

EXPLORING THE ERGONOMIC ASSESSMENT METHODS OF  
ERGO@WSH POSTURE ANALYSIS APP FOR APPLE DEVICES

by

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A thesis submitted in partial fulfillment of the  
requirements for the degree of

Masters of Science in Industrial Hygiene

Montana Tech of the University of Montana

2014

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## Abstract

Safety and health and industrial hygiene professionals rely on accurate and precise tools to perform their jobs. Apps are being developed to aid in the field, but many professional are questioning the quality of these apps. This project examined an app for analyzing sitting posture called ERGO@WSH.

The project had three objectives:

1. To test the association between the analyst and app regarding agreement with ANSI standards.
2. To test for repeatability and reproducibility of analysts performing postural assessments using the ERGO@WHS computer ergonomic app.
3. To evaluate the ERGO@WSH app measurement system analysis for body angles using two methods: controlled measurement versus experimental measurements.

A faculty member volunteered to pose for lateral photographs while assuming six different postures at a computer workstation. These six postures consisted of three conforming and three nonconforming to the ANSI Standards for computer workstation postures. Three graduate students with backgrounds in ergonomics and anatomy participated as analysts. They randomly analyzed the six postures using the ERGO@WSH app at two different times.

Results for Objective 1 indicated that a posture evaluated for conformance/nonconformance to the ANSI Standard did not show very good agreement when using the app compared to using a method with visible markers on the subjects clothing. Results for Objective 2 indicated the app method showed acceptable but not strong repeatability and reproducibility. Except for wrist angle, results for Objective 3 showed the app method for marking key joint angles produced angles similar to those produced using a method based on the subject having visible markers on his clothing. Wrist angle measurements were significantly different. The results of these statistical analyses do not support using the app metrics as used for this project. The author suspects that more structured training, with feedback, could improve performance of analysts.

**Keywords: Safety, Apps, Technology, Office Ergonomics, Posture**

## **Dedication**

I would like to thank my wife Abbey for all the proof reading and support during this thesis writing process. I would like to thank Dr. Julie Hart, Dr. Roger Jensen, and Theresa Stack for the continuous council they provided throughout this writing process. I would like to thank Dr. Bill Spath for his council on my statistical analysis.

## **Acknowledgements**

I would like to thank the Safety Health and Industrial Hygiene department for giving me financial support for the ANSI standards and also for purchasing the Apps need for my research. Through my two years of education at Montana, Tech, I was partially supported by training Grant No. T03 OH008630 from the Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health. The contents of this thesis are solely the responsibility of the authors and do not necessarily represent the official views of the National Institute for Occupational Safety and Health.

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## Glossary of Terms

Apps	A self-contained program or piece of software designed to fulfill a particular purpose; an application, esp. as downloaded by a user to a mobile device.
ANSI	The American National Standards Institute (ANSI, /'ænsi:/ AN-see) is a private non-profit organization that oversees the development of voluntary consensus standards for products, services, processes, systems, and personnel in the United States.
OSHA	The United States Occupational Safety and Health Administration (OSHA) is an agency of the United States Department of Labor. Congress established the agency under the Occupational Safety and Health Act, which President Richard M. Nixon signed into law on December 29, 1970.
Repeatability	The variation in measurements taken by a single person or instrument on the same or replicate item and under the same conditions.
Reproducibility	The variation induced when different operators, instruments, or laboratories measure the same or replicate specimen
Smart device	A smart device is an electronic device, generally connected to other devices or networks via different protocols such as Bluetooth, NFC, WiFi, 3G, etc., that can operate to some extent interactively and autonomously.

# 1. Introduction

## 1.1. Apps for Industrial Hygiene

With technology growing exponentially in the 21st century, a survey done by Pew Research states that 56% of American adults own a smartphone (Smith, 2013) and this number will only continue to grow. A smartphone is a cellular phone that is able to perform many of the functions of a computer, typically having a relatively large screen and an operating system capable of running general-purpose applications (Google search, 2013). Applications or apps are self-contained programs or pieces of software designed to fulfill a particular purpose; an application can be downloaded by a user to a mobile device (Google search, 2013). In this mobile world of cell phones and tablets there are two major companies that dominate the field: Apple and Google. Each is unique, which makes it hard to say which is better than the other because of user's preference.

Android is a Google company that is the main competitor for Apple. Android is an open source operating system composed of a large community of companies and developers who maintain and contribute toward developing new apps and updating existing versions, all of this is done under Google's discretion. Unlike Apple's iOS operating system for mobile devices, the Android operating system's ongoing development is not hidden behind lock and key. In fact, about 80 companies are members of the group. This open market allows innovation, which gives the Android system a large variety in ways each device can be set up (Begun). There are more than 70 types of Android phones across all four major U.S. carriers, ensuring there is an option that suits your lifestyle and meets your mobile needs (Nielsen). There is a myriad of phones that run on the Android operating system. They have different physical properties (screen size CPU processing); app developers have to take this into consideration. The end result of this variety is

that some apps are incompatible on some devices and other times the apps function, but certain features will not work. In some instances, the apps appear to run great only for a few minutes and then suddenly stop working (Begun). According to Google there are over 700,000 titles available as of October 2012 (Google play, 2013).

Apple is a company that designs, develops and sells consumer electronics. They are known best for their computers, iPods, iPhones and iPads (Apple). Apple is the world's second largest information technology company and the world's third largest mobile phone maker (Gartner press release, 2012). In the first quarter of sales for the iPhone 5, there were 48 million units, making Apple the most successful company in the market. Apple has strict guidelines for creating apps on their system (Apple, 2012). As of February 10, 2012, there are at least 1,100,000+ third-party apps officially available on the App Store (Apple Event). Apple's iOS is known for its clean, sleek interface, which does not vary from device to device; that makes for a solid operating system running the apps smoothly without glitches. This is advantageous for the average user because the learning curve is shorter. For these reasons, research will focus on the Apple devices and Apple apps.

There are many apps being released daily, which make it hard to keep up with the newest apps. After searching the App Store for ergonomic apps, and testing every app, none were found that analyzed sitting posture; they are reminders for when to stretch or to just evaluate the chair height. The most advanced app that was found to date is the ERGO@WSH app.

## **1.2. ERGO@WHS Application**

The Work Place Safety and Health (WSH) Institute was created as part of the WSH 2008 strategy to put Singapore's WSH performance on par with leading countries. Envisioned as a key initiative to build strong WSH capabilities in Singapore, the Institute's work will help deepen

stakeholders' understanding of how current and emerging work environments, work processes, and worker behavior shape WSH. They will be able to use such knowledge to develop solutions and improve WSH practices. This is similar to what has been established in leading countries in their national drives to improve worker safety and health. Drawing from the experiences of these countries, Singapore's Ministry of Manpower worked with the WSH Council to set up the WSH Institute in Singapore (About WSH institute, 2011). As a result of this council, the ERGO@WSH app was designed as a tool to improve the health of office workers.

The app is meant for workplace safety and health professionals and the general public. WSH professionals can use it to identify, evaluate, and monitor ergonomic hazards in the workplace and provide recommendations to prevent musculoskeletal disorders (MSDs). For the general public, it is an interactive and fun way to help family and friends improve their sitting and lifting postures at home and at work. By tapping on the camera function of the smart-phone, users can simply take a photograph or video and perform a guided analysis of their postures (Fact sheet on Ergo@WAH mobile application, 2011).

ERGO@WSH is a free app available in the iTunes store and Google play. ERGO@WSH is designed to be interactive, easy to use, and to be readily accessible to help the user evaluate sitting and lifting postures using a photo or video. The app allows the safety professional to create profiles for each client. This profile is used to track all the posture analysis that has been performed for the client and any of the health complaints. An example of this chart is illustrated in Figure 1.

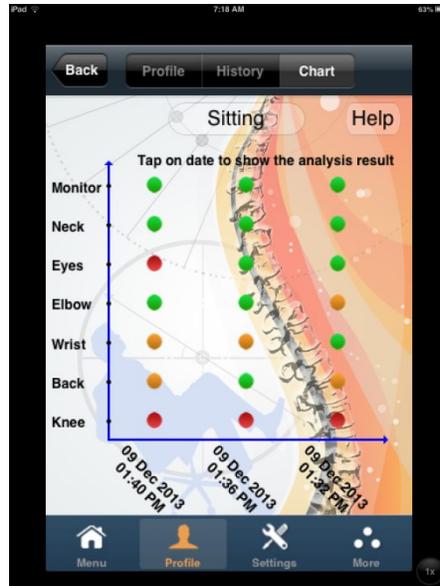


Figure 1: Example of posture records on the ERGO@WSH App

The app works by taking a picture of a person working at a computer work station. When taking the picture the app has a silhouette overlay which helps the user gauge the proper distance. Figure 2 illustrates the silhouette overlay before fitting it to the person.

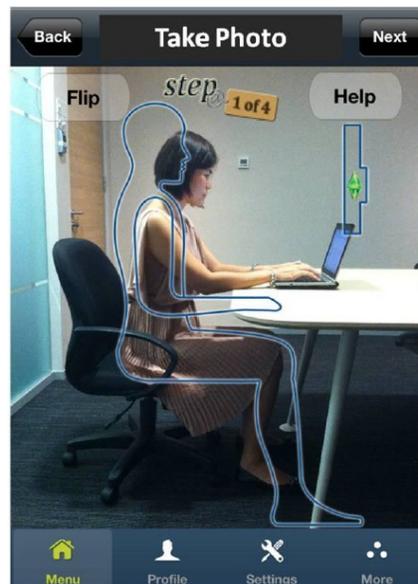


Figure 2: Example of using the silhouette to gauge the proper distance

After the taking the picture using the silhouette, the unaligned body postural markers appear. The app user needs to move each body postural marker to its designated body part (see Figure 3). When aligning the posture marker to the proper body part, you can zoom in on the picture to facilitate aligning to the proper part or joint. After the body parts are aligned with the proper body marker, the app will analyze the posture.

When posture analysis is complete, the assessment is color coded: green means good posture, amber means poor posture and red means very bad posture (see Figure 4). The blue postural markers are simply there as markers and not used in measuring. By clicking on the poor/bad posture, the app gives the user recommendations to correct the posture. If needed, a digital version of the postural recommendation can be sent via email and it creates a PDF file of the picture along with the recommendations. The recommendations are not evaluated in this research.

Figure 4 and 5 are included in the app to illustrate placement of the marker. A simple visual examination of these figures shows inconsistencies in placement markers for the head and hip joints.

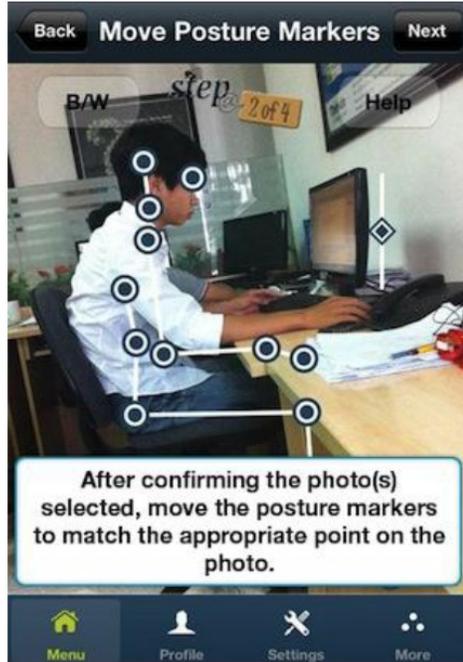


Figure 3: Example of ERGO@WSH app displaying pre-aligning postures of markers to the proper body part



Figure 4: Example of ERGO@WSH app displaying the body posture markers

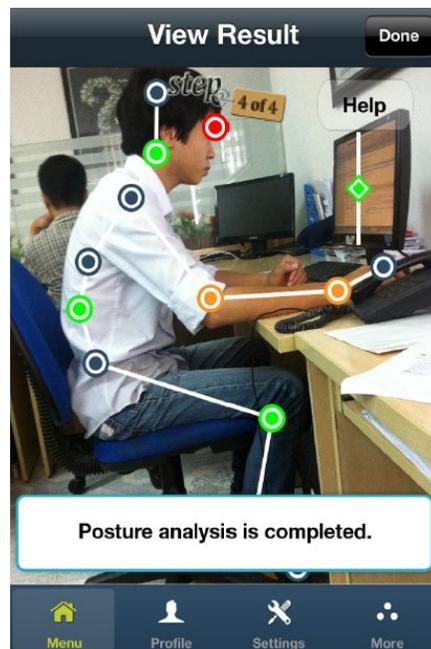


Figure 5: Example of ERGO@WSH app showing markers and color coding

### **1.3. Statement of the Problem**

In the 21<sup>st</sup> Century, employees are expected to be able to work from anywhere; this task is largely completed by the use of smart devices. Safety and health and industrial hygiene professions are not exempt. The technological world of mobile devices has penetrated every professional field to a degree, whether it is beneficial or detrimental. In 2008, the mobile subscribers worldwide hit 4.2 billion; Foster and Sullivan research predicts that the mobile subscribers will hit 6.8 billion in 2018 (Sullivan).

In the occupational health and safety field there are currently several apps being used; dosimeters, inclinometers, audits form, compliance assistance, ergonomics, and the list continues. Industrial hygienists heavily rely on expensive, calibrated tools to perform sampling. The question arises, are there inexpensive apps that can be downloaded to a mobile device that could do the same job as these expensive tools? Will they be accurate and save time and money?

Safety professionals are more valuable out in the field monitoring the workers than they are in the office doing paperwork. For this reason the apps are becoming popular in the safety and industrial hygiene profession because the apps make quick work of office work such as doing audits, recordkeeping, writing reports and other varieties of tasks. In the industrial hygiene and safety profession, keeping records are vital; if it is not recorded, then it never happened. Smart devices streamline the record-keeping process by submitting it in real time. In the digital age, everything needs to be backed up; with apps you can back everything up to the cloud. Professionals with smart devices can easily carry the standards and regulations with them.

There are several ergonomic tools designed for evaluating dynamic forces for each individual body angle; two popular ones are REBA and RULA. Today, when it comes to evaluating static forces, ergonomists would adopt a systematic approach when dealing with a

seated worker, looking at the work being performed, the design of the workplace and the work schedule, and the work environment (Corlett, 2007).

Good office ergonomics is good business; this philosophy is catching company's interests. Liberty Mutual Insurance did an 18-month study on their employees. Over the 18 months the employees received ergonomic training, one-third of the employees had reduced back pain (Kroemer, 2001). Francis and Dressel found that it only takes 11 months to see the return after investing in an ergonomic program (Sauter, 1990).

For evaluating computer workstations without an app, ergonomists would take a photo, print it, use a protractor to measure each angle, and consult a guideline to determine if the posture is correct or incorrect. This process is slow but accurate; technology is evolving rapidly and trying to expedite this process. Apps on smart devices have created solutions for many problems. Singapore's Ministry of Man Power has developed an app to expedite office ergonomics. The concern is that with this technology migrating into the field, ergonomists question if it is accurate and reliable. This project explores the ergonomic assessment metrics of the ERGO@WSH app.

#### **1.4. Three Objectives**

This project had three objectives that addressed (1) determination of conformance to ANSI standards, (2) repeatability and reproducibility, and (3) consistency with a traditional method. More specific objective statements follow.

- Objective 1      To test the association between the analyst and app regarding agreement with ANSI standards. The statistical test, Cohen Kappa, is used to provide the quantification between analyst using the app results and the ANSI standards.
- Objective 2      To test the repeatability and reproducibility of analysts performing postural

assessments using the ERGO@WHS computer ergonomic app, by comparing inter-analyst variation for specific body posture measurements. The statistical test for repeatability and reproducibility uses the Gage R&R analysis.

Objective 3 To evaluate the ERGO@WSH app measurement system analysis for body angles using two methods: photos with postural markers measurements versus photos without postural markers measurements. These are referred to in this thesis as controlled and experimental methods, respectively. A paired t-test is suitable for testing the significance between the angles determined from the controlled and experimental methods.

## **1.5. Three Hypothesis**

### **1.5.1. Statistical Method 1**

The ERGO@WSH app is a tool to help an analyst assess the body posture of a person sitting at a workstation and makes recommendations to correct the posture. The app software determines joint angles and compares body angles relative to a range of recommended angles that are programmed into the software. An alternative method is to print a photo of the sitting person and analyze body angles using a ruler and protractor. The found angles are compared to the 2007 ANSI/HFES standard for conformity. Both methods can be used to obtain dichotomous conclusions—conforming or nonconforming—using the same person posing in the same posture.

For comparing results of the two methods, a test was planned to provide the data for quantifying the strength of the association between conclusions obtained by applying the two methods to the same postures. The Cohen Kappa statistic provided the quantification. It is not used for statistical hypothesis testing; rather it provides a numeric indicating strength of

association. The analysis was initiated with no hypothesis as to the association being strong or weak.

### **1.5.2. Statistical Method 2**

The app method requires an analyst to mark the locations of various joints with body posture markers. A test was designed to test the repeatability and reproducibility of analysts performing this task. It was hypothesized that each joint angle (eye, shoulder, elbow, wrist, torso, and knee) would not be significantly affected by the analysts repeating the joint-marking process (repeatability), or by different analysts applying body posture markers to the same postures using the app (reproducibility). The Gage R&R Method within the measurement system analysis tools in Minitab 16 provided convenient analysis methods for testing the following hypotheses.

For repeatability, the null and alternative hypotheses are:

- H<sub>0</sub> The joint angle is not significantly affected by an analyst repeating the marking process twice.
- H<sub>1</sub> The joint angle is significantly affected by an analyst repeating the marking process twice.

For reproducibility, the hypotheses are:

- H<sub>0</sub> The joint angle is not significantly affected by the analyst.
- H<sub>1</sub> The joint angle is significantly affected by the analyst.

To test for an interaction between the analysts and their repeated trials an appropriate test for this is an ANOVA model with two factors and their interaction. This is an option in the Gage R&R Method. The significance level for these tests was set at a p-value of 0.05.

- H<sub>0</sub> The joint angle is not significantly affected by the interaction of analyst and trial.
- H<sub>1</sub> The joint angle is significantly affected by the interaction of analyst and trial.

