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DETECTING KEY INTER-JOINT DISTANCES AND ANTHROPOMETRY EFFECTS FOR STATIC GESTURE DEVELOPMENT USING MICROSOFT KINECT

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14. ABSTRACT
In the effort to design three-dimensional gestural interfaces for surface ship platforms, this study was conducted to evaluate the critical anthropometric factors that influence developing mutually exclusive static posture recognition algorithms. Using the Microsoft Kinect, 400 inter-joint distances determining critical key joint factors were collected to identify 15 static postures. By using a discriminant analysis, 9 out of 400 possible key inter-joint distances were identified for distinguishing the 15 postures. Comparing the discriminant function model predictions to the actual observed values for the 15 postures resulted in an overall prediction accuracy of 97 percent.

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FOREWORD

The goal of this study was to determine if individual differences in anthropometric structure have an effect on perceived inter-joint distances for static gestures detected by Microsoft Corporation's Kinect controller. A static gesture is synonymous with the term "posture"; therefore, posture detection can be viewed as a subfield of gesture recognition [10]. By using a discriminant analysis, we were able to identify 9 out of 400 possible key inter-joint distances for distinguishing the 15 postures used in the experiment. Comparing the discriminant function model predictions to the actual observed values for the 15 postures resulted in an overall prediction accuracy of 97 percent. A critical observation of the nine key inter-joint distances is the strong relationship between hand/wrist and hip joint locations. This relationship is not surprising; joint locations from the hip down remained relatively stable across postures with hand/wrist locations varying considerably.

Further studies should evaluate the biomechanical and physiological effects of interacting with gross motor gestural control devices over long periods of time. There are numerous static and dynamic muscular loading curves used to inform individuals of their muscular fatigue rate due to a given loading condition. In regard to 3D gestural devices, especially the ones that require standing, there is no data providing information on the muscular fatigue rate for prolonged gross motor gestural device interaction. This data could be used to determine what type of actions should be gestural controlled and to provide thresholds for informed design of gross motor gestural devices with respect to fatigue.

This document has been reviewed by Anita Kirkland, Warfare Systems Department.

Approved by

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GLOSSARY

3D	three dimensional
ANOVA	analysis of variance
BMI	body mass index
DV	dependent variable
HPL	Human Performance Laboratory
IV	independent variable
NSWCDD	Naval Surface Warfare Center
NWA	network activity

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1.0 INTRODUCTION

The development of such gesture recognition devices as Nintendo's Wii,[1] Sony's PlayStation Move,[2] and Microsoft's Kinect[3] has given a new meaning to the concept of human-computer interaction. Each device takes a unique approach in enabling an individual to use human kinematics and their anthropometry as an event trigger for computer control. The Kinect has generated the most interest because, unlike the competition, a remote is not required. Owing to the inexpensiveness of the system, it encourages researchers and developers to evaluate the possibility of implementing three-dimensional (3D) display systems like those portrayed in such films as *Minority Report* and the *Iron Man* series.

Microsoft released the Kinect in November 2010; the first commercial virtual game controller that enabled users the ability to play video games without the need of a physical device of any kind [1]. The release of the Kinect for Windows Software Development Kit has opened the door to infinite possibilities with regard to programming the device according to users' needs. Many programs have been created within the realm of human body tracking, hand detection, gesture recognition, and face and voice recognition. Algorithms have been developed that are able to infer a person's skeletal structure in real time, allowing for the recognition and classification of a set of actions [2].

An extensive amount of research has been conducted using the Kinect with varying objectives and applications. The medical field is a good example of an industry that could benefit from using a hands-free device to review images without sterilization concerns [3]. Full, human body detection research has been conducted by many people and organizations using different types of programming strategies [4] [5]. Further studies have successfully been able to isolate and identify the human hand even among real-world, complex backgrounds [6] [7] [8]. Specifically, Ren, Meng, Yuan, and Zhang [9] demonstrated the ability of the Kinect to compute arithmetic and play a game of rock-paper-scissors based on the recognition of hand gestures.

