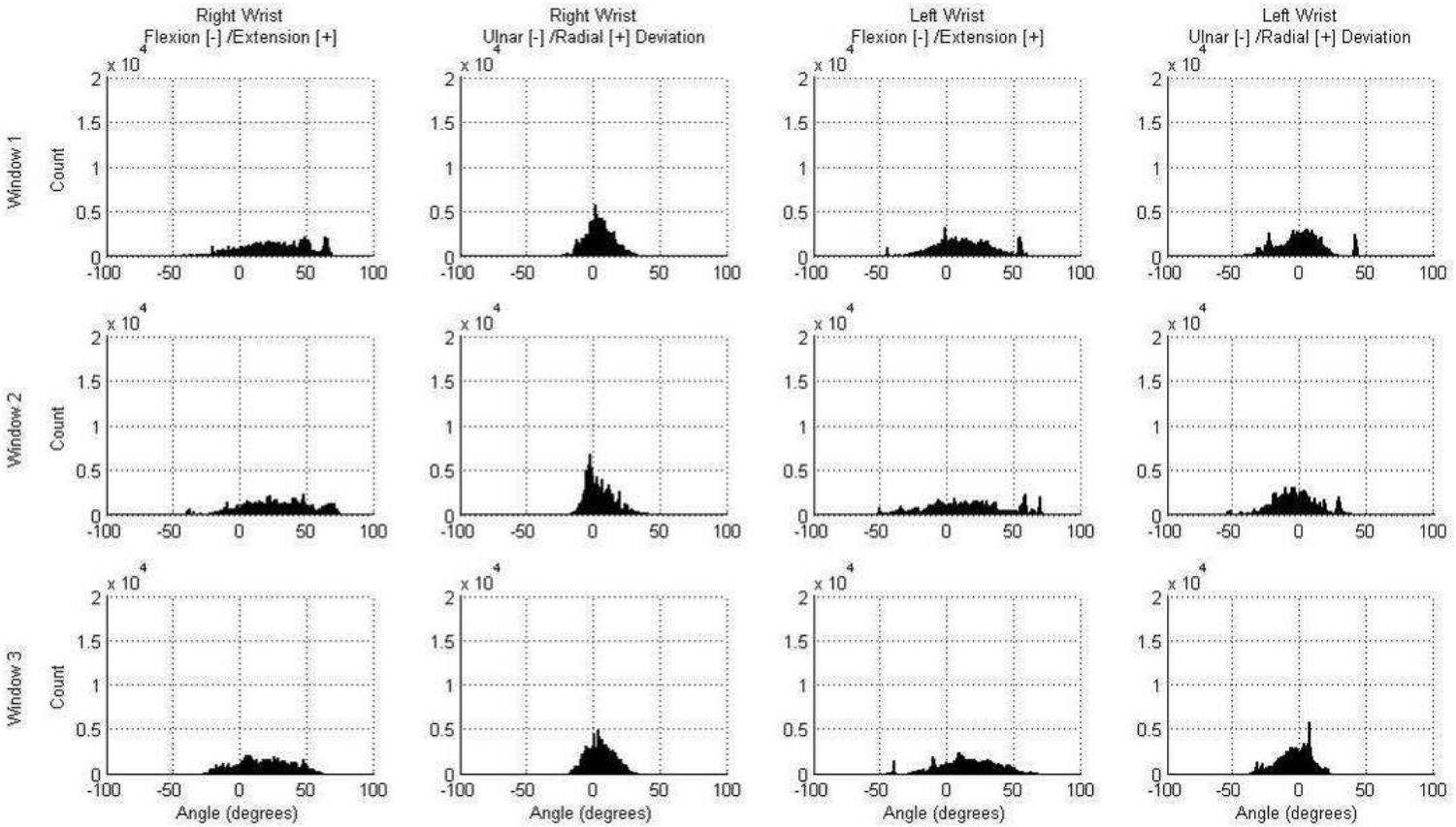


Figure 26: Circuit Board Fastening Movement Histograms