### 1.5.3. Statistical Method 3

To test the ERGO@WSH app measurement system, two methods are used to analyze body angles obtained from postural photos with and without original postural markers. When run through the Gage R&R the graphs:

- H<sub>0</sub> There is no significant difference between joint angles obtained by the researcher with body markers visible, and those obtained from the app users without invisible body markers. In both cases, the photos were printed and angles measured by the researcher using a protractor.
- H<sub>1</sub> There is a significant difference between joint angles obtained by the two methods. Either a paired-data t-test or ANOVA could be used. The t-test was chosen for this project.

## **2. Background**

### **2.1. Prior Research**

The technology of apps is recent and very little scientific research has been conducted concerning validity or exploring the metrics behind these apps in context of the occupational health and safety field. There have been articles in magazines like the Synergist, Safety and Health, but these articles are the opinions of professionals saying that they are good for getting a quick reference and should not replace the traditional industrial hygiene tools because they are not backed by scientific research. These articles also talk about how some apps enable the professional to spend more time working with employees and less time in the office doing paperwork. The editor of Safety + Health magazine talked to several safety professionals and found that many professionals are turning to apps on their mobile device to help with their jobs. Most of these professionals hesitated to suggest that apps can directly save lives on the job, but did say that mobile devices have made the managerial side of the job easier (Morrison, 2013).

### **2.2. Studies of Sitting Postures**

The study of the ergonomic stress while sitting at a work station has been extensive. The study of posture has gone all the way back to 1723. The father of industrial hygiene, Ramazzini, stated that workers who sat still, stooped, looking down at their work often became round-shouldered and suffered from numbness in their legs and sciatica. He generalized that “all sedentary workers suffer from lumbago,” and he recommended workers not to sit in the same position but to change positions frequently (Kroemer, 2001).

“Ergonomics (or human factors) is an interdisciplinary field of study that seeks to design tools, equipment and tasks to optimize the human interface” (MacLeod, 2013). Two types of forces are studied: (1) dynamic, a rhythmic change of contraction and relaxation of the muscles,

and (2) static, a slow contraction with a heavy load or holding a position for long periods of time (Grandjean, 1977). Sitting is an example of static posture. Low levels of static exertion especially when combined with poor posture have been identified as a risk factor for the onset of cumulative trauma disorders in epidemiology studies (Sjogaard & Jensen, 2005). Static, in mechanical terms, means no motion or muscle contraction. It may be counterintuitive to think that static behaviors like sitting at a computer workstation would be a risk because we normally think of risk in high muscle contraction over-stressing joints and tendons. Low forces in holding posture over time causes mini ruptures or tears in the muscle and over time causes fatigue fracture and without proper recovery time, makes static postures a risk for these musculoskeletal disorders (MSDs) (Sjogaard & Jensen, 2005). Studies by Corlett found that people who have been sitting in the same posture for long periods of time have a harder time recovering from postural loadings (Corlett, 2007).

Millions of people sit at computer workstation for an occupational or recreational purpose. Many of these people suffer back aches while sitting for long periods of time (OSHA Fact Sheet: back injuries, 2013). Prolonged sitting can lead to static muscle strain and muscle fatigue. Some cross-sectional epidemiological studies found that over 50% of adults suffer from backache during at least one period of their lives. The cause is believed to be pathological degeneration of the discs in the spine (Grandjean, 1977).

Because each person is unique, adjusting the computer workstation is a challenge. To understand the best way to set up a computer workstation, it is helpful to understand the concept of neutral body positioning. This is a comfortable working posture in which your joints are naturally aligned. While working with the body in a neutral position, the stress and strain on the

muscles, tendons, and skeletal system are minimized, and the risks of developing a musculoskeletal disorders is reduced.

To eliminate the development of MSDs from working at the computer workstation, the current belief is that small adjustments need to be made frequently (Computer Workstation, 2012). Dan McLeod in his book "*The Rules of Works*" states that "when working at a computer workstation there is no single posture that is correct for long extended periods of time." The idea is to adjust your posture multiple times a day because the body needs movement (MacLeod, 2013). In *Office Ergonomics*, Kroemer states that the body is built for motion and not static motion. Sustaining a static posture can be taxing on the body. That is why our body tells us to get up and move, but the stress of work keeps people static (Kroemer, 2001). Corlett agrees with Kroemer and MacLeod. In his research, he states that it should be accepted as a principle that a work chair must enable users to adopt as many positions as possible. Performing office work should not require postures that will jeopardize a worker's health (Corlett, 2007).

The sitting posture is the most common posture in industrialized countries. This has not always been the case but due to technology, the evolution of posture has gone from standing to sitting (Grandjean, 1977). Early studies (Yamaguchi, 1970) in Japan, investigated various seat inclinations on the lumbar muscle activity. Investigators recorded the tension between vertebrae to determine which relations of the seat angle and the backrest angle produced the lowest tension. The results of the study found that 125 degree angle minimizes the spine tension (Yamaguchi, 1970). About the same time, there were other studies being conducted in Sweden on the effects of sitting posture on spinal disc pressure. With lumbar supports, the lumbar disc pressure was reduced as back rest inclination increased from 90 to 120. Table I summarizes each

of the study's results. The ANSI standards states, the farthest incline should be 120 and not 125 degrees (ANSI/HFES, 2007).

**Table I: Early studies on lumbar disc pressure correlated to angle**

	<b>Low disc pressure Nachemson (1970) Anderson (1974)</b>	<b>Minimum of discomfort Grandjean (1964)</b>	<b>Tension between vertebrae Yamaguchi and Umezawa (1970)</b>
Seat inclination (to horizontal line)	14°	16-30°	
Back rest inclination (to horizontal line)	110-130°	125-138°	125°

Nigel Corlett, considered one of the foremost authorities on sitting posture, created recommendations for having good sitting postures. His first recommendation is that when sitting, the lumbar curve should be maintained like when standing. The lumbar curve in the small of the back allows one to stand upright with a minimum of back muscle activity. The body is designed to reduce back muscle movement when standing by distributing the weight of the upper body down the back and through the hips to the ground.

His second recommendation suggests that the old 90-90-90 rules for sitting (where the knees, hips, and elbows are at 90° angles) loads the spine with unwanted pressure. To avoid this posture, the seat pan should be slightly raised which results in opening the hip torso angle; this will enable retention of the lumbar curve. Having this elevated seat pan takes pressure off the lumbar spine when standing up. Dr. Corlett commented that having poor seated posture reduces one's physical capacity for effort and can lead to bodily distortion over long periods of time. He notes that the human body is designed for motion, and changing posture allows recovery for muscles (Corlett, 2007).

### **2.3. Health Effects of Prolonged Sitting**

The American Heart Association and the American College of Sport Medicine recommend that a person should get a minimum of 30 minutes of moderate intensity of physical activity for 5 days a week. This recommendation is based on the evidence linking physical activity to decreased rates of morbidity and mortality (Katzmarzyk). In the 21<sup>st</sup> century, the vast majority of work is performed seated on a conventional office chair with a backrest. This contributes to the decrease in daily physical activity (Corlett. 2007). People who work in the office at a computer are not exempt from having back pain. This pain comes from static forces that act on the body and are exacerbated by poor posture and the development of a back-related MSD. People adopt a sitting posture for many different purposes broadly split between work and leisure. An explanation is quoted below.

Prolonged sitting has been identified as a serious metabolic health problem due to several pathogenic mechanisms linking muscular inactivity to increased health risks: low energy expenditure, leading to accumulation of visceral fat and activation of low-grade systemic inflammation; impaired endocrine function of the skeletal muscle causing malfunction of several organs and tissues of the body; and low shear stress followed by decreased anti-inflammatory and antioxidant responses (Ekblom-Bak, 2012).

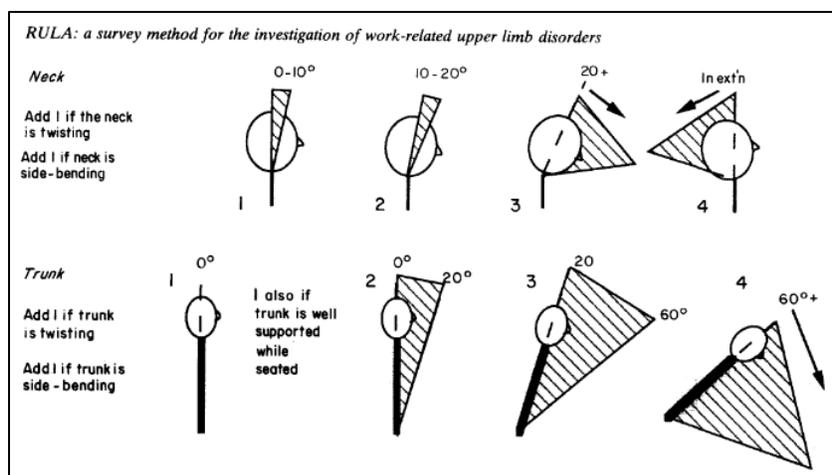
According to the Occupational Health and Safety Administration (OSHA), back pain, strain, or injury is the nation's number one workplace safety problem and preventing back injuries is a major workplace safety challenge. According to the Bureau of Labor Statistics, more than one million workers suffer back injuries each year, and back injuries account for one of every five workplace injuries or illnesses. One-fourth of all compensation indemnity claims involve back injuries, costing industry billions of dollars on top of the pain and suffering borne

by employees. Sitting for long periods of time runs a high risk of lower back injury second to lifting heavy objects (OSHA Fact Sheet: back injuries, 2013). Along with the increasing recognition of the negative effects on prolonged sitting is an increased interest in postural analysis methods.

#### **2.4. Postural Analysis Methods for Sitting**

Postural analysis can be a powerful technique for assessing work activities. The risk of musculoskeletal injury associated with poor postures can be a motivation to making improvements. It is a rigorous task to do an assessment of current working postures, comparing observations to healthy posture guidelines, and finding feasible recommendations for improvement.

There are several methods used in the field to assess posture. Two common methods are the Rapid Entire Body Assessment (REBA) and Rapid Upper Body Assessment (RULA). RULA is a survey method developed for use in ergonomic investigations of workplaces where work-related upper limb disorders are reported. This tool requires no special equipment in providing a quick assessment of the postures of the neck, trunk and upper limbs along with muscle function and the external loads experienced by the body. A coding system is used to generate an action list, which indicates the level of intervention required to reduce the risks of injury due to physical loading on the operator (MacLeod, 2013). Figure 6 is used in RULA to gauge the neck and trunk angles.



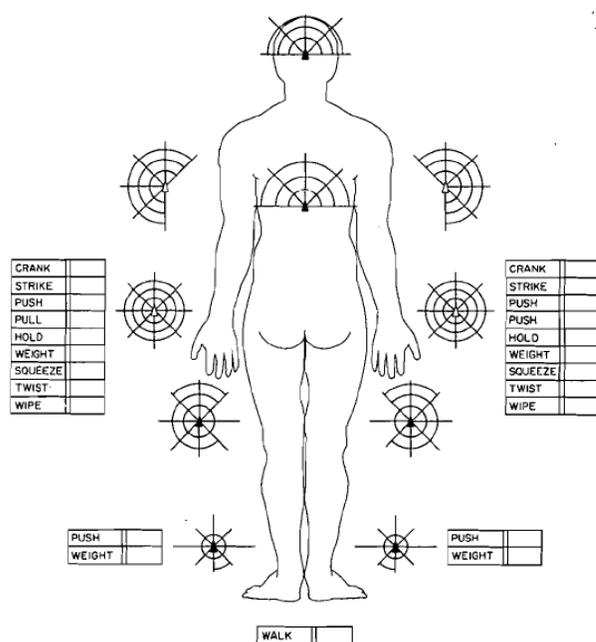
**Figure 6: RULA's diagram on measuring the neck and trunk**

REBA is a tool like RULA that does not require specialized tools. REBA was developed as a postural analysis system sensitive to musculoskeletal risks in a variety of tasks. It has the user divide the body into segments and then code postural attributes individually with reference to the planes of movement. A scoring system for the muscle activity is used for static and dynamic postures. Coupling is included in the REBA calculations; then, after calculating all factors, a score is tabulated. The score is associated with an action level and indication of urgency.

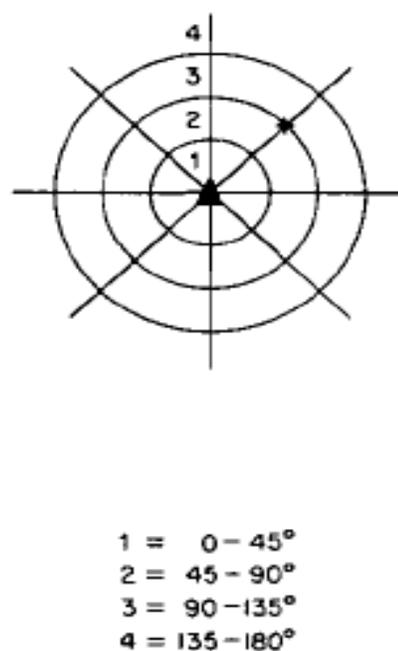
There are recommendations from OSHA and America National Standard Institute (ANSI) to assess posture in a more static environment like sitting at a computer work station.

Postural analysis can be a powerful technique for assessing work activities. The availability of task-sensitive field techniques is of great assistance for the ergonomic practitioner. Most postural analysis techniques have two, usually contradictory, qualities of generality and sensitivity (Fransoon-Hall, 1995). High generality in a postural analysis method may be accompanied by low sensitivity, for example; the Ovako Working posture Analysis System (Karhu et al., 1977) has a wide range of use but the results can be low in detail (Hignett, 1994).

Corlett developed a detailed technique to record postures. The recording can be done on a diagram of the body (Figure 7) that has a set of segmented concentric circles like a target. The targets are placed next to each body part. A target has four circles (Figure 8) that represent the ranges of movement in degrees, allowing a grade to be assigned to the body part. Corlett said it can be easily learned and has a high percentage of repeatability and accuracy for a posture that is held for a long period of time (Corlett, 1979). This method of postural analysis is very similar in design to the ERGO@WSH app in trying to measure the angle of each body angle.



**Figure 7: Corlett's body targeting technique for associated body part**



**Figure 8: Corlett's body target used for recording bod part displacement via angles**

## 2.5. Computer Workstation Standard Recommendations

With ample amounts of research on sitting posture there is one common theme, it cannot be quantified as a correct posture. Each posture is unique in nature. It is dependent on the person sitting. For this reason there has not been any official government regulation on sitting posture;

however, OSHA does offer recommendations on its web site. The OSHA recommendations are exactly the same as the ANSI recommendations. ANSI is a private non-profit organization that develops voluntary consensus standards for products, services process, systems, and personnel in the United States. (Introduction to ANSI, 2013). Generally, ANSI standards are more current than OSHA's because ANSI updates their standards every four years. The Human Factor and Ergonomic Society worked within the ANSI procedural framework to produce the *Human Factors Engineering of Computer Workstations* standard. Since the standard is a voluntary standard, it is not enforced by OSHA. For this thesis, the ANSI guidelines are treated as a gold standard.

### **3. Materials and Methods**

#### **3.1. Materials**

A 32 gig iPad 2 (serial number DN6GW2YJDKPJ and model number MC980LL/A) was used for taking the posture pictures and running the ERGO@WSH app. The iPad 2 is equipped with iOS6 operating system and a back camera that takes 960-by-720 photos. The ERGO@WSH app is the March 2013 updated version. The PDF report from the ERGO@WSH app was printed off giving the recommendation along with a picture that measure 6.25 by 4.75 inch (159 by 108 mm). This was used to hand measure the shoulder, elbow, wrist, lower back and knee angle. Each of these angles was measured with a standard 6-inch clear protractor. The computer workstation was set up in an office in the Science and Engineering building at Montana Tech. The desk that was used had a height of 33 inches and has a height-adjustable keyboard and monitor. The desk had no sides. The computer chair that was used is a basic office chair that could be adjusted up and down along with the back rest being able to adjust forward and backward. The chair had no arm rests. The postural model was a male with a thin body type. He was wearing business casual attire. Basic bright stickers were used as body posture markers. Each posture was set up using a 12-inch clear plastic goniometer. Minitab 16 and Microsoft Excel were used to run all statistical analyses.

#### **3.2. Procedures**

Six sitting postures were pre-planned. One faculty member volunteered to pose while a second faculty member guided the first to assume the pre-planned posture. Three postures were set to conform to the ANSI standards. Three nonconforming postures were set up that did not meet the ANSI standards for sitting posture. All six postures were set up by placing basic bright postural stickers on the: upper and lower back, shoulder, elbow, wrist, hip, knee, ankle and toe.

These postural markers locations matched those used for the app. A goniometer was used to make sure that each body angle was close to that pre-planned. Using the app, all six photos were taken at 6 feet away from the person sitting at the computer workstation.

Table II summarizes the conforming postures. The first posture was set up to the ANSI upright posture. The torso was set at 90 degrees, knee angle to 89 degrees and the elbow 104 degrees. The second conforming posture parameters were set up to ANSI's reclined posture. The torso angle was 115 degrees, the elbow angle is 111 degrees and the knee remained at 89 degrees. The third conforming posture parameters was set to meet the ANSI declined posture. The seat was raised to open the torso angle set to 113 degrees, which changed the elbow to 101 degrees. The knee changed to 96 degrees.

**Table II: Conforming posture set up for postures 2-4**

Angle measured	Conforming Posture Numbers		
	#5	#6	#7
<b>Torso</b>	90°	115°	113°
<b>Elbow</b>	104°	111°	101°
<b>Knee</b>	89°	89°	96°

Table III summarizes the conforming postures. The first was set up so the: torso angle was 113 degrees and the elbow was 94 degrees. The knee angle was set at 87 degrees. The second nonconforming posture parameters were set up as follows: the torso angle was 110 degrees, the elbow was 98 degrees and the knee angle was 89 degrees. The third nonconforming posture was set up so the torso angle was 121 degrees, the elbow was 113 degrees, and the knee angle was 83 degrees.

**Table III: Nonconforming postures 5-7 set up**

<b>Angle measured</b>	<b>Nonconforming Posture Numbers</b>		
	<b>#5</b>	<b>#6</b>	<b>#7</b>
<b>Torso</b>	113°	110°	121°
<b>Elbow</b>	94°	98°	113°
<b>Knee</b>	87	89°	83°

For each control posture, the researcher used the unedited photos to be analyzed by the ERGO@WSH app. The body posture markers from the app's silhouette were placed on the actual body postural markers that were left in the photos. These images were subsequently printed and the researcher measured the angles with a protractor. This is illustrated in Figure 9. Postures 2-4 were set up to be conforming to the ANSI standards. Postures 5-7 were set up nonconforming to the ANSI standard.