2.0 RESEARCH PURPOSE

This study is part of a larger research effort investigating the feasibility of using a 3D gestural control display system on board naval vessels and in command and control environments. Many modern naval vessel Command Information Centers contain a video wall that spans approximately 24 feet. The video wall provides sailors increased situational awareness and the ability to collaborate and coordinate warfare operations through a shared informational display. By allowing 3D gestural control of a video wall, ships' officers would have the ability to navigate, rearrange, and manipulate the information presented without the need of additional physical equipment or delivering orders to other shipmates. If implemented appropriately, the new capability could potentially reduce processing time for informational display configuration and empower Commanding Officers and other officers with real-time data management without decreasing situational awareness.

When considering the inclusion of new technology in military applications, the hardware and software must be reliable and efficiently and effectively perform the developed capability.

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[1] Registered trademark of Nintendo Company, Ltd.
[2] PlayStation is a registered trademark of Sony Computer Entertainment; PlayStation Move ® (Sony Computer Entertainment)
[3] Registered trademark of Microsoft Corporation

Before implementing gesture control devices into military applications, we must make sure the gestures developed are mutually exclusive, task relevant, easily learned and remembered, and that the detection and identification of each gesture is possible across the spectrum of body types and interaction environments. In order to account for all these considerations in accessing the feasibility and the design of future 3D gestural systems, extensive research exploring the effects and interactions of these elements is necessary.

Previously, the use of 3D gestural controls in systems was commercially cost prohibitive, which in turn reduced the need for academic and commercial research and development into gestural interaction. However, the introduction of the Kinect, a low-cost motion capture tracking system, has removed this barrier, enabling developers and researchers alike to create new designs and provide answers to critical research questions that will improve the design of future gestural systems. The Kinect, as well as other motion capture tracking systems, track the human body within a limited range, identifying human joint locations relative to a given reference point. While other more expensive gross motor motion tracking systems could have been used to evaluate our research questions, the Kinect was selected for its low cost and ease of development, and from this point forward will be referenced exclusively.

The Kinect has the ability to detect and interpret gestures; however, one of the possible concerns with gesture interfaces is the accuracy and reliability of detection given the variability in postures and motions because of individual differences. From an algorithm development perspective, gestures must be developed and detected in a way that allows for the accurate prediction and identification of each gesture given variability in both the physical execution of a command and the anthropometrics of the individual performing the command. The fifth edition of *The American Heritage Dictionary of the English Language* defines anthropometry as "The study of human body measurement for use in anthropological classification and comparison." Anthropometry plays an important role in gestural research since many systems rely on the measurement of joint locations relative to each other to identify individual gestures. While the anthropometrics of individuals are unique, not all anthropometric measures vary equivalently; some measures are more distinct and variable than others across the population. This is a critical aspect when selecting appropriate measures for inclusion in gestural detection algorithms; measures having high variability between gestures and low variability between individuals are more desirable.

The first goal of this study is to determine if individual differences in anthropometric structure have an effect on perceived inter-joint distances for static gestures detected by the Kinect. A static gesture is synonymous with the term "posture"; therefore, posture detection can be viewed as a subfield of gesture recognition [10]. Static gestures will be referred to as postures for the remainder of this paper. The second goal of this study is to identify the key inter-joint difference that provide the highest discrimination ability across postures and are the least affected by individual differences.

An inter-joint distance is defined as the linear distance from one joint to another. Microsoft's Kinect has the ability to identify and track 19 bones and 20 joints of the human body. From head to toe, the joints tracked throughout this study are the head, spine, center of shoulders, center of hips, right and left shoulders, elbows, wrists, hands, hips, knees, ankles, and feet. The structures the Kinect identifies as "joints" are not necessarily joints by the definition of the word. For example, the head is not technically a joint; however, it is a point tracked by the Kinect and will be referred to as a joint in this document. Figure 1 is representative of those joints.