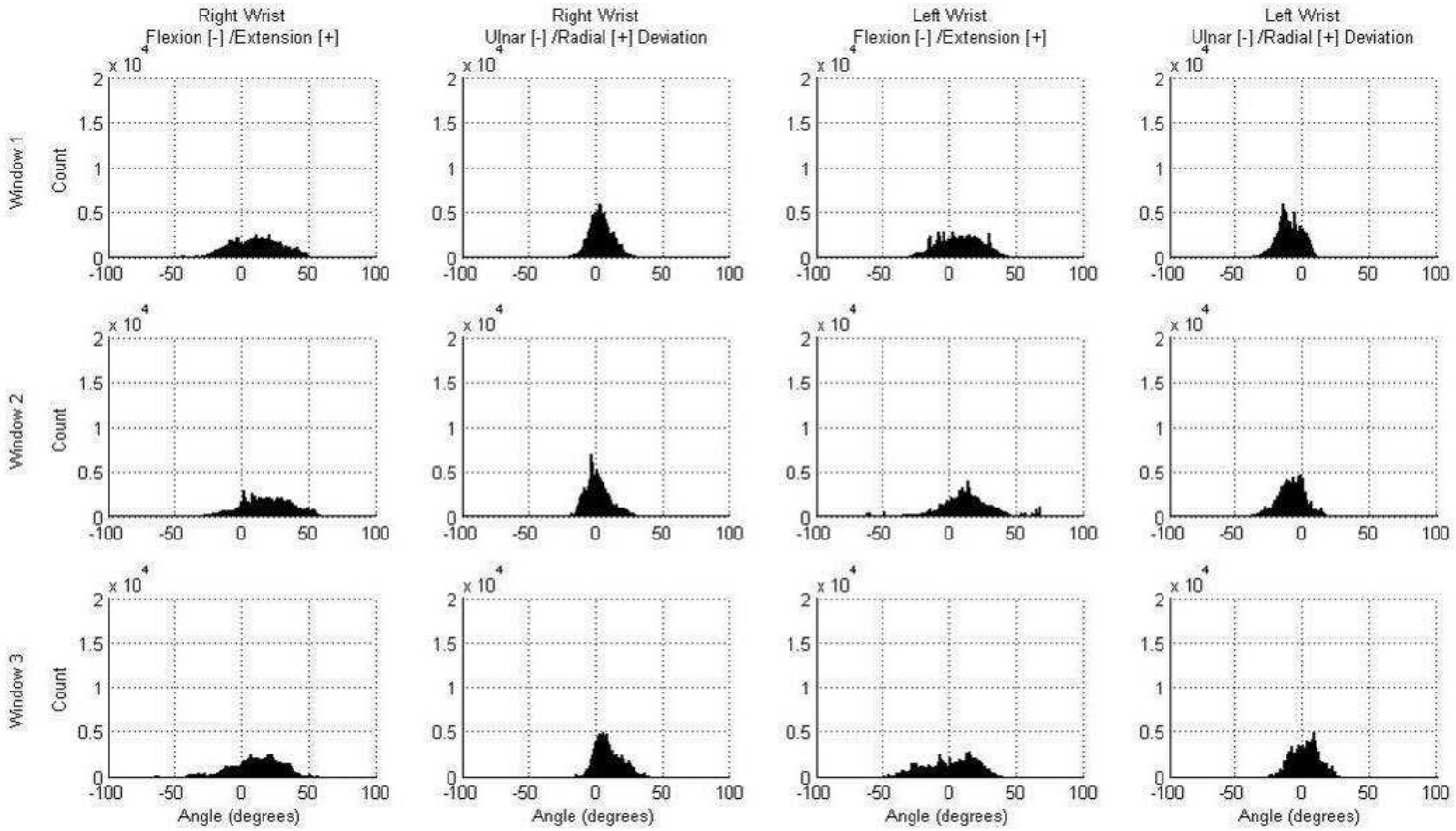


Figure 27: Assembling Switches Movement Histograms