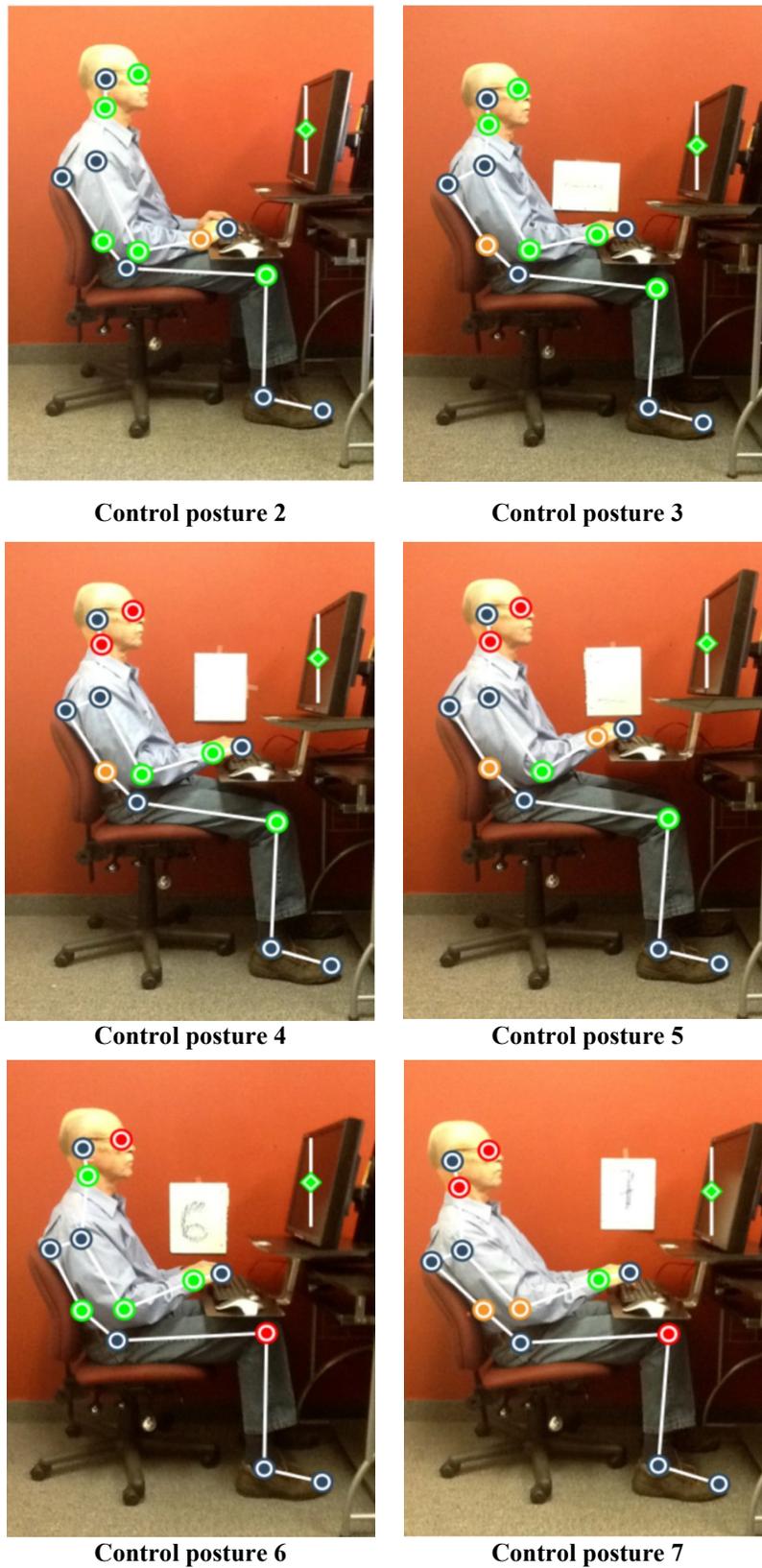
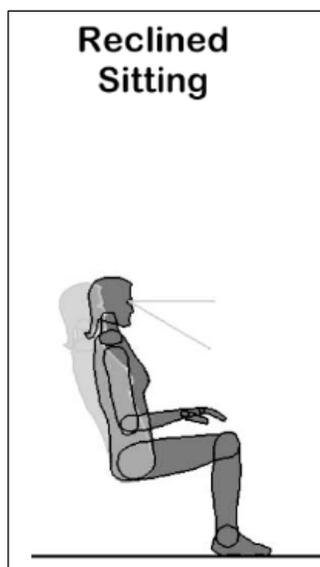
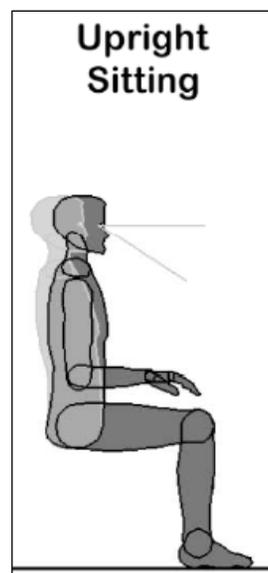


Figure 9: Photos with markers for ANSI conforming and nonconforming postures.

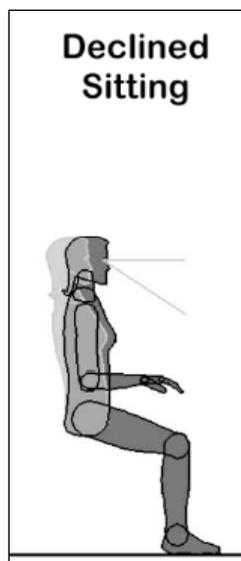
ANSI recommends three correct sitting postures that are reclined, upright and declined. These are defined using the angle formed by the torso-bend line and the horizontal. The torso-bend line created from the leg to the hip and from the hip up to the shoulder. In the reclined posture, the torso and neck recline between 105 and 120 degrees to horizontal (see Figure 9). In the upright posture, the torso and neck are approximately vertical and in line between 90 and 105 degrees to horizontal. The thighs are approximately horizontal and the lower legs are vertical (see Figure 10). In the declined posture, the thighs are inclined below the horizontal, the torso is vertical or slightly reclined behind the vertical, and the angle between the thighs and the torso is greater than 90 degrees (see Figure 11) (ANSI/HFES, 2007).



**Figure 10: ANSI recommended recline posture: torso at 105 to 120 degrees**



**Figure 11: ANSI's recommended upright posture: torso-neck 90 to 105 degrees**



**Figure 12: ANSI's recommended declined sitting posture:  
torso-thigh angle > 90 degrees**

The photos were edited to make the body postural markers invisible. The edited photos were then provided to the three analysts for their analyses.

The three analysts who participated in this study were industrial hygiene students in the graduate program at Montana Tech. They all were taking an advanced ergonomic class at the time. All had passed an anatomy and physiology. These photos with the markers are provide in Appendix A.

### **3.2.1. App Analyst Procedures**

Each analyst was given basic training on how to use the ERGO@WSH app. The training included: how to align the silhouette to the model, how to move the app's body postural markers, zooming in and out, and how the app defined where each body posture marker should go.

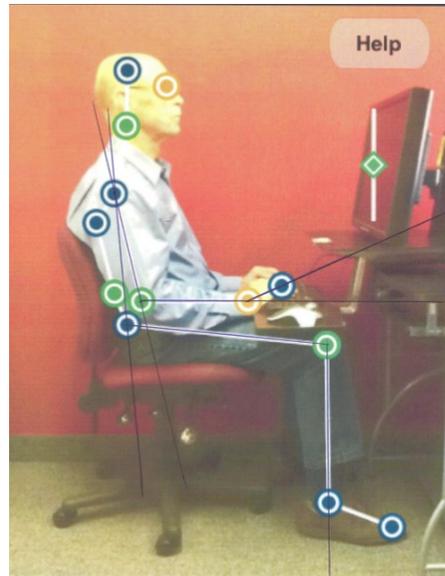
The three analysts analyzed all six postural photos using the ERGO@WSH app in random order two separate times. The time span between trials was about three weeks. This is considered sufficient time to test the intra-analysts variation.

### **3.2.2. Researcher Procedures**

After the three analysts completed their positioning of markers, each of the posture analyses was printed off in a PDF format that gives the recommendations and a photo with traffic color coded body postural markers. These traffic colored postural markers are produced by the app. The photos of each posture were broken down further to include the torso, arm, and elbow and shoulder angles.

The basic anatomy of an angle consists of a vertex and two legs that extend from the vertex. The anatomical angles shown in a printed photo are measured by placing a protractors center point on the vertex. The shoulder, elbow, wrist, hip, and knee postural markers were the vertices of each measured angle. These angles were compared to the ANSI recommendations as part of the projects objective 1.

Figure 13 shows the markers placed by one of the analysts and the lines are used to determine angles. Note that this analyst places the head marker above the ear, whereas they were trained to place it on the ear.



**Figure 13: Photo demonstrates how each body angle was measured**

Postures 2, 3 and 4 are the conforming posture according to ANSI and postures 5, 6 and 7 are the nonconforming postures. Posture 1 was discarded due to incorrect methodology.

Posture 2 was set up to the ANSI upright posture. The pre-planned angles of the torso, neck, and knee angle were 90 degrees. By placing the center of the goniometer at the joint and then moving the legs of the goniometer to the pre-planned angle, the researcher could align the model body parts to the goniometer. The keyboard height measured 25.5 inches from the ground and the top of the seat pan measured 20 inches. Posture 3 was set up to the ANSI reclined posture. The chair remained at 20 inches; the back of the chair was reclined causing the torso angle to open up to 113 degrees. The knee angle and keyboard were not changed. Posture 4 was set as the ANSI declined posture. The chair was raised to 21.75 inches, which caused the torso to open to 115 degrees and the knee to be 92 degrees. The keyboard was not changed.

Experimental posture 5 had everything the same as experiment 4, except the keyboard height was changed to 31 inches, which resulted in an improper posture. Posture 6 is the second improper posture. First, the seat was lowered all the way down to 17 inches and the keyboard

height was 25.5 inches. The torso angle measured 110 degrees. The knees angle was less than 90 degrees. Posture 7 was set up exactly like posture 6 but the torso angle was adjusted to 121 degrees. Later, using the printed photos, the various angles were measured, resulting in the angles reported in Tables II and III.

The photos containing markers by the three analysts (Appendix A) were printed. The researcher drew lines connecting joints markers and measured the angles with a protractor. These angle values were subsequently used as part of objective 3.

### 3.3. Statistical Methods

The statistical method for objective 1 used the kappa statistic, a general test for several similar measures of agreement used with categorical data. Typically, it is used in assessing the degree to which two or more raters or two or more tests examine the same thing and assign it the same categories. Kappa values can range from zero, representing no agreement beyond what is expected by chance, to a value of one representing perfect agreement (Daly, 2000). This test is illustrated in Table IV showing the results of determining the accuracy of the ERGO@WSH compared to the ANSI standards. In order to account for chance agreement, the third table is calculated to rule chance out. For this analysis, the postures were assigned to categories by ERGO@WSH and by the researcher using the photos and a protractor. The categories were conforming or not conforming to ANSI recommended postures.

**Table IV: Format of Data Table for Computing Cohen's Kappa**

		Researcher		
		Conforming	Nonconforming	
Analyst	Conforming	A	B	A+B
	Nonconforming	C	D	C+D
		A+C	B+D	A+B+C+D

Counts of observations are entered into the cells A, B, C, and D. Cell A is the number of times both analysts reported conforming postures. Cell D is the number of times both analysts reported nonconforming postures. The numbers of postures for which both agreed is A + D. Cells B and C is a situation of disagreement. A simple way to express agreement is to report the number of agreement as a percentage of all observations. This method is unsatisfactory because it fails to account for some observations agreeing purely by chance alone. Cohen proposed a procedure that adjusts for the expected number of chance agreement. The expected agreement in conforming is computed as:

$$E(\text{cell A}) = \frac{(A + B) \times (A + C)}{A + B + C + D} \quad (1)$$

and the expected agreement in nonconforming (cell D) is computed as:

$$E(\text{Cell D}) = \frac{(C+D) \times (B+D)}{A+B+C+D} \quad (2)$$

The sum of E (cell A) and E (cell D) is denoted  $\sum AD$ . Cohen's Kappa is computed as:

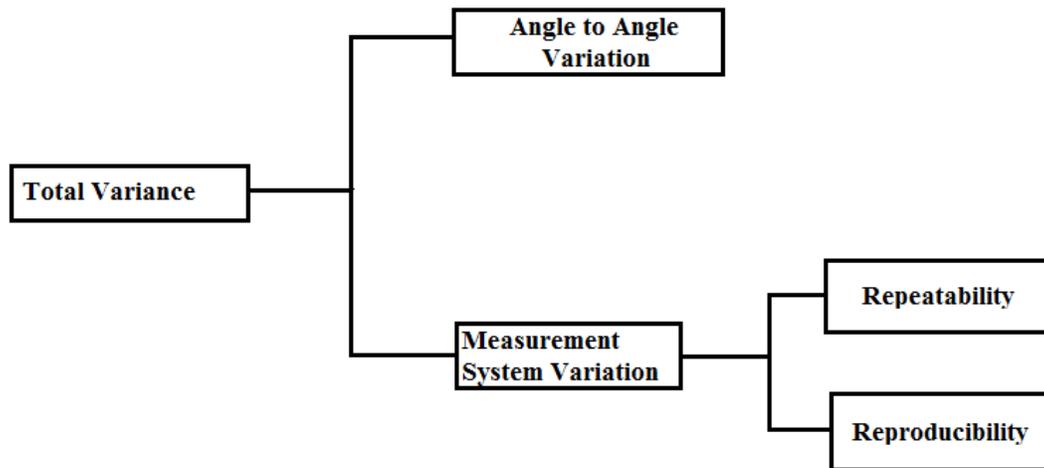
$$K = \frac{A + D - \sum AD}{N - \sum AD} \quad (3)$$

The values of Kappa are regarded as measures of the degree of concordance. The following guidelines may be used to interpret the values (Daly, 2000).

**Table V: Cohen's Kappa level of agreement**

<b>K value</b>	<b>Interpretation</b>
≤ .20	Poor
.21-.40	Fair
.41-.60	Moderate
.61-.80	Good
.81-1.0	Excellent

The statistical methods for objective 2 were an ANOVA and Gage R&R statistical analysis. Gage R&R is a tool for quantifying the percentage of total variance due to repeatability, reproducibility, and the things measured. It determines how much of the total observed variability is due to the instrument and isolates the components of variability in the measurement system. Figure 14 depicts the variance breakdown for total variance.



**Figure 14: Variance breakdown for total variance**

Determining the capability of a measurement system is an important aspect for quality and process improvement activities. A typical measurement system will consist of a measuring instrument and the operators that use it at two different points of time (Montgomery, 2013). A crossed Gage R&R analysis was used in Minitab 16 program. Using the crossed Gage R&R tool, measured posture angles were examined to determine how much of the measurement variability came from each variation source. The sources included were the actual angle difference and the precision of the measurement system. The precision is further broken down into repeatability and reproducibility.

The Automobile Industry Action Group (AIAG) has created criteria for levels for measurement metric assessments. (Automotive Industry Action Group, 2002) The AIAG criteria uses categories of acceptability based on the percentage of total variability due to repeatability and reproducibility. These are depicted in table VI.

**Table VI: Measurement System Acceptability**

<b>Contribution to Total Variability (%)</b>	<b>Level of Acceptability</b>
Less than 1%	The measurement system is acceptable
Between 1% and 9%	The measurement system is acceptable depending on the application: cost of device, cost of repair, other factors
Greater than 9%	The measurement system is unacceptable and should be improved

The statistical method for objective 3 was a paired t-test. It compared the angles values obtained two ways. A 0.05 level of significance was set to see if the two angle means are the same. If the results of the paired t-test are above the significance level then the angles means are not the same. If the results of the paired t-test are below evidence suggest the means are the same.

## 4. Results

### 4.1. Objective 1 Results

Results of the Kappa analysis are in Table VII. The elbow and knee angles were fair agreement. The torso and wrist angle had a poor level agreement.

**Table VII: Results for the Kappa analysis for level of agreement**

Angle	Kappa	Level of Agreement
<b>Elbow</b>	.2778	Fair
<b>Torso</b>	.1667	poor
<b>Knee</b>	.2222	Fair
<b>Wrist</b>	.0714	Poor

### 4.2. Objective 2 Results

An analysis of variance was performed to assess the significance of various sources on the measured angle values. Each angle was examined separately using an ANOVA with the independent variables: (1) posture, (2) analyst, and (3) posture\*analyst interaction. The results in Tables VIII shows the  $p$  values obtained from the angle-specific ANOVA. The interaction term was significant only for torso.

**Table VIII: Angle-specific  $p$  values for posture, analyst, and their interaction**

Source Term	$p$ Value				
	Shoulder	Elbow	Wrist	Torso	Knee
<b>Posture</b>	0.382	0.016	0.000	0.002	0.005
<b>Analyst</b>	0.180	0.007	0.474	0.971	0.006
<b>Interaction</b>	0.602	0.568	0.363	0.034	0.325

Minitab automatically re-runs this three-term ANOVA model when the  $p$  value of the interaction term is greater than 0.25. Thus, the ANOVA was re-run without the interaction term for shoulder, elbow, wrist, and knee. The re-run ANOVA produced the  $p$  values shown in Table IX. No  $p$  values are shown for torso because the interaction term significantly contributed to the variance in the torso angle measurements, that is, for torso angle, the results in Table VIII are best.

**Table IX: Angle-specific  $p$  values for posture and analyst without interaction**

Source Term	$p$ Value				
	Shoulder	Elbow	Wrist	Torso	Knee
<b>Posture</b>	0.407	0.004	0.000	*	0.000
<b>Analyst</b>	0.181	0.002	0.421	*	0.000

The posture term was significant for all angles except shoulder. The analyst term was significant for elbow angle and knee angle, but not for the other angles.

The Gage R&R Study (Crossed) results are summarized in Table X. This table shows for each angle the percentage of total variability contributed by repeatability, reproducibility, and angle-to-angle differences. Note the large percentage of variability from Gage R&R.