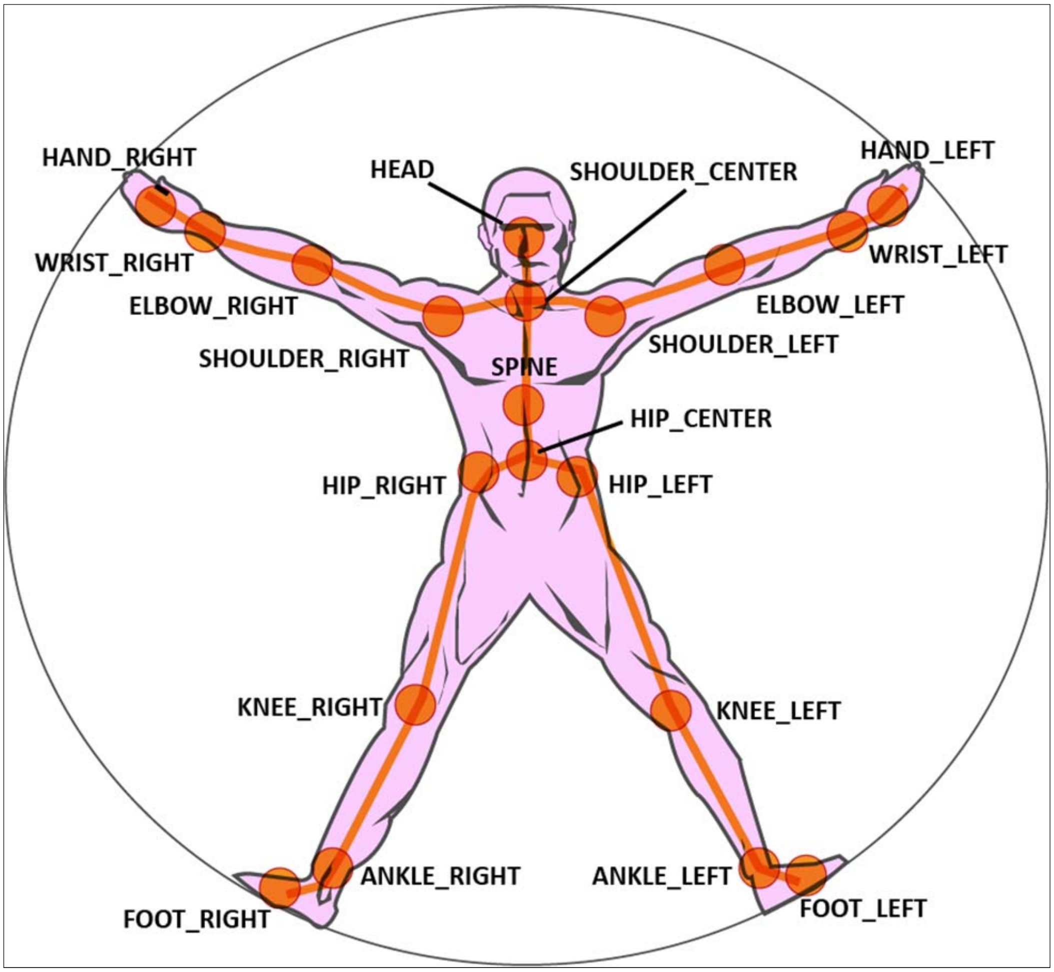

Figure 1: Joints Tracked by Microsoft Kinect

There are 400 possible inter-joint distances that can be used to develop a static posture for system manipulation. This research evaluated all the possible joint distances and determined the appropriate combinations of key, critical inter-joint distances for clear posture recognition.

3.0 RESEARCH OBJECTIVES

The objective of this research was to quantify the difference of inter-joint distances owing to anthropometric dissimilarities. First, this study will quantify the critical key distance between the 20 tracked joints for static posture recognition. Second, this study will develop an approach to clearly recognize an activated static posture. The three hypotheses that will be investigated on the key critical inter-joints distances are as follows:

a. The key inter-joint distances will vary significantly based on a person's height, limb length, and circumference of upper body structures. The distance between certain joints will increase as height, limb length, and circumference increase.
b. Inter-joint distances will vary significantly based on a person's body mass index (BMI). The distance between certain joints will increase as BMI increases.

c. Inter-joint distances will vary significantly based on a person's gender. The direction of influence is unknown at this time; however, a significant difference is expected to be seen between the anthropometrics of men and women.

4.0 METHODOLGY

In this section, the experimental methods and participants are defined. The independent and dependent variables are also described.

4.1 Participants

A total of 60 participants, 30 males and 30 females, completed the research study. A stratified sampling procedure, with gender as the stratification variable, was used to recruit participants. All of the participants were either Department of Defense civilians or military personnel.