**Table X: Results of Gage R&R analysis, showing percent contribution to variance**

Source of variability	% Contribution for Posture Angle				
	Shoulder	Torso	Knee	Wrist	Elbow
<b>Total Gage R&amp;R</b>	94.44	33.88	99.55	28.12	72.85
<b>Repeatability</b>	57.42	18.53	74.71	28.12	46.62
<b>Reproducibility</b>	37.02	15.35	24.83	0	26.23
<b>Angle to Angle</b>	5.56	66.12	.45	71.88	27.15
<b>Total variation</b>	100	100	100	100	100

Degrees of Freedom = 35

For each of the angles measured, the Gage R&R analysis produced three graphs for each body angle. The top graph is the observed angle by posture, middle is observed angle by analyst, and the bottom graph is posture-analyst interaction. These three graphs are presented in Figures 15 through 19 for the shoulder, elbow, wrist, torso, and knee, respectively.

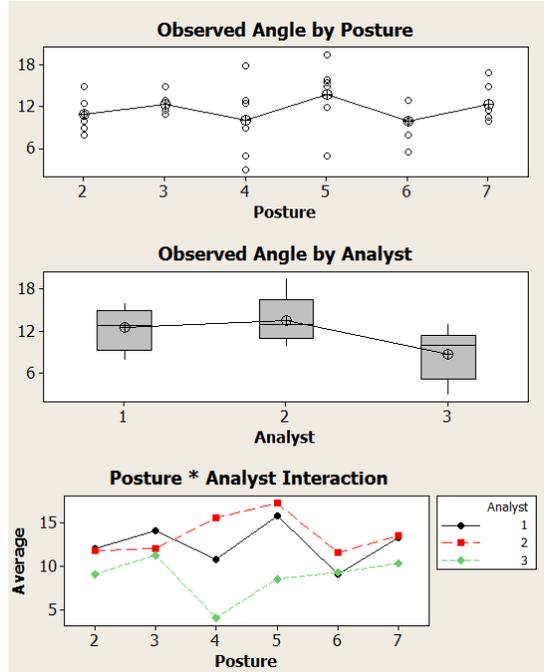


Figure 15: Shoulder Gage R&R graph

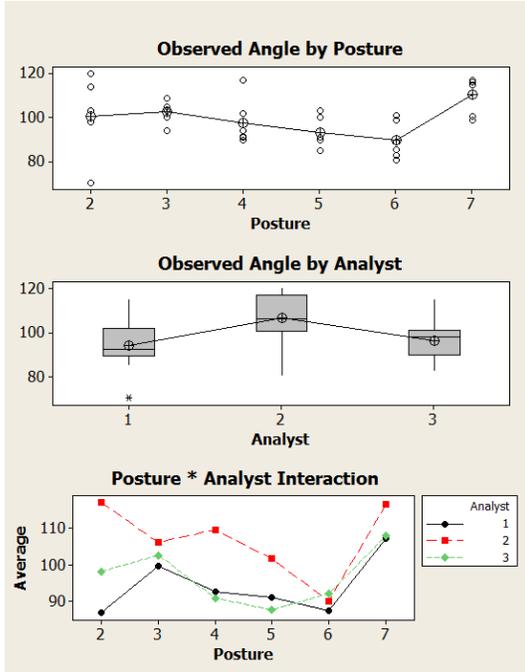


Figure 16: Elbow Gage R&R graph

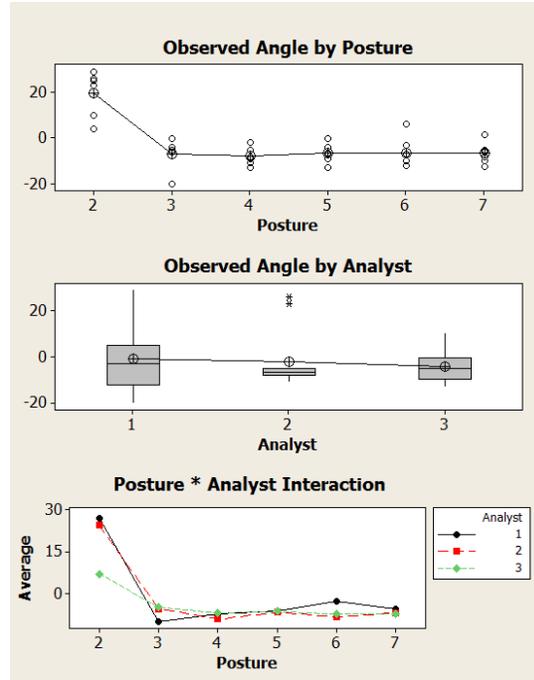


Figure 17: Wrist Gage R&R graph

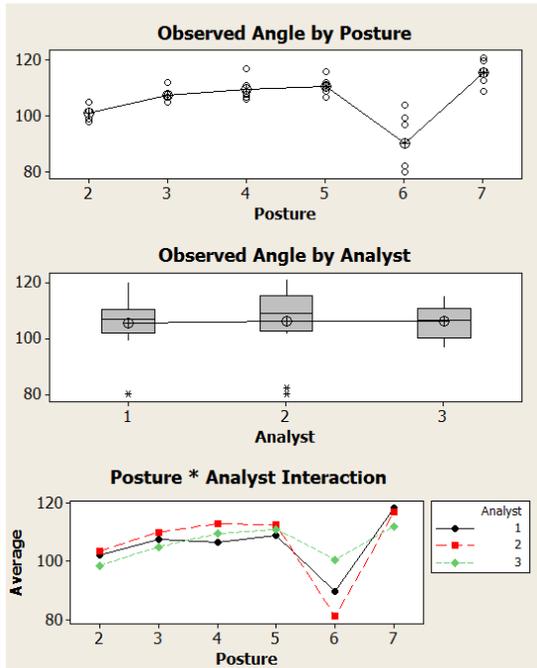


Figure 18: Torso Gage R&R graph

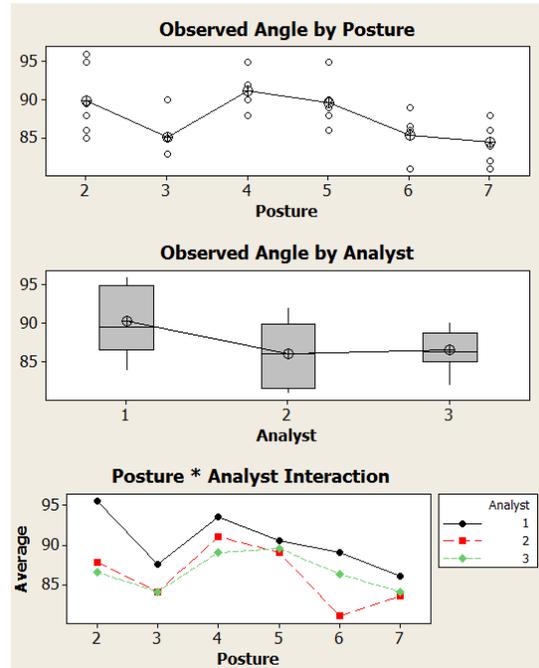


Figure 19: Knee Gage R&R graph

The shoulder and the elbow had the most difference in variance (Figure 15 & 16). The least variance in observed angle across posture was the wrist angle (Figure 17).

### 4.3. Objective 3 Results

To evaluate the ERGO@WSH app measurement system, two methods are used in the analysis of body angles. The most precise method to obtain angles is using unedited photos in the apps. The researcher obtained these by using the app to set markers based on images with markers visible, printing the photos, and measuring angles with a protractor. The others, referred to as the “experimental” measurements, were obtained by the three analysts based on images lacking visible markers. These were printed and measured by the researcher using a protractor.

A paired data t-test is used to determine the significance between the controls and experimental angle values. The results in Tables XI through XV show values for mean, standard deviation, and standard error of the mean (SE Mean). The  $p$  value indicates the probability of no difference between the controls and the experimental data. Results of this analysis fell into three distinct categories:

- 1) Clearly no difference in shoulder angle ( $p = .856$ ) and torso angle ( $p = .613$ );
- 2) Inconclusive difference in elbow angle ( $p = .064$ ), and knee angle ( $p = .10$ ); and
- 3) Clearly different in the wrist angle ( $p = .00$ ).

**Table XI: Results of the paired t-test for the shoulder angle**

	<b>N</b>	<b>Mean</b>	<b>StDev</b>	<b>SE Mean</b>
<b>Controls Angle</b>	36	13.83	4.51	0.75
<b>Experimental Angle</b>	36	14.36	17.95	2.99
<b>Difference</b>	36	-.53	17.33	2.89
<b><math>p</math> value=0.856</b>				

Table XII: Results of the paired t-test for the torso angle

	N	Mean	StDev	SE Mean
<b>Controls Angle</b>	36	110.33	9.83	1.64
<b>Experimental Angle</b>	36	109.28	6.72	1.12
<b>Difference</b>	36	1.06	12.43	2.07
<b><i>p</i> value=0.613</b>				

Table XIII: Results of the paired t-test for the elbow angle

	N	Mean	StDev	SE Mean
<b>Controls Angle</b>	36	102.17	5.95	0.99
<b>Experimental Angle</b>	36	99.06	11.57	1.93
<b>Difference</b>	36	3.11	9.76	1.63
<b><i>p</i> value=0.064</b>				

Table XIV: Results for the paired t-test for the wrist angle

	N	Mean	StDev	SE Mean
<b>Controls Angle</b>	36	-13.0	10.18	1.70
<b>Experimental Angle</b>	36	-2.47	11.66	1.94
<b>Difference</b>	36	-10.53	7.29	1.21
<b><i>p</i> value=0.000</b>				

Table XV: Results for the paired t-test for the knee angle

	N	Mean	StDev	SE Mean
<b>Controls Angle</b>	36	88.833	3.902	0.650
<b>Experimental Angle</b>	36	91.639	4.038	0.673
<b>Difference</b>	36	1.194	4.243	0.707
<b><i>p</i> value= 0.100</b>				

The wrist angle is the only angle that had a *p* value below the predetermined level of 0.05. The mean wrist angle measured by the controlled method had a mean of -13.0 degrees, compared to that of the experimental method, -2.47 degrees.

## 5. Discussion

This discussion section has five subsections: the three objectives, limitations, and future work. The first three subsections restate the applicable objective and comments on the extent to which the objectives were achieved.

### 5.1. Objective 1

The first object of this research was to test the association between the analysts and app regarding agreement with ANSI standards. The Cohen Kappa analyses showed fair agreement for elbow and knee angle. The torso and wrist had a poor level of agreement. In the safety world this would not be strong enough evidence to start using it and replacing the old methods for posture evaluation.

### 5.2. Objective 2

The second objective of this research was to test the repeatability and reproducibility of analysts performing postural assessments using the ERGO@WSH computer ergonomic app by comparing inter-analyst and intra-analyst variation in body posture measurements. It was hypothesized that:

- Each joint angle would not be significantly affected by the analyst repeating the joint-marking process (repeatability).
- Each joint angle would not be significantly affected by different analysts applying body posture markers to the same postures using the app (reproducibility)

The results for the Gage R&R indicated that none of the postural analyses measurement methods used in this research achieved a level considered acceptable according to table VI. One way to lower the percent contribution would be have more in-depth training on how to use the

ERGO@WSH app. An appropriate training program would involve having numerous photos of different people in different postures, having the trainee mark the joints, and providing feedback on the accuracy of their marks. A target level of acceptable accuracy would be defined, and the trainee would need to achieve it before being passed.

### **5.3. Objective 3**

The third objective of this research was to evaluate the ERGO@WSH app measurement system analysis for body angles using two methods referred to as controlled and experimental. The controlled measurements used the unedited images that still have the body postural markers showing in the ERGO@WSH app for analysis. The experimental measurements used the same images but with the markers edited out. The results of the paired t-test showed that the wrist angle difference was the only angle to have a  $p$  value less than 0.05. Thus, wrist angles obtained using the controlled measurements and the experimental method differed significantly. The knee was close with a  $p$  value of 0.064. Thus, using images with joint marker provided significantly different angle values for the wrist, almost significantly different for the knee, and not significantly different for the shoulder, torso, and elbow.

### **5.4. Study Limitations**

Minitab guidelines for Gage R&R studies recommend using two or three analyst, with two or three replicates and 10 parts. This research had three analysts with two replicated trials and six postures. Thus, a limitation of this study was using a smaller number of postures than recommended by Minitab.

Determining how the neck angle is measured is inconsistent within the ergonomic field. Additionally, the methodology described in the ANSI standard for measuring the neck angle is convoluted. For this reason this study did not included the neck measurement.

Guidelines for viewing angle are in the ANSI standard and the app. This project began with intent to include viewing angle, but it proved more difficult than anticipated. It requires an upper line drawn from the head marker through the eye. Because these are very close together, a small variation in placement of the head marker causes a large difference in the upper vertex used for measuring viewing angle. The analysts in this project were imprecise and inconsistent in their placement of the head marker. As a result, viewing angle results were discarded. It is recommended that future studies and guidelines use more precise anatomical points for establishing viewing angle. A promising set of points are the ear canal and the eye. These are used for defining line of sight known as the Line of Sight Ear Eye (LOSEE) method (Kroemer, 2009). This method eliminates the confusion of which anatomical land marks to be used as anchors for viewing angle. These markers may also be used for defining neck and head angles, although the exact way of doing this is beyond the scope of this project.

## **5.5. Future Work**

App technology is always progressing, meaning that apps are being updated frequently. How often it is updated is dependent on the company. Updates can range from minor bug fixes to major overhaul of the app. In the case of the EGRO@WSH app, these updates may completely change the apps metrics. If the metrics changed during an updated, there is a need for more work to be done to validate the app again.

Future work may be done on including the monitor marker since this was not included in this study. There needs to be more research done on how this app evaluates the lower back as a good or poor posture. When setting up the postures that were to be used in the analysis, the body markers that was placed on a model wearing business attire. This attire was loose fitting, which

caused the body posture markers to be less accurate in their placement. In future studies, having attire that is form fitting could result in better placement of the body postural markers.

For the future work, the researcher should measure the wrist and shoulder angle with a goniometer. These measurements were overlooked by the researcher. Including these angle measurements make the research more precise and accurate.

Training was done in this research, but for future work, a more in-depth training on what is expected would reduce the human error factor.

The measurement method for the eye angle should use the LOSEE method. The anatomical land marks for determining neck and head angle also need more exacting specifications.

## **5.6. Conclusion**

Technology is defined as the making, modification, usage, and knowledge of tools, machines, techniques, crafts, systems, and methods of organization, in order to solve a problem, improve a pre-existing solution to a problem, achieve a goal, handle an applied input/output relation or perform a specific function (Technology, 2014). The advancements of mobile devices have aided in this movement of solving problems in all professions, including the industrial hygiene and safety. It is the professional responsibility to insure that any technology that enters the profession needs to accurate and precise. If not done then by definition it is not technology.

This research on the ERGO@WSH app is just the tip of the iceberg of the research of technology that is entering the industrial hygiene and safety profession. This research found that using the app needs does not ensure reliable results because much is dependent on the app user. There may be a place for this technology in the ergonomic profession, but the technology is not

advanced enough to be as accurate and precise as it needs to be for the industrial hygiene and safety profession.

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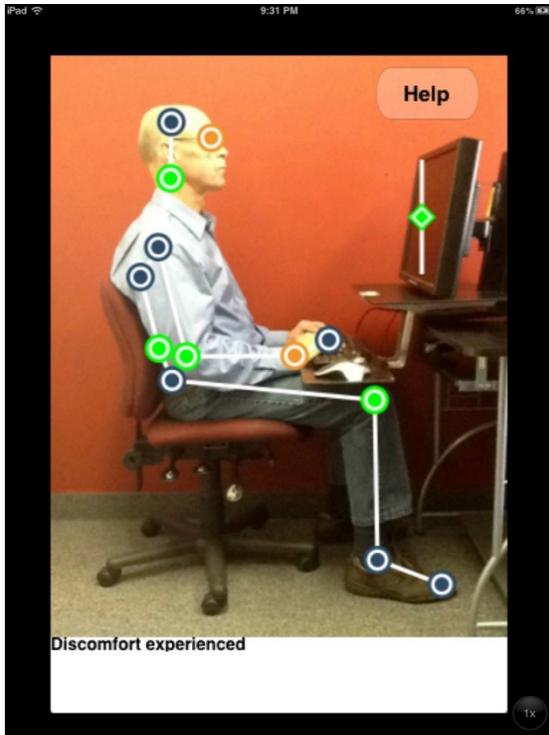
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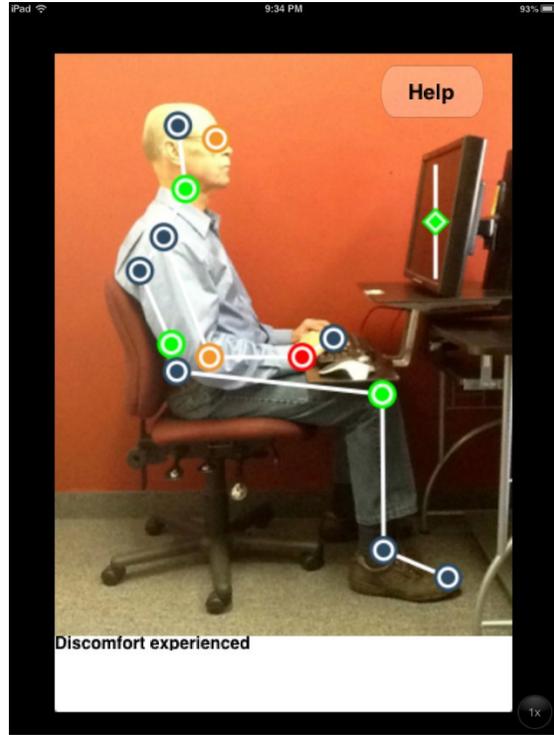
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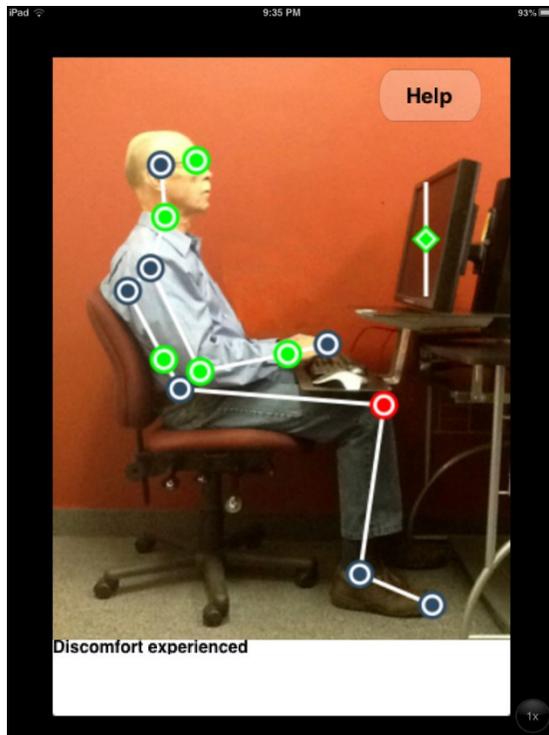
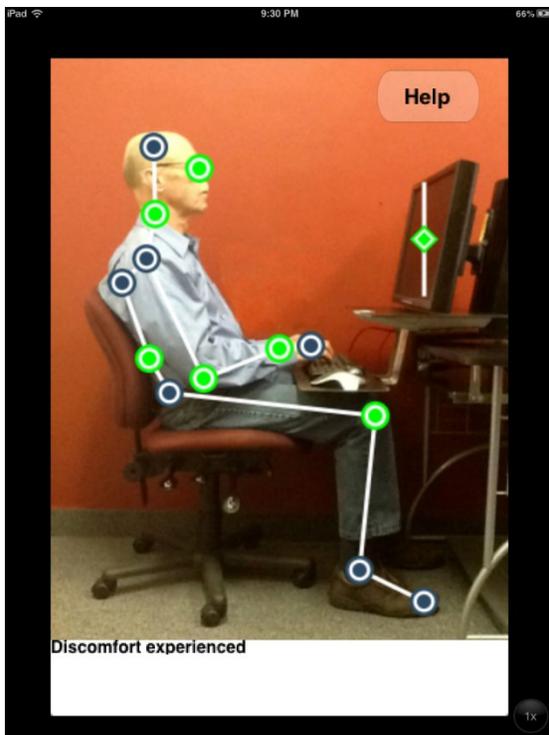
### Appendix A: Photos Analyzed



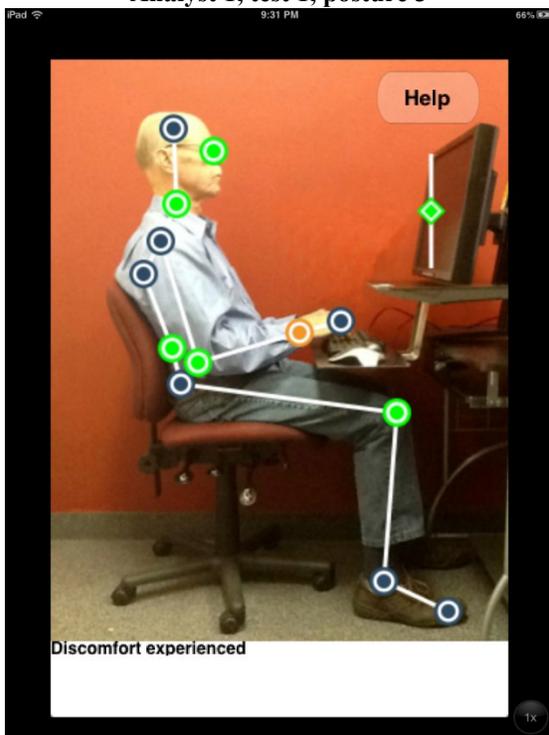
Analyst 1, test 1, posture 2



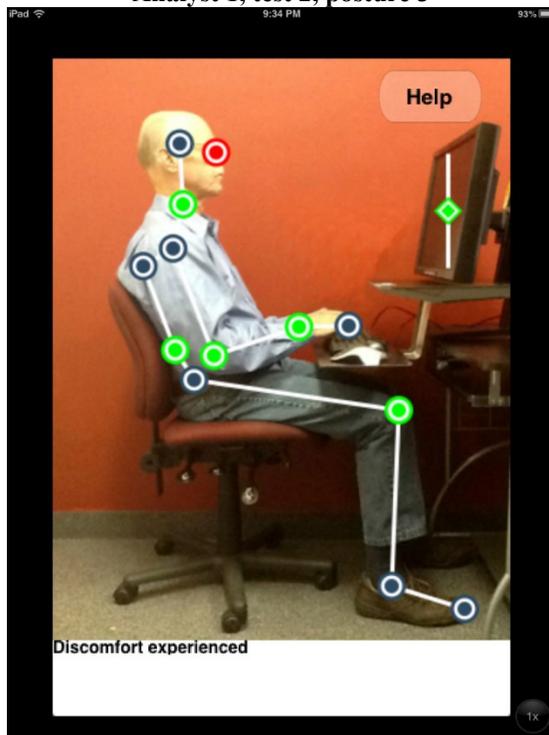
Analyst 1, test 2, posture 2



**Analyst 1, test 1, posture 3**

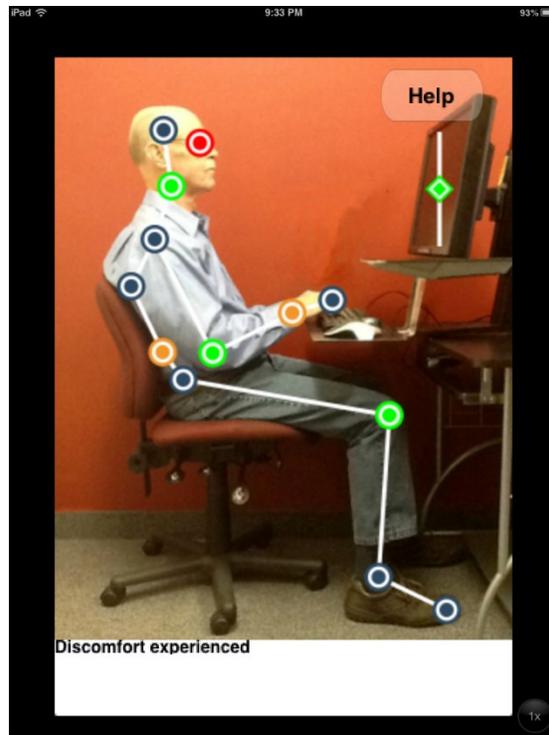
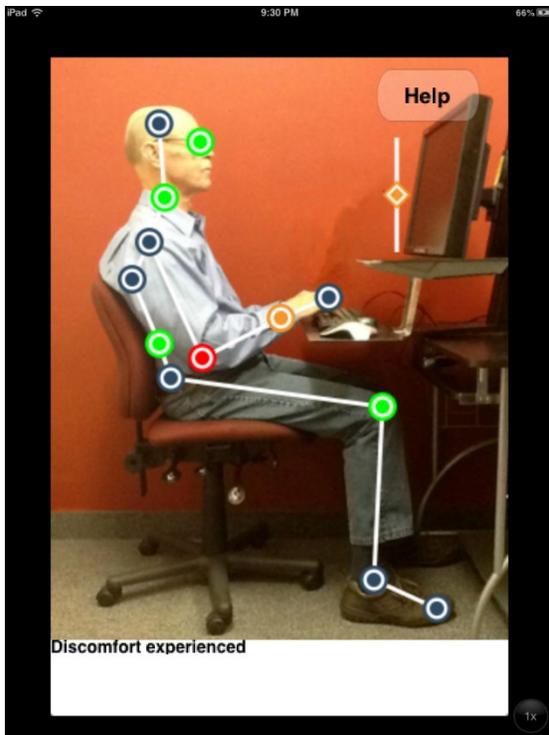


**Analyst 1, test 2, posture 3**

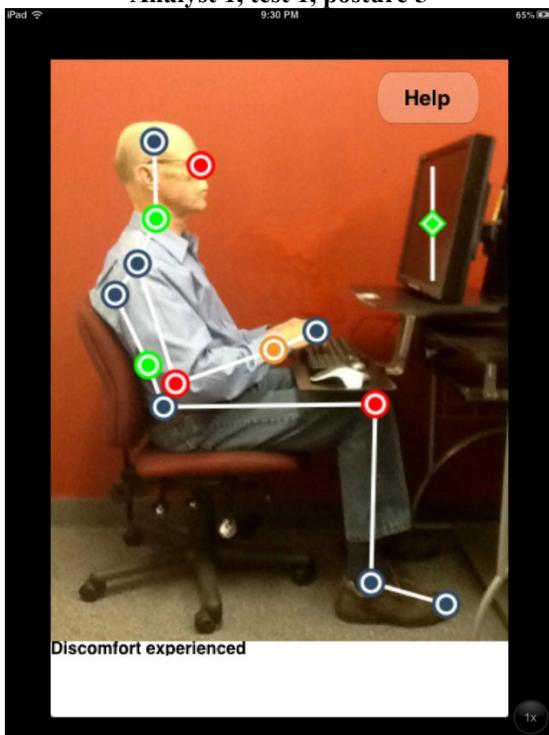


**Analyst 1, test 1, posture 4**

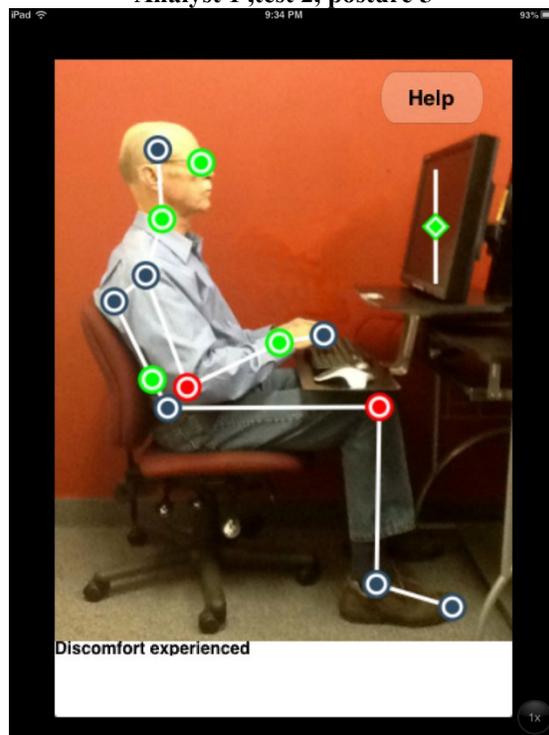
**Analyst 1, test 2, posture 4**



**Analyst 1, test 1, posture 5**

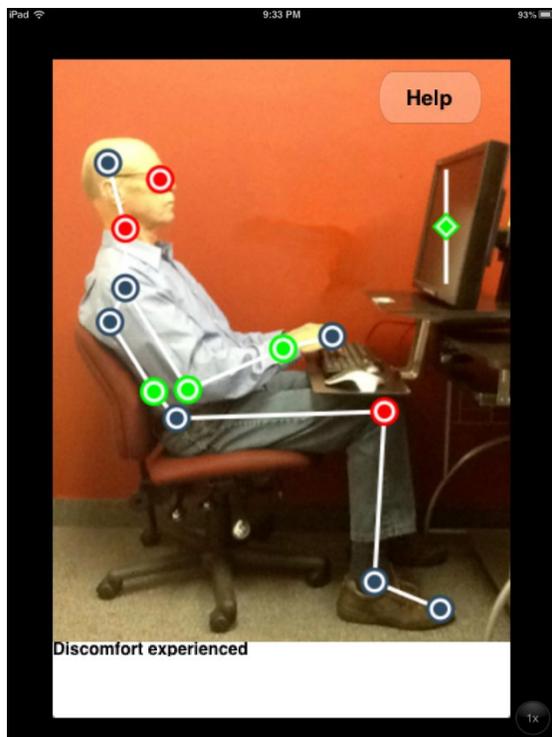
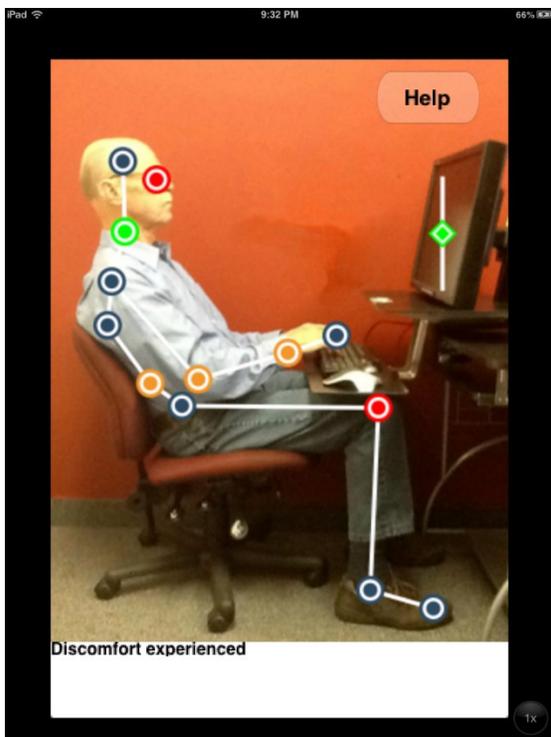


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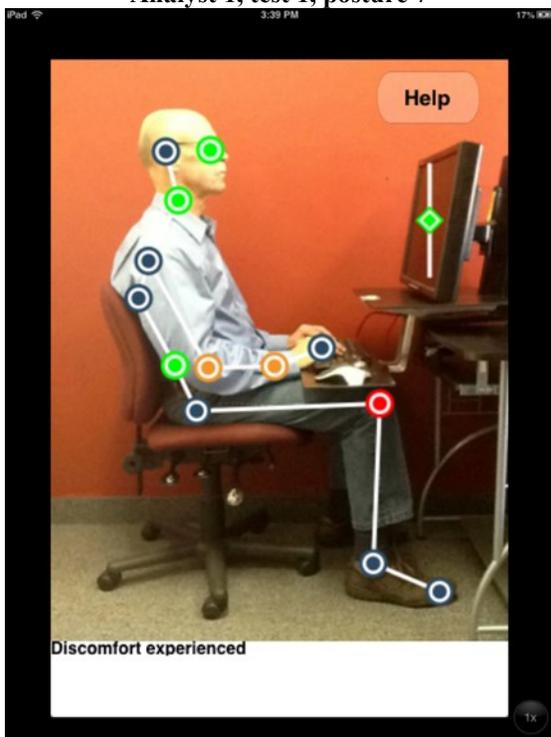


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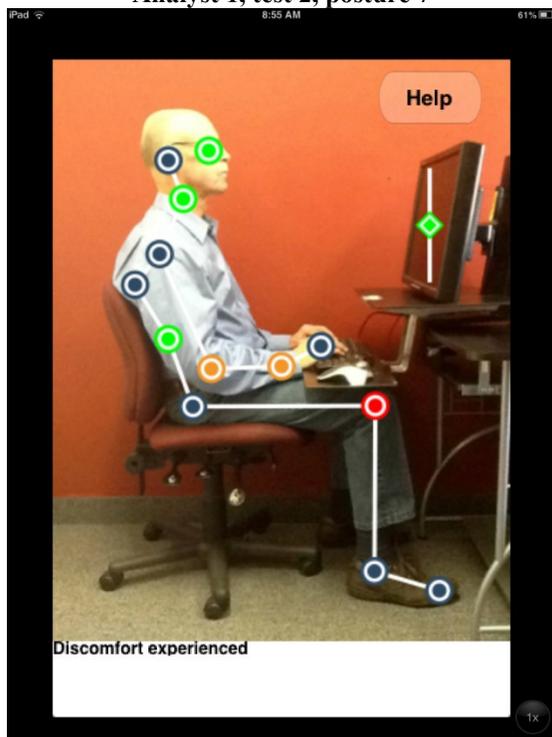
**Analyst 1, test 2, posture 6**



Analyst 1, test 1, posture 7

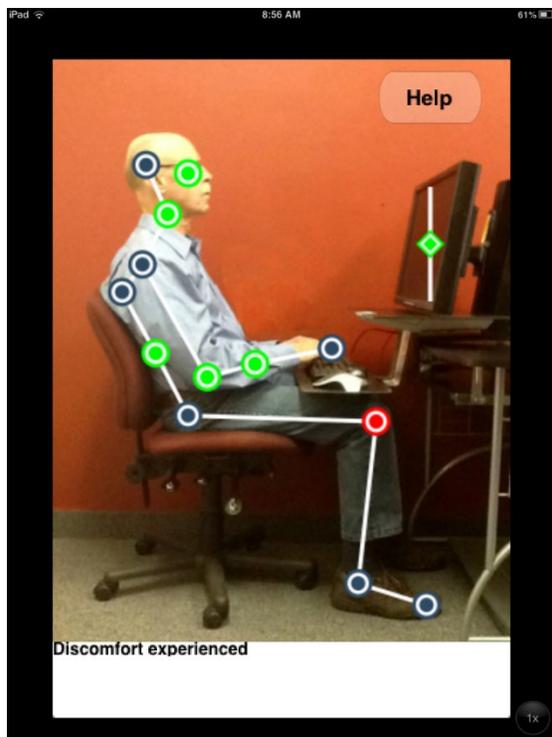
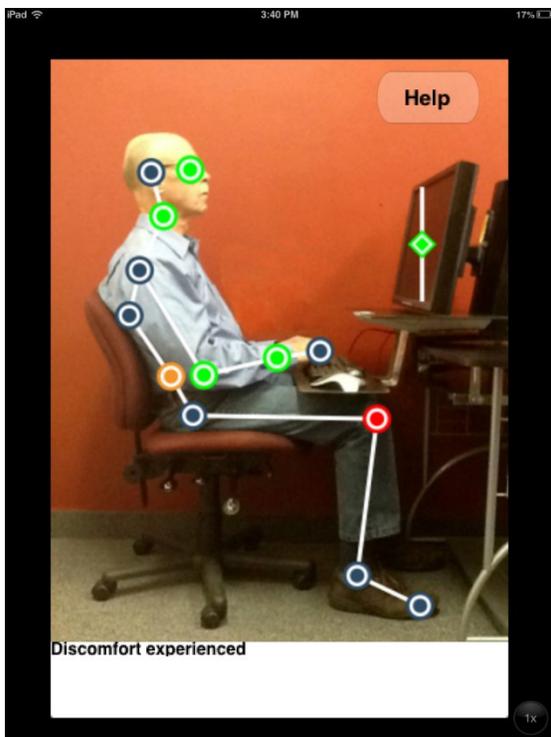