4.2 Experimental Design

A mixed factorial experimental design was used to quantify the effects of gender; BMI; height; fist-to-elbow and elbow-to-shoulder length; and chest, waist, and bicep circumference with respect to inter-joint differences while performing 15 postures. The postures were acquired from NAVAIR 00-80T-113, *Aircraft Signals NATOPS[4] Flight Manual* [11] and the *2012 Official Playing Rules and Casebook of the National Football League* [12]. All postures have been forfeited of their original names and meanings for the purpose of this study and are referred to as postures 1–15 (refer to Appendix A for a full list and brief descriptions).

A step-wise discriminant analysis was conducted to identify critical posture detection dependent variables (DVs) and to build a predictive model for the 15 postures used in this study. The model consisted of a set of 15 discriminant functions based on linear combinations of the DVs that most accurately discriminate between the postures. The DVs selected for inclusion in the model were based upon which variable at each step minimizes the overall Wilks' lambda, the proportion of the total variance in the discriminant scores not explained by differences in the postures. The model was then validated against the existing cases to provide a level of accuracy. The model can then be used in an algorithm to predict which of the 15 postures an existing or new individual is performing with the system.

The main effects for each independent variable were calculated for the critical DVs with omitting two-way and larger interactions. All of the independent variables (IVs) will be within-subjects, and a Tukey pair-wise comparison post-hoc analysis will be conducted as needed on the significant findings. All factors will be considered significant at an alpha level of .05.

4.3 Independent Variables

Eight IVs were investigated in this study: gender; BMI; height; fist-to-elbow and elbow-to-shoulder length; chest, waist, and bicep circumference. Naturally, there are two genders: male and female. Traditionally, body mass index is classified into five groups. These groups are listed below [13].

a. Underweight/Normal weight: 14.9 kg.m-2 < BMI ≤ 24.9 kg.m-2
b. Overweight: 25 kg.m-2 ≤ BMI ≤ 29.99 kg.m-2
c. Obese Class 1: 30.0 kg.m-2 ≤ BMI ≤ 34.99 kg.m-2
d. Obese Class 2: 35 kg.m-2 ≤ BMI ≤ 39.99 kg.m-2
e. Obese Class 3: BMI > 40.00 kg.m-2

BMI is divided into three levels for this study: small, medium, and large. Table 1 provides

[4] Naval Air Training and Operating Procedures Standardization

BMI classification details.

Table 1: Body Mass Index Classification

Classification	BMI (kg/m^2)
Small	0-24.9
Medium	25-34.9
Large	> 35

The anthropometric measurements (height, two limb lengths and two circumferences) have three levels, each based upon the 5th, 50th, and 95th percentiles of the average U.S. population for 40-year old males and females [13] [14]. The waist circumference data was gathered from the National Health Statistics Report Reference Data [15]. The Mean Data for the Percentile Bands were used as the cutoff points for condition levels. The percentile groups were divided into the following categories based on the 5th, 50th, 95th percentile. Table 2 details the anthropometric measurements.

Table 2: Anthropometric Measurement Ranges

Male						
Population Level	**Length (cm)**			**Circumference (cm)**		
	Height	**Fist-Elbow**	**Elbow-Shoulder**	**Waist**	**Chest**	**Bicep (Flexed)**
5th	0 >= 169.7	0 >= 33.2	0 >= 33.7	0 >= 78.9	0 >= 89.4	0 >= 29.4
50th	169.8 >= 179.9	33.3 >= 35.8	33.8 >= 36.6	80.0 >= 101.8	89.5 >= 100	29.5 >= 33.2
95th	180 > ∞	35.9 > ∞	36.7 > ∞	101.9 > ∞	100.1 > ∞	33.3 > ∞
Female						
Population Level	**Length (cm)**			**Circumference (cm)**		
	Height	**Fist-Elbow**	**Elbow-Shoulder**	**Waist**	**Chest**	**Bicep (Flexed*)**
5th	0 >= 148.9	0 >= 37.3	0 >= 27.2	0 >= 71.6	0 >= 73.2	0 >= 24.3
50th	149 >= 157.0	37.4 >= 41.7	27.3 >= 29.8	71.7 >= 89.3	73.4 >= 82.1	24.4 >= 28
95th	157.1 > ∞	41.8 > ∞	29.9 > ∞	89.4 > ∞	82.2 > ∞	28.1 > ∞

(*) National Aeronautics and Space Administration (NASA) anthropometric data was missing for female bicep flex. One inch was added to the relaxed data sets provided for the bicep flexed data for females.