Analyst 1, test 2, posture 7

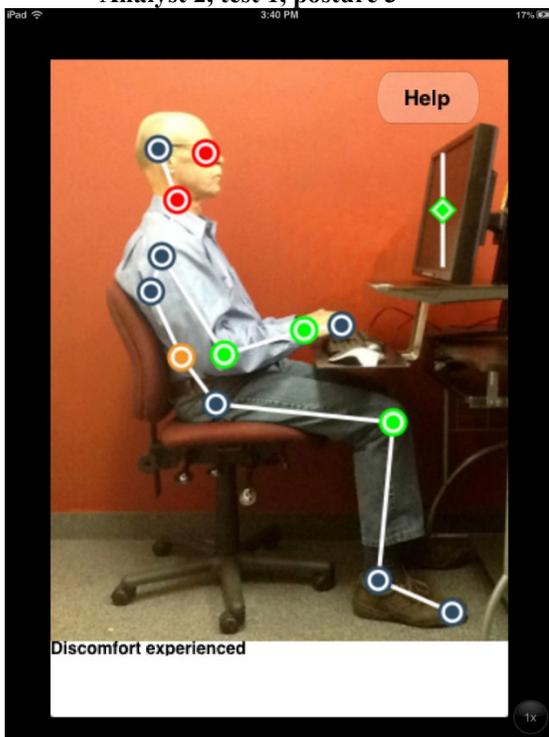


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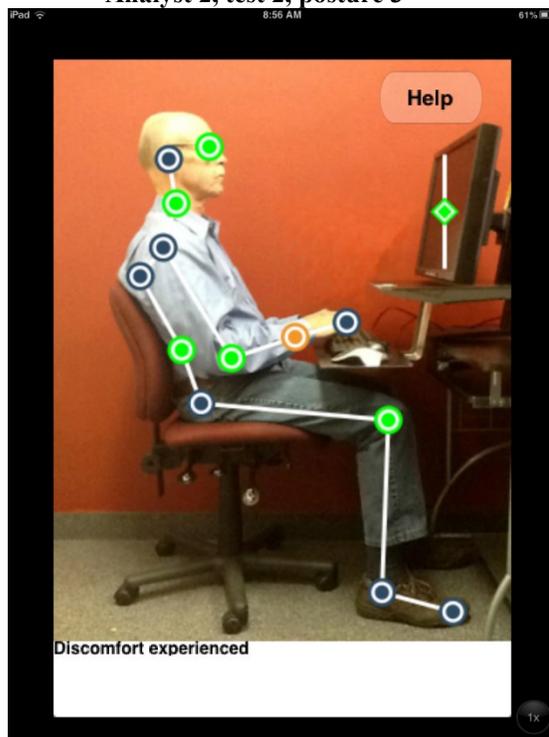
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**Analyst 2, test 1, posture 3**

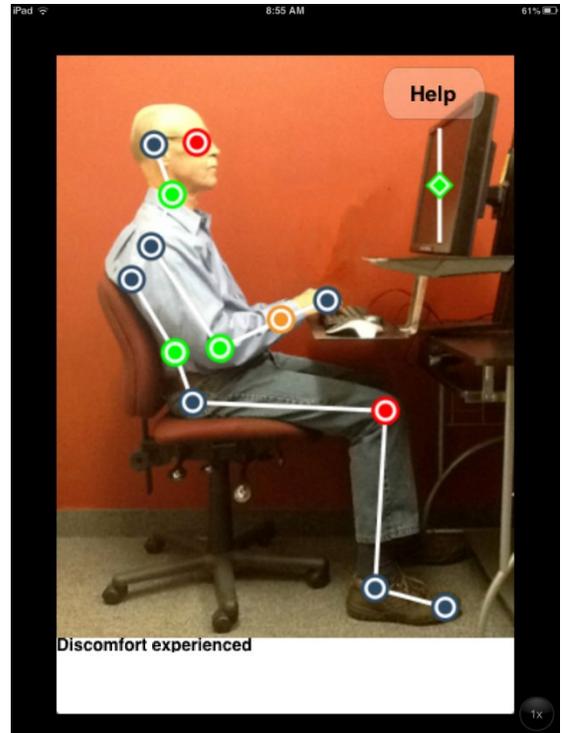
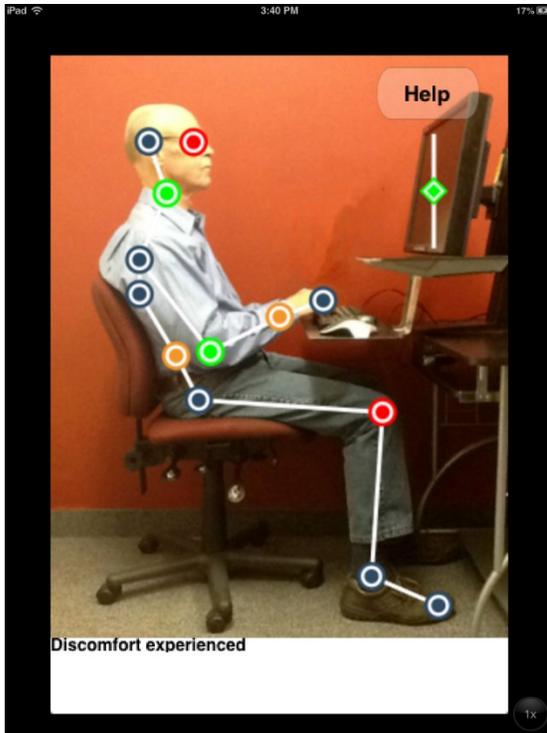


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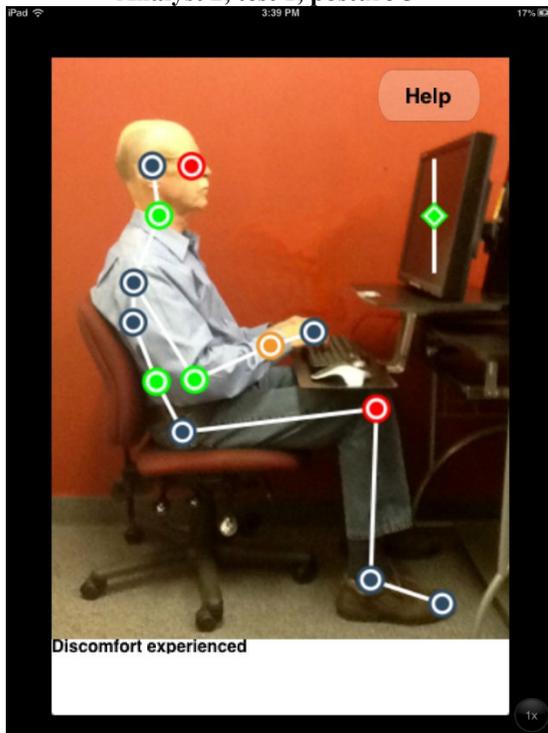


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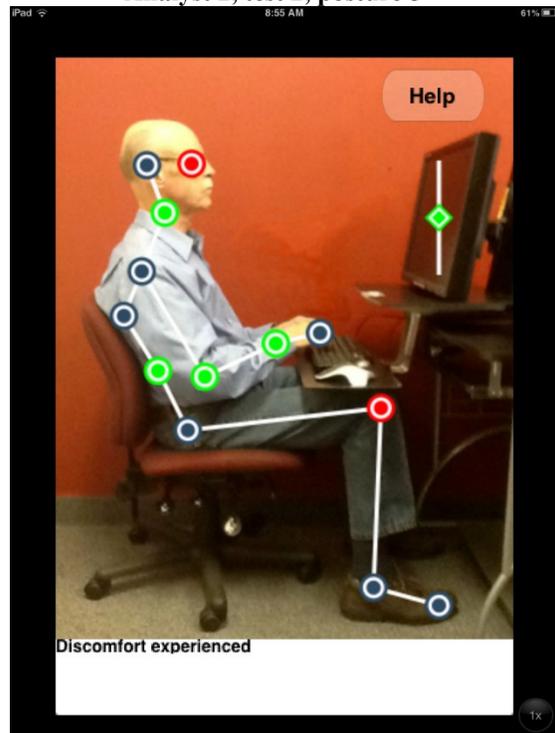
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**Analyst 2, test 1, posture 5**

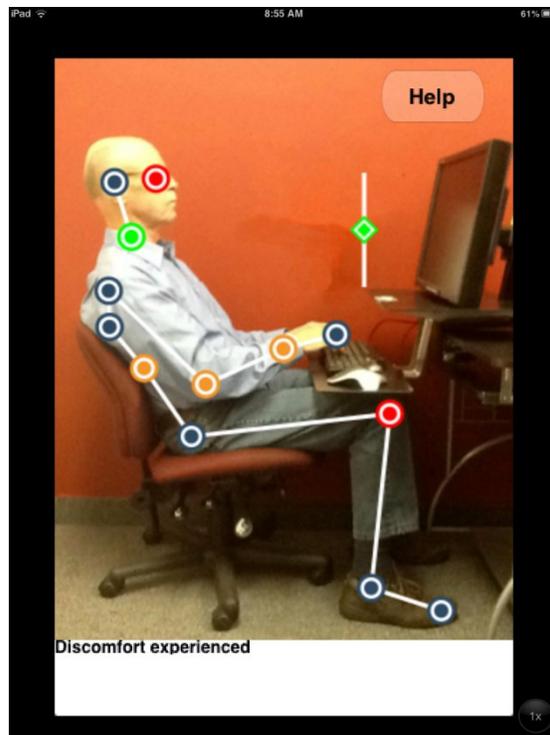
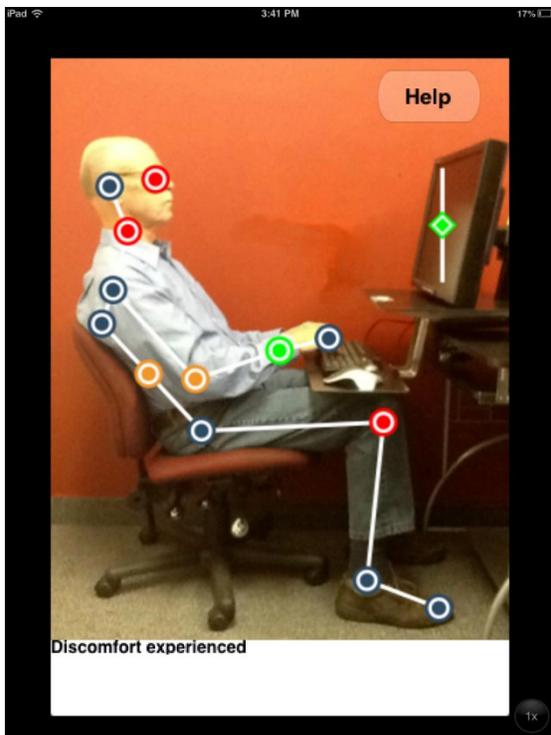


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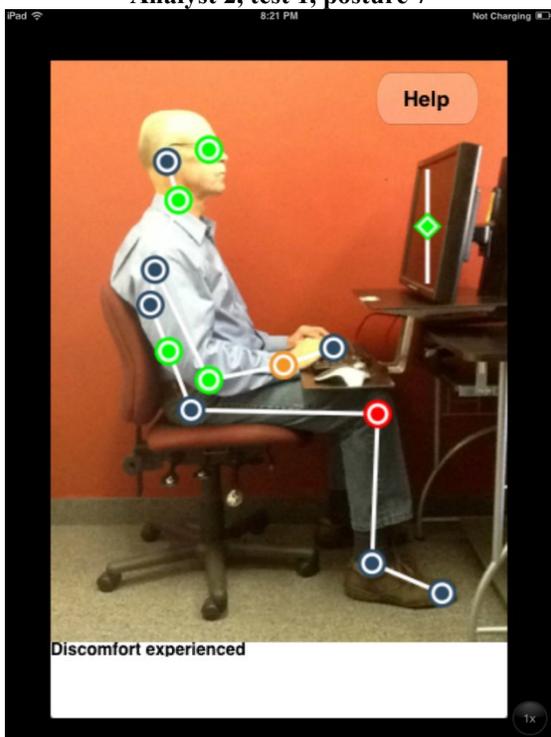


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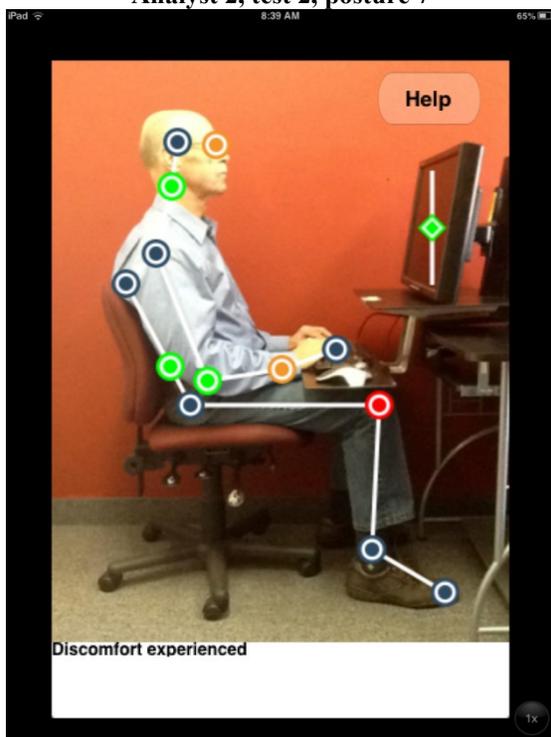
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Analyst 2, test 1, posture 7

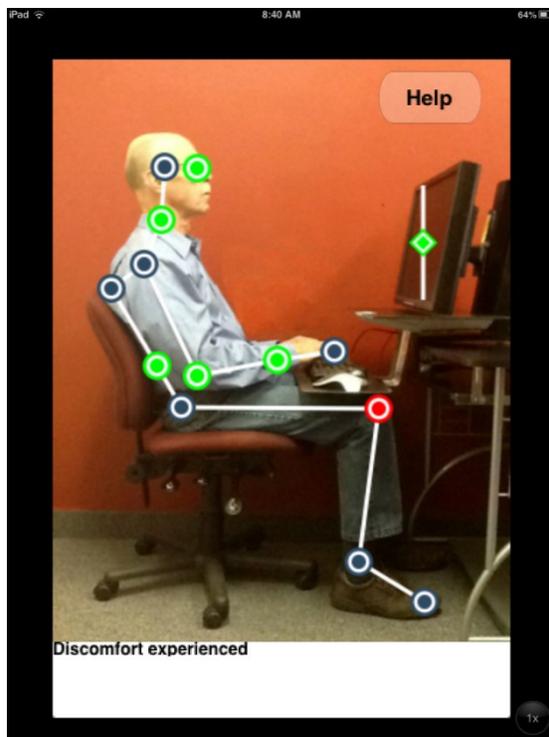
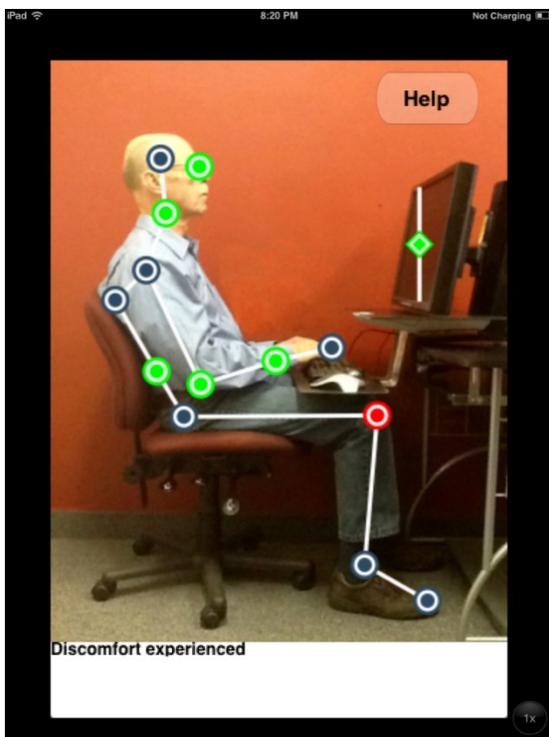


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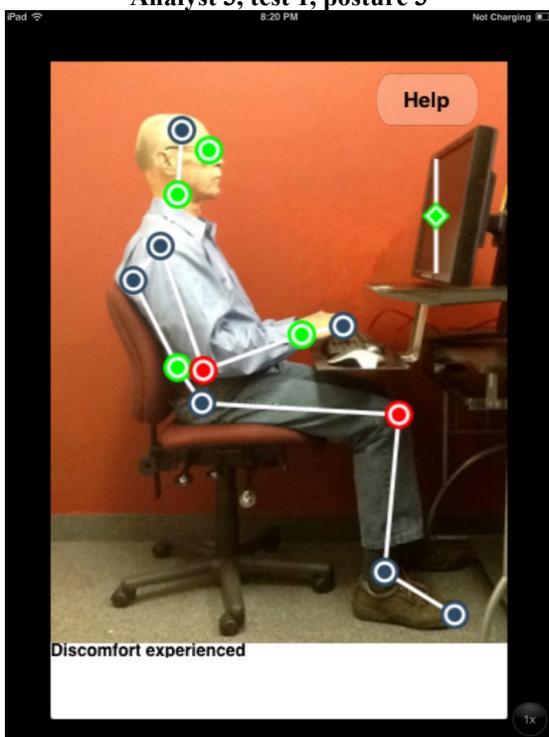


Analyst 3, test 1, posture 2

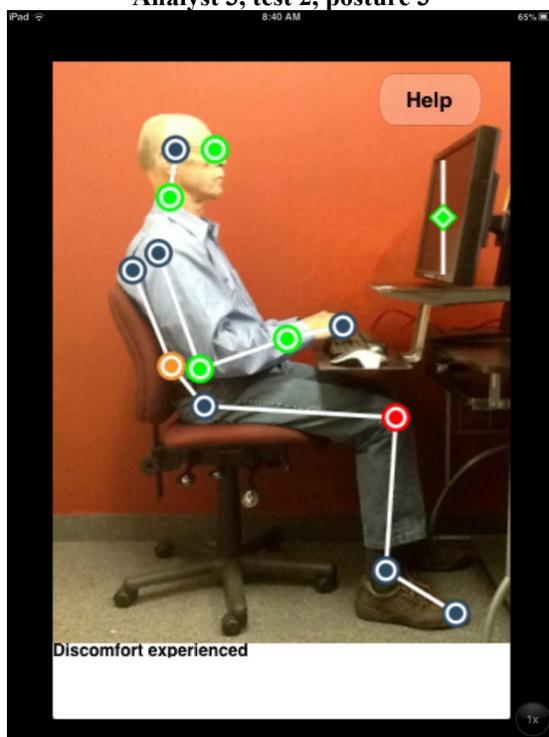
Analyst 3, test 2, posture 2



Analyst 3, test 1, posture 3

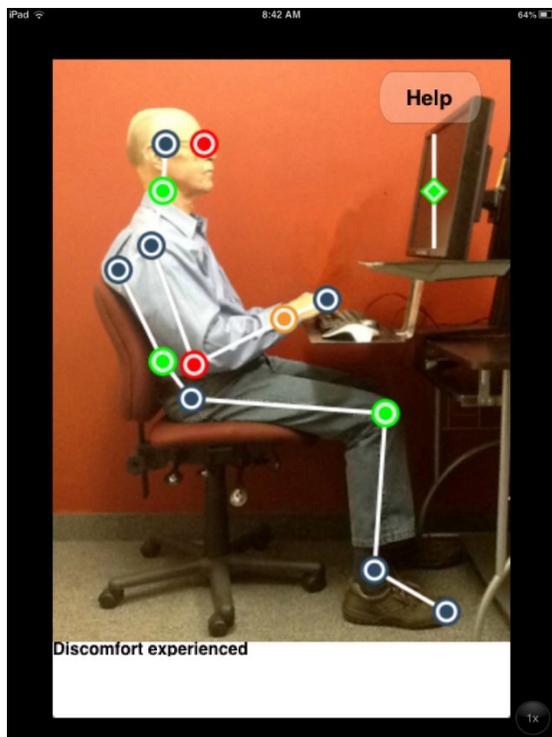
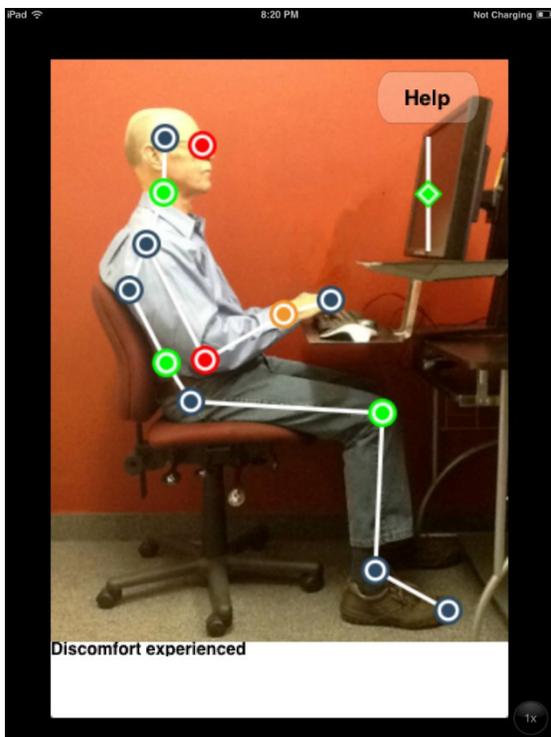


Analyst 3, test 2, posture 3

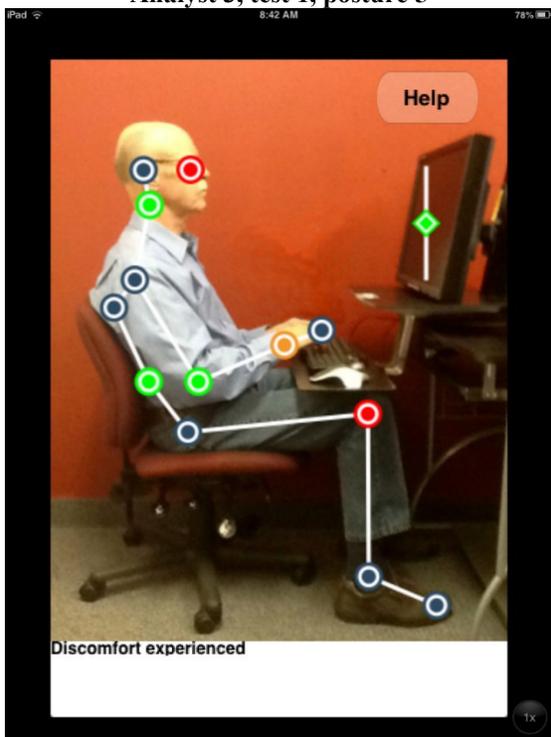


Analyst 3, test 1, posture 4

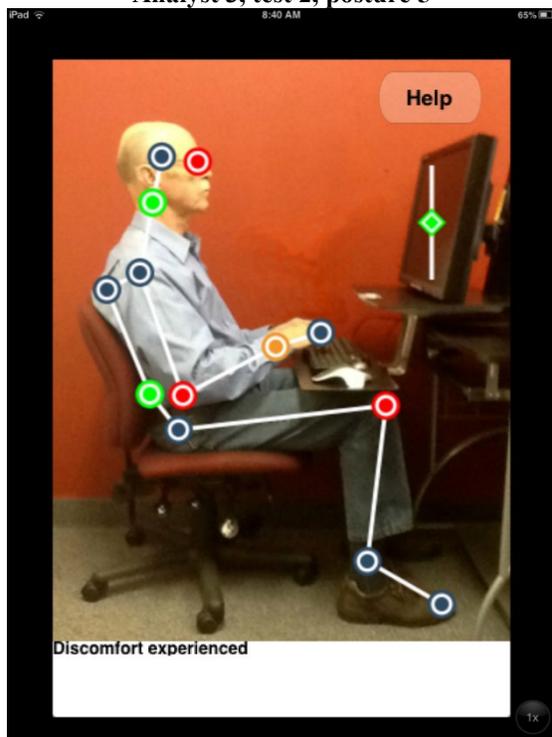
Analyst 3, test 2, posture 4



Analyst 3, test 1, posture 5

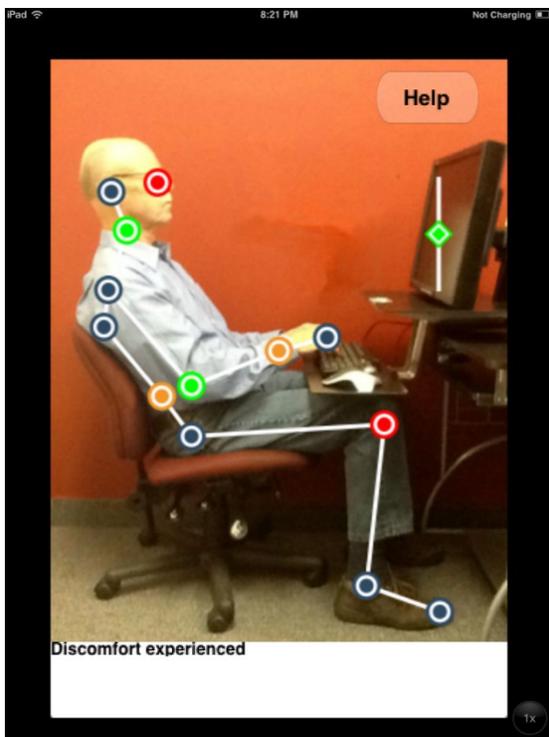


Analyst 3, test 2, posture 5

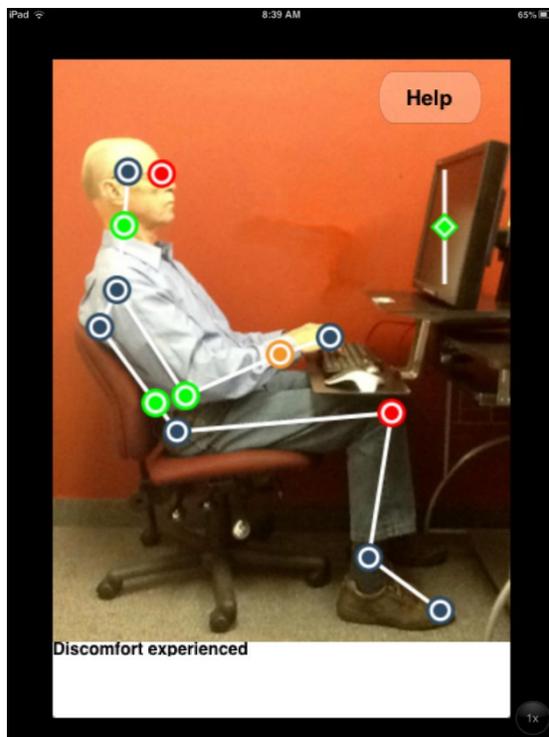


Analyst 3, test 1, posture 6

Analyst 3, test 2, posture 6



Analyst 3, test 1, posture 7



Analyst 3, test 2, posture 7

## Appendix B: MINITAB OUTPUTS FOR ANOVA & GAGE R&R

### Gage R&R Study - ANOVA Method

Gage R&R for Observed Angle

Gage name: Elbow Angles  
 Date of study:  
 Reported by:  
 Tolerance:  
 Misc:

### Two-Way ANOVA Table With Interaction

Source	DF	SS	MS	F	P
Posture	5	1595.72	319.144	4.89152	0.016
Analyst	2	1100.72	550.361	8.43537	0.007
Posture * Analyst	10	652.44	65.244	0.87904	0.568
Repeatability	18	1336.00	74.222		
Total	35	4684.89			

Alpha to remove interaction term = 0.25

### Two-Way ANOVA Table Without Interaction

Source	DF	SS	MS	F	P
Posture	5	1595.72	319.144	4.49399	0.004
Analyst	2	1100.72	550.361	7.74983	0.002
Repeatability	28	1988.44	71.016		
Total	35	4684.89			

### Gage R&R

Source	VarComp	%Contribution (of VarComp)
Total Gage R&R	110.961	72.85
Repeatability	71.016	46.62
Reproducibility	39.945	26.23
Analyst	39.945	26.23
Part-To-Part	41.355	27.15
Total Variation	152.316	100.00

Source	StdDev (SD)	Study Var (6 * SD)	%Study Var (%SV)
Total Gage R&R	10.5338	63.2029	85.35
Repeatability	8.4271	50.5625	68.28
Reproducibility	6.3202	37.9214	51.21
Analyst	6.3202	37.9214	51.21
Part-To-Part	6.4308	38.5846	52.11
Total Variation	12.3416	74.0498	100.00

Number of Distinct Categories = 1

## Gage R&R Study - ANOVA Method

Gage R&R for Observed Angle

Gage name: Knee Angle  
 Date of study:  
 Reported by:  
 Tolerance:  
 Misc:

### Two-Way ANOVA Table With Interaction

Source	DF	SS	MS	F	P
Posture	5	255.889	51.1778	6.82497	0.005
Analyst	2	132.181	66.0903	8.81367	0.006
Posture * Analyst	10	74.986	7.4986	1.25267	0.325
Repeatability	18	107.750	5.9861		
Total	35	570.806			

Alpha to remove interaction term = 0.25

### Two-Way ANOVA Table Without Interaction

Source	DF	SS	MS	F	P
Posture	5	255.889	51.1778	7.8418	0.000
Analyst	2	132.181	66.0903	10.1268	0.000
Repeatability	28	182.736	6.5263		
Total	35	570.806			

## Gage R&R

Source	VarComp	%Contribution (of VarComp)
Total Gage R&R	11.4900	60.69
Repeatability	6.5263	34.47
Reproducibility	4.9637	26.22
Analyst	4.9637	26.22
Part-To-Part	7.4419	39.31
Total Variation	18.9319	100.00

Source	StdDev (SD)	Study Var (6 * SD)	%Study Var (%SV)
Total Gage R&R	3.38968	20.3381	77.90
Repeatability	2.55466	15.3280	58.71
Reproducibility	2.22793	13.3676	51.20
Analyst	2.22793	13.3676	51.20
Part-To-Part	2.72799	16.3679	62.70
Total Variation	4.35108	26.1065	100.00

Number of Distinct Categories = 1

## Gage R&R for Observed Angle

## Gage R&R Study - ANOVA Method

Gage R&R for Observed Angle

Gage name: Knee Angle  
 Date of study:  
 Reported by:  
 Tolerance:  
 Misc:

### Two-Way ANOVA Table With Interaction

Source	DF	SS	MS	F	P
Trial	1	14.694	14.6944	15.9098	0.057
Analyst	2	132.181	66.0903	71.5564	0.014
Trial * Analyst	2	1.847	0.9236	0.0656	0.937
Repeatability	30	422.083	14.0694		
Total	35	70.806			

Alpha to remove interaction term = 0.25

### Two-Way ANOVA Table Without Interaction

Source	DF	SS	MS	F	P
Trial	1	14.694	14.6944	1.10920	0.300
Analyst	2	132.181	66.0903	4.98876	0.013
Repeatability	32	423.931	13.2478		
Total	35	570.806			

## Gage R&R

Source	VarComp	%Contribution (of VarComp)
Total Gage R&R	17.6514	99.55
Repeatability	13.2478	74.71
Reproducibility	4.4035	24.83
Analyst	4.4035	24.83
Part-To-Part	0.0804	0.45
Total Variation	17.7317	100.00

Source	StdDev (SD)	Study Var (6 * SD)	%Study Var (%SV)
Total Gage R&R	4.20135	25.2081	99.77
Repeatability	3.63976	21.8385	86.44
Reproducibility	2.09846	12.5908	49.83
Analyst	2.09846	12.5908	49.83
Part-To-Part	0.28349	1.7009	6.73
Total Variation	4.21091	25.2654	100.00

Number of Distinct Categories = 1

## Gage R&R Study - ANOVA Method

Gage R&R for Observed Angle

Gage name: Shoulder Angles

### Two-Way ANOVA Table With Interaction

Source	DF	SS	MS	F	P
Posture	5	1609.6	321.928	1.18542	0.382
Analyst	2	1111.9	555.965	2.04720	0.180
Posture * Analyst	10	2715.7	271.574	0.83618	0.602
Repeatability	18	5846.0	324.778		
Total	35	11283.3			

Alpha to remove interaction term = 0.25

### Two-Way ANOVA Table Without Interaction

Source	DF	SS	MS	F	P
Posture	5	1609.6	321.928	1.05282	0.407
Analyst	2	1111.9	555.965	1.81821	0.181
Repeatability	28	8561.7	305.776		
Total	35	11283.3			

## Gage R&R

Source	VarComp	%Contribution (of VarComp)
Total Gage R&R	326.625	99.18
Repeatability	305.776	92.85
Reproducibility	20.849	6.33
Analyst	20.849	6.33
Part-To-Part	2.692	0.82
Total Variation	329.317	100.00

Source	StdDev (SD)	Study Var (6 * SD)	%Study Var (%SV)
Total Gage R&R	18.0728	108.437	99.59
Repeatability	17.4865	104.919	96.36
Reproducibility	4.5661	27.396	25.16
Analyst	4.5661	27.396	25.16
Part-To-Part	1.6407	9.844	9.04
Total Variation	18.1471	108.883	100.00

Number of Distinct Categories = 1

## Gage R&R Study - ANOVA Method

Gage R&R for Observed Angle

Gage name: Torso  
 Date of study:  
 Reported by:  
 Tolerance:  
 Misc:

### Two-Way ANOVA Table With Interaction

Source	DF	SS	MS	F	P
Posture	5	2392.17	478.433	9.05838	0.002
Analyst	2	3.17	1.583	0.02998	0.971
Posture * Analyst	10	528.17	52.817	2.65744	0.034
Repeatability	18	357.75	19.875		
Total	35	3281.25			

Alpha to remove interaction term = 0.25

### Gage R&R

Source	VarComp	95% CI	%Contribution (of VarComp)	95% CI
Total Gage R&R	36.346	(24.302, 83.883)	33.88	( 6.23, 72.33)
Repeatability	19.875	(11.348, 43.465)	18.53	( 3.73, 48.69)
Reproducibility	16.471	( 0.317, 62.268)	15.35	( 0.00, 50.75)
Analyst	0.000	( 0.000, 4.977)	0.00	( 0.00, 0.60)
Analyst*Posture	16.471	( 0.000, 71.213)	15.35	( 0.00, 62.61)
Part-To-Part	70.936	(19.802, 470.206)	66.12	(27.67, 93.77)
Total Variation	107.282	(57.961, 508.345)	100.00	

Source	StdDev (SD)	95% CI	Study Var (6 * SD)	95% CI
Total Gage R&R	6.0288	(4.930, 9.159)	36.1725	(29.578, 54.953)
Repeatability	4.4581	(3.369, 6.593)	26.7488	(20.212, 39.557)
Reproducibility	4.0584	(0.563, 7.891)	24.3506	( 3.376, 47.346)
Analyst	0.0000	(0.000, 2.231)	0.0000	( 0.000, 13.385)
Analyst*Posture	4.0584	(0.000, 8.439)	24.3506	( 0.000, 50.633)
Part-To-Part	8.4224	(4.450, 21.684)	50.5341	(26.700, 130.105)
Total Variation	10.3577	(7.613, 22.547)	62.1462	(45.679, 135.279)

Source	%Study Var (%SV)	95% CI
Total Gage R&R	58.21	(24.97, 85.04)
Repeatability	43.04	(19.33, 69.78)
Reproducibility	39.18	( 0.00, 71.24)
Analyst	0.00	( 0.00, 7.76)
Analyst*Posture	39.18	( 0.00, 79.12)
Part-To-Part	81.31	(52.61, 96.83)
Total Variation	100.00	

Number of Distinct Categories = 1  
 95% CI = (0.874790, 5.48517)

## Gage R&R Study - ANOVA Method

Gage R&R for Observed Angle

Gage name: Wrist Angle  
 Date of study:  
 Reported by:  
 Tolerance:  
 Misc:

### Two-Way ANOVA Table With Interaction

Source	DF	SS	MS	F	P
Posture	5	3485.06	697.011	14.7221	0.000
Analyst	2	76.22	38.111	0.8050	0.474
Posture * Analyst	10	473.44	47.344	1.1816	0.363
Repeatability	18	721.25	40.069		
Total	35	4755.97			

Alpha to remove interaction term = 0.25

### Two-Way ANOVA Table Without Interaction

Source	DF	SS	MS	F	P
Posture	5	3485.06	697.011	16.3358	0.000
Analyst	2	76.22	38.111	0.8932	0.421
Repeatability	28	1194.69	42.668		
Total	35	4755.97			

## Gage R&R

Source	VarComp	%Contribution (of VarComp)
Total Gage R&R	42.668	28.12
Repeatability	42.668	28.12
Reproducibility	0.000	0.00
Analyst	0.000	0.00
Part-To-Part	109.057	71.88
Total Variation	151.725	100.00