Posture type was a control variable in the study, consisting of 15 different static postures demonstrated by each participant. After data collection was completed, participants were assigned to a treatment group based on their anthropometric data.

4.4 Dependent Variables

The dependent variable (DV) is the inter-joint distance between each of the 20 tracked joints in the human body, identified by the Kinect.

The space occupied by the user and sensors are located in a 3D real coordinate space: R^3 placement of the origin is not canonical. The origin is located at the face of the Kinect sensor array. The z-axis (depth) extends in the direction the sensor array points (toward the user), the y-axis is normal to the top of the sensor and extends vertically, and the x-axis extends horizontally from the sensor array as viewed from the user in front of the sensor. Joint positions are given in Cartesian coordinates relative to the sensor array. The algorithm used in the study for calculating inter-joint distance follows.

The joint position is given by the sensor, which is represented as

$$\text{JointPosition} = (x, y, z)$$

4.4.1 Defining Vectors between Joints

Let $\text{Joint}_1\text{Position} = (x_1, y_1, z_1) \quad \text{Joint}_2\text{Position} = (x_2, y_2, z_2)$

The vector from Joint 1 to Joint 2 is therefore:

$$v_{1,2} = (x_2 - x_1, y_2 - y_1, z_2 - z_1)$$

or

$$v_{1,2} = (x_{1,2}, y_{1,2}, z_{1,2})$$

4.4.2 Vector Length

The magnitude of the above vector is therefore:

$$\left\|v_{1,2}\right\| = \sqrt[2]{(x_2 - x_1)^2 + (y_2 - y_1)^2 + (z_2 - z_{1)}{}^2}$$

or

$$\left\|v_{1,2}\right\| = \sqrt[2]{{x_{1,2}}^2 + {y_{1,2}}^2 + {z_{1,2}}^2}.$$

5.0 TASK PROTOCOL

Participants were escorted into the Human Performance Laboratory (HPL) one at a time, and seated at a table where they were provided an informed consent document and a network activity (NWA) form. The informed consent document outlined the details of the study and their rights as participants. The NWA form contained the approved charge code to which they charged one hour of their time for participating. Two researchers were present to answer any questions prior to beginning the study. Once the participants read and signed all the necessary paperwork, they were assigned an ID number that was used during data collection.

The next step was to record specific anthropometric data for each participant. A total of seven measurements were taken, including height; weight; circumference of the chest, waist, and bicep; and length from fist to elbow and elbow to shoulder. Measurements were taken by hand using a tailor’s measuring tape, and weight was recorded using a digital scale. This information was recorded to the nearest inch or pound in a spreadsheet. Body measurements were taken in a semiprivate area of the laboratory where the participants were out of sight of other individuals.

Participants were then directed to the experimental data collection area. The Microsoft Kinect was set up and connected to a desktop computer and large monitor. Each volunteer was asked to stand within the Kinect sensor’s viewing range, between 8.5 and 11.5 feet away from the device, to ensure everyone’s entire body was properly tracked. Shorter participants stood closer to the sensor while taller participants stood further away from it. Floor markings were made ahead of time to identify the proper viewing range.

Upon signing in to the computer, the researcher entered the participant ID, gender, and anthropometric information into a data entry field, creating a file for each participant. Throughout the experiment, participants could view four pieces of information displayed on the monitor: feedback from the Kinect camera allowed them to see themselves; an image that illustrated the desired posture; 19 circles across the top of the screen that were representative of the joints being tracked by the Kinect (the circles were green when the Kinect had a direct line of sight and red when the position of the joint was being inferred); and the researchers' control buttons.

When a participant was in the appropriate posture, the researcher clicked the "Save" button and then the "Record" button, which recorded the inter-joint distances for eight seconds and was saved to a text file. This process was repeated until all 15 postures had been completed. Participants were thanked for their time and reminded to take a copy of the informed consent and NWA form with them in case they had any questions after they left.