Source	StdDev (SD)	Study Var (6 * SD)	%Study Var (%SV)
Total Gage R&R	6.5320	39.1923	53.03
Repeatability	6.5320	39.1923	53.03
Reproducibility	0.0000	0.0000	0.00
Analyst	0.0000	0.0000	0.00
Part-To-Part	10.4430	62.6583	84.78
Total Variation	12.3177	73.9060	100.00

Number of Distinct Categories = 2

## APPENDIX C: MINITAB OUTPUTS FOR PAIRED-DATA T-TEST

### Elbow paired t-test

#### Paired T-Test and CI: True Angle, True Angle

Paired T for True Angle - True Angle

	N	Mean	StDev	SE Mean
True Angle	36	102.167	5.955	0.992
True Angle	36	102.167	5.955	0.992
Difference	36	0.000000	0.000000	0.000000

95% CI for mean difference: (0.000000, 0.000000)

T-Test of mean difference = 0 (vs not = 0): T-Value = \* P-Value = \*

### Knee paired t-test

#### Paired T-Test and CI: True Angle, Observed Angle

Paired T for True Angle - Observed Angle

	N	Mean	StDev	SE Mean
True Angle	36	88.833	3.902	0.650
Observed Angle	36	87.639	4.038	0.673
Difference	36	1.194	4.243	0.707

95% CI for mean difference: (-0.241, 2.630)

T-Test of mean difference = 0 (vs not = 0): T-Value = 1.69 P-Value = 0.100

### Shoulder paired t-test

#### Paired T-Test and CI: True Angle, Observed Angle

Paired T for True Angle - Observed Angle

	N	Mean	StDev	SE Mean
True Angle	36	13.83	4.51	0.75
Observed Angle	36	14.36	17.95	2.99
Difference	36	-0.53	17.33	2.89

95% CI for mean difference: (-6.39, 5.34)

T-Test of mean difference = 0 (vs not = 0): T-Value = -0.18 P-Value = 0.856

**Torso paired t-test****Paired T-Test and CI: True Angle, Observed angle**

Paired T for True Angle - Observed angle

	N	Mean	StDev	SE Mean
True Angle	36	110.33	9.83	1.64
Observed angle	36	109.28	6.72	1.12
Difference	36	1.06	12.43	2.07

95% CI for mean difference: (-3.15, 5.26)

T-Test of mean difference = 0 (vs not = 0): T-Value = 0.51 P-Value = 0.613

**Wristed paired t-test****Paired T-Test and CI: True Angle, Observed Angle**

Paired T for True Angle - Observed Angle

	N	Mean	StDev	SE Mean
True Angle	36	-13.00	10.18	1.70
Observed Angle	36	-2.47	11.66	1.94
Difference	36	-10.53	7.29	1.21

95% CI for mean difference: (-12.99, -8.06)

T-Test of mean difference = 0 (vs not = 0): T-Value = -8.67 P-Value = 0.000

Posture	Analyst	Trial	Knee True Angle	Knee Observed Angle	Recommendation	Difference from true and observed	Percentage off the true value
2	1	1	89	95	Correct	6	6.741573
2	2	1	89	86	Incorrect	-3	-3.370787
2	3	1	89	85	Incorrect	-4	-4.494382
3	1	1	89	90	Correct	1	1.1235955
3	2	1	89	83	Incorrect	-6	-6.741573
3	3	1	89	85	Incorrect	-4	-4.494382
4	1	1	96	92	Correct	-4	-4.166667
4	2	1	96	90	Correct	-6	-6.25
4	3	1	96	88	Incorrect	-8	-8.333333
5	1	1	87	86	Correct	-1	-1.149425
5	2	1	87	90	Incorrect	3	3.4482759
5	3	1	87	89	Correct	2	2.2988506
6	1	1	89	89	Incorrect	0	0
6	2	1	89	81	Incorrect	-8	-8.988764
6	3	1	89	86	Incorrect	-3	-3.370787
7	1	1	83	88	Incorrect	5	6.0240964
7	2	1	83	81	Incorrect	-2	-2.409639
7	3	1	83	82	Incorrect	-1	-1.204819
2	1	2	89	96	Correct	7	7.8651685
2	2	2	89	89.5	Incorrect	0.5	0.5617978
2	3	2	89	88	Incorrect	-1	-1.123596
3	1	2	89	85	Incorrect	-4	-4.494382
3	2	2	89	85	Incorrect	-4	-4.494382
3	3	2	89	83	Incorrect	-6	-6.741573
4	1	2	96	95	Correct	-1	-1.041667
4	2	2	96	92	Correct	-4	-4.166667
4	3	2	96	90	Correct	-6	-6.25
5	1	2	87	95	Correct	8	9.1954023
5	2	2	87	88	Incorrect	1	1.1494253
5	3	2	87	90	Correct	3	3.4482759
6	1	2	89	89	Incorrect	0	0
6	2	2	89	81	Incorrect	-8	-8.988764
6	3	2	89	86.5	Incorrect	-2.5	-2.808989
7	1	2	83	84	Incorrect	1	1.2048193
7	2	2	83	86	Incorrect	3	3.6144578
7	3	2	83	86	Incorrect	3	3.6144578

Posture	Analyst	Trial	Wrist True Angle	Wrist Observed Angle	Recommendation	Difference from true and	Percentage off the true
2	1	1	8	25	Incorrect	17	212.5
2	2	1	8	23	Incorrect	15	187.5
2	3	1	8	10	Incorrect	2	25
3	1	1	-17	-20	Correct	-3	17.64705882
3	2	1	-17	-5	Correct	12	-70.58823529
3	3	1	-17	-4	Correct	13	-76.47058824
4	1	1	-10	-2	Incorrect	8	-80
4	2	1	-10	-10.5	Correct	-0.5	5
4	3	1	-10	-9	Correct	1	-10
5	1	1	-21	-4	Incorrect	17	-80.95238095
5	2	1	-21	-7	Incorrect	14	-66.66666667
5	3	1	-21	-13	Incorrect	8	-38.0952381
6	1	1	-20	6	Incorrect	26	-130
6	2	1	-20	-7	Incorrect	13	-65
6	3	1	-20	-3	Incorrect	17	-85
7	1	1	-18	1.5	Incorrect	19.5	-108.3333333
7	2	1	-18	-6	Correct	12	-66.66666667
7	3	1	-18	-10	Incorrect	8	-44.44444444
2	1	2	8	29	Incorrect	21	262.5
2	2	2	8	26	Incorrect	18	225
2	3	2	8	4	Incorrect	-4	-50
3	1	2	-17	0	Correct	17	-100
3	2	2	-17	-6	Correct	11	-64.70588235
3	3	2	-17	-6	Correct	11	-64.70588235
4	1	2	-10	-13	Correct	-3	30
4	2	2	-10	-8	Incorrect	2	-20
4	3	2	-10	-5	Correct	5	-50
5	1	2	-21	-9	Incorrect	12	-57.14285714
5	2	2	-21	-6.5	Incorrect	14.5	-69.04761905
5	3	2	-21	0	Incorrect	21	-100
6	1	2	-20	-12	Correct	8	-40
6	2	2	-20	-10	Correct	10	-50
6	3	2	-20	-12	Incorrect	8	-40
7	1	2	-18	-12.5	Correct	5.5	-30.55555556
7	2	2	-18	-8	Incorrect	10	-55.55555556
7	3	2	-18	-5	Incorrect	13	-72.22222222

Posture	Analyst	Trial	Elbow True Angle	Elbow Observed Angle	Recommendation	Difference	Percentage off the true
2	1	1	104	103	Correct	-1	-0.961538462
2	2	1	104	120	Incorrect	16	15.38461538
2	3	1	104	98	Correct	-6	-5.769230769
3	1	1	103	94	Correct	-9	-8.737864078
3	2	1	103	109	Correct	6	5.825242718
3	3	1	103	100	Correct	-3	-2.912621359
4	1	1	101	91	Correct	-10	-9.900990099
4	2	1	101	117	Correct	16	15.84158416
4	3	1	101	90	Incorrect	-11	-10.89108911
5	1	1	94	91	Incorrect	-3	-3.191489362
5	2	1	94	103	Correct	9	9.574468085
5	3	1	94	90	Incorrect	-4	-4.255319149
6	1	1	98	89	Incorrect	-9	-9.183673469
6	2	1	98	81	Correct	-17	-17.34693878
6	3	1	98	101	Correct	3	3.06122449
7	1	1	113	115	Incorrect	2	1.769911504
7	2	1	113	117	Incorrect	4	3.539823009
7	3	1	113	115	Correct	2	1.769911504
2	1	2	104	70.5	Incorrect	-33.5	-32.21153846
2	2	2	104	114	Incorrect	10	9.615384615
2	3	2	104	98	Correct	-6	-5.769230769
3	1	2	103	105	Correct	2	1.941747573
3	2	2	103	103	Correct	0	0
3	3	2	103	105	Correct	2	1.941747573
4	1	2	101	94	Correct	-7	-6.930693069
4	2	2	101	102	Correct	1	0.99009901
4	3	2	101	91.5	Correct	-9.5	-9.405940594
5	1	2	94	91	Correct	-3	-3.191489362
5	2	2	94	100	Correct	6	6.382978723
5	3	2	94	85	Incorrect	-9	-9.574468085
6	1	2	98	85.5	Incorrect	-12.5	-12.75510204
6	2	2	98	99	Correct	1	1.020408163
6	3	2	98	83	Incorrect	-15	-15.30612245
7	1	2	113	99	Correct	-14	-12.38938053
7	2	2	113	116	Incorrect	3	2.654867257
7	3	2	113	100.5	Correct	-12.5	-11.0619469

Posture	Analyst	Trial	Torso True Angle	Torso Observed Angle	Recommendation	Difference from true and observed	Percentage off the true
2	1	1	90	111	Correct	21	23.333333
2	2	1	90	119	Correct	29	32.222222
2	3	1	90	123	Correct	33	36.666667
3	1	1	115	104	Correct	-11	-9.565217
3	2	1	115	116	Incorrect	1	0.8695652
3	3	1	115	109	Correct	-6	-5.217391
4	1	1	113	106	Correct	-7	-6.19469
4	2	1	113	117	Incorrect	4	3.539823
4	3	1	113	108	Correct	-5	-4.424779
5	1	1	113	110	Correct	-3	-2.654867
5	2	1	113	115	Incorrect	2	1.7699115
5	3	1	113	114	Correct	1	0.8849558
6	1	1	110	100	Correct	-10	-9.090909
6	2	1	110	115	Correct	5	4.5454545
6	3	1	110	111	Correct	1	0.9090909
7	1	1	121	99	Incorrect	-22	-18.18182
7	2	1	121	109	Incorrect	-12	-9.917355
7	3	1	121	103	Incorrect	-18	-14.87603
2	1	2	90	93	Correct	3	3.3333333
2	2	2	90	110	Correct	20	22.222222
2	3	2	90	109	Correct	19	21.111111
3	1	2	115	102	Correct	-13	-11.30435
3	2	2	115	115	Correct	0	0
3	3	2	115	105	Correct	-10	-8.695652
4	1	2	113	113	Correct	0	0
4	2	2	113	119	Correct	6	5.3097345
4	3	2	113	106	Incorrect	-7	-6.19469
5	1	2	113	101	Incorrect	-12	-10.61947
5	2	2	113	116	Correct	3	2.6548673
5	3	2	113	107	Correct	-6	-5.309735
6	1	2	110	101	Correct	-9	-8.181818
6	2	2	110	105	Correct	-5	-4.545455
6	3	2	110	105	Correct	-5	-4.545455
7	1	2	121	109	Correct	-12	-9.917355
7	2	2	121	120	Incorrect	-1	-0.826446
7	3	2	121	109	Correct	-12	-9.917355

Posture	Analyst	Trial	True Angle	Shoulder Observed Angle	Difference from true and observed	Percentage off the true
2	1	1	10	9	-1	-10
2	2	1	10	11	1	10
2	3	1	10	8	-2	-20
3	1	1	10	15	5	50
3	2	1	10	11	1	10
3	3	1	10	11	1	10
4	1	1	9	9	0	0
4	2	1	9	13	4	44.44444444
4	3	1	9	5	-4	-44.44444444
5	1	1	19	16	-3	-15.78947368
5	2	1	19	15	-4	-21.05263158
5	3	1	19	12	-7	-36.84210526
6	1	1	15	8	-7	-46.66666667
6	2	1	15	13	-2	-13.33333333
6	3	1	15	13	-2	-13.33333333
7	1	1	20	15	-5	-25
7	2	1	20	10	-10	-50
7	3	1	20	10	-10	-50
2	1	2	10	15	5	50
2	2	2	10	12.5	2.5	25
2	3	2	10	10	0	0
3	1	2	10	13	3	30
3	2	2	10	13	3	30
3	3	2	10	11.5	1.5	15
4	1	2	9	12.5	3.5	38.88888889
4	2	2	9	18	9	100
4	3	2	9	3	-6	-66.66666667
5	1	2	19	15.5	-3.5	-18.42105263
5	2	2	19	19.5	0.5	2.631578947
5	3	2	19	5	-14	-73.68421053
6	1	2	15	10	-5	-33.33333333
6	2	2	15	10	-5	-33.33333333
6	3	2	15	5.5	-9.5	-63.33333333
7	1	2	20	11.5	-8.5	-42.5
7	2	2	20	117	97	485
7	3	2	20	10.5	-9.5	-47.5

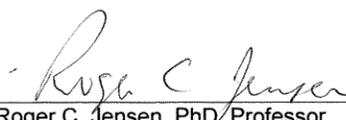
		<b>Elbow</b>					
<b>COUNTS</b>		Using app					
		Correct	Incorrect				
Measured Angles	Correct (green)	14	4			N = C4 + D4 + C5 + D5	
	Incorrect (yellow/red)	9	9				
			N=	36			
<b>PROPORTIONS</b>		Using app					
		Correct	Incorrect				
Measured Angles	Correct (green)	0.388889	0.111111	0.5		Pcc = Ncc/N = C4/E6	
	Incorrect (yellow/red)	0.25	0.25	0.5		Pcn = Ncn/N = D4/E6	
		0.638889	0.361111	1		Pnc = Nnc/N = C5/E6	
						Pnn = Nnn/N = D5/E6	
<b>EXPECTED BY CHANCE</b>		Using app				P1 = Pcc + Pcn = C11 + D11	
		Correct	Incorrect			Q1 = Pnc + Pnn = C12 + D12	
Measured Angles	Correct (green)	0.319444	0.180556	P1		P2 = Pcc + Pnc = C11 + C12	
	Incorrect (yellow/red)	0.319444	0.180556	Q1		Q2 = Pcn + Pnn = D11 + D12	
		P2	Q2	1			
Po is observed proportions in agreement = Pcc + Pnn = C11 + D12							
	Po =	0.63888889					
Pe is expected proportions in agreement = P1*P2 + Q1*Q2 = C18 + D19							
	Pe =	0.5					
Kappa = (Po - Pe)/(1 - Pe) = (B24-B26)/(1-B26)							
	Kappa =	0.27777778					

		<b>Torso</b>					
<b>COUNTS</b>		Using app					
		Correct	Incorrect				
Measured Angles	Correct (green)	15	3			N = C4 + D4 + C5 + D5	
	Incorrect (yellow/red)	12	6				
			N=	36			
<b>PROPORTIONS</b>		Using app					
		Correct	Incorrect				
Measured Angles	Correct (green)	0.416667	0.083333	0.5		Pcc = Ncc/N = C4/E6	
	Incorrect (yellow/red)	0.333333	0.166667	0.5		Pcn = Ncn/N = D4/E6	
		0.75	0.25	1		Pnc = Nnc/N = C5/E6	
						Pnn = Nnn/N = D5/E6	
<b>EXPECTED BY CHANCE</b>		Using app				P1 = Pcc + Pcn = C11 + D11	
		Correct	Incorrect			Q1 = Pnc + Pnn = C12 + D12	
Measured Angles	Correct (green)	0.375	0.125	P1		P2 = Pcc + Pnc = C11 + C12	
	Incorrect (yellow/red)	0.375	0.125	Q1		Q2 = Pcn + Pnn = D11 + D12	
		P2	Q2	1			
Po is observed proportions in agreement = Pcc + Pnn = C11 + D12							
	Po =	0.583333333					
Pe is expected proportions in agreement = P1*P2 + Q1*Q2 = C18 + D19							
	Pe =	0.5					
Kappa = (Po - Pe)/(1 - Pe) = (B24-B26)/(1-B26)							
	Kappa =	0.166666667					

		<b>Knee</b>					
COUNTS		Observer 1					
		Comply	Noncomply				
Measured Angles	Correct (green)	8	10			N = C4 + D4 + C5 + D5	
	Incorrect (yellow/red)	4	14				
			N=	36			
PROPORTIONS		Using app					
		Correct	Incorrect				
Measured Angles	Correct (green)	0.222222	0.277778	0.5		Pcc = Ncc/N = C4/E6	
	Incorrect (yellow/red)	0.111111	0.388889	0.5		Pcn = Ncn/N = D4/E6	
		0.333333	0.666667	1		Pnc = Nnc/N = C5/E6	
						Pnn = Nnn/N = D5/E6	
EXPECTED BY CHANCE		Using app				P1 = Pcc + Pcn = C11 + D11	
		Correct	Incorrect			Q1 = Pnc + Pnn = C12 + D12	
Measured Angles	Correct (green)	0.166667	0.333333	P1		P2 = Pcc + Pnc = C11 + C12	
	Incorrect (yellow/red)	0.166667	0.333333	Q1		Q2 = Pcn + Pnn = D11 + D12	
		P2	Q2	1			
Po is observed proportions in agreement = Pcc + Pnn = C11 + D12							
	Po =	0.611111111					
Pe is expected proportions in agreement = P1*P2 + Q1*Q2 = C18 + D19							
	Pe =	0.5					
Kappa = (Po - Pe)/(1 - Pe) = (B24-B26)/(1-B26)							
	Kappa =	0.222222222					

**SIGNATURE PAGE**

This is to certify that the thesis prepared by William Andrew Groesbeck entitled "EXPLORING THE ERGONOMIC ASSESSMENT METHODS OF ERGO@WSH POSTURE ANALYSIS APP FOR APPLE DEVICES" has been examined and approved for acceptance by the Safety, Health, and Industrial Hygiene Department, Montana Tech of The University of Montana, on this 16th day of June, 2014.



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