6.0 RESULTS

Table 3 lists the mean and standard deviation of the experimental population for the three BMI levels. Sixty percent of the population was in the medium BMI classification. Based on the mean and standard deviation of the medium group, this group will be considered in the overweight category. The small classification group had the second-largest amount of participants, and the large group had six participants to meet the criteria for this classification, which represents 10 percent of the total population.

Table 3: BMI Descriptive Statistics

Classification	Overall (μ(S.D.){n})	Male (μ(S.D.){n})	Female (μ(S.D.){n})
Small	22.52 (2.39) {18}	24.05 (0.83) {6}	21.76 (2.55) {12}
Medium	28.50 (2.81) {36}	29.08 (3.07) {22}	27.60 (2.06) {14}
Large	42.41 (7.88) {6}	37.15 (1.27) {2}	45.05 (8.48) {4}

Table 4 provides the mean and standard deviation of the anthropometry data of the sample population, based on the 5th, 50th, and 95th population percentiles that will be considered condition levels for the analysis of variance (ANOVA) statistics. Since gender was the only control variable for participant recruitment, six condition levels, specifically for the female population, were not able to be populated because participants did not meet the qualification criteria.

Table 4: Anthropometric Descriptive Statistics

Overall (μ(S.D.){n})						
Population Level	**Length (cm)**			**Circumference (cm)**		
	Height	**Fist-Elbow**	**Elbow-Shoulder**	**Waist**	**Chest**	**Bicep (Flexed)**
5th	160.87 (5.28) {3}	33.78 (1.49) {30}	30.48 (0.00) {1}	72.39 (3.87) {2}	87.63 (1.29) {2}	27.94 (0.00) {1}
50th	170.01 (7.97) {15}	36.06 (1.01) {10}	35.56 (0.00) {7}	88.57 (7.70) {39}	96.01 (1.91) {5}	29.27 (2.90) {19}
95th	173.93 (11.64) {42}	38.98 (1.66) {20}	37.80 (2.71) {52}	108.55 (15.66) {19}	104.52 (11.45) {53}	35.43 (3.89) {40}

Male (μ(S.D.){n})						
Population Level	**Length (cm)**			**Circumference (cm)**		
	Height	**Fist-Elbow**	**Elbow-Shoulder**	**Waist**	**Chest**	**Bicep (Flexed)**
5th	160.36 (5.28) {3}	33.02 (0.00) {2}	30.48 (0.00) {1}	76.20 (0.00) {1}	87.63 (1.29) {2}	27.94 (0.00) {1}
50th	173.78 (2.84) {12}	35.56 (0.00) {8}	35.56 (0.00) {7}	93.47 (6.05) {20}	96.01 (1.91) {5}	31.75 (1.27) {10}
95th	185.76 (5.33) {15}	38.98 (1.66) {20}	39.83 (1.78) {22}	112.04 (5.94) {9}	109.99 (6.69) {23}	37.16 (2.63) {19}

Population Level	Female (μ(S.D.){n})					
	Length (cm)			Circumference (cm)		
	Height	Fist-Elbow	Elbow-Shoulder	Waist	Chest	Bicep (Flexed)
5th	**No Data**	33.02 (1.52) {28}	**No Data**	68.58 (0.00) {1}	**No Data**	**No Data**
50th	154.94 (0.00) {3}	38.10 (0.00) {2}	**No Data**	83.41 (5.61) {19}	**No Data**	26.52 (1.26) {9}
95th	167.36 (8.60) {27}	**No Data**	36.32 (2.28) {30}	105.41 (20.36) {10}	100.33 (12.52) {30}	33.86 (4.17) {21}

6.1 Key Inter-Joint Distance Selection

Using the inter-joint difference measures collected for each of the 15 postures, a step-wise discriminant analysis was conducted to identify the linear combination of these variables that most accurately separates the postures into a corresponding set of 15 groups. A Wilks' lambda step-wise method was applied using an F entrance value of 120 and removal value of 115. The results of the discriminant analysis produced nine critical variables from the full set of DVs analyzed (see Table 5). The following acronyms will be used to indicate the nine DVs produced by the discriminant analysis for the remainder of the paper:

a. LHRH = Distance (Left Hand Position::Right Hand Position)
b. HRH = Distance(Head Position::Right Hand Position)
c. RSRH = Distance(Right Shoulder Position::Right Hand Position)
d. LSRH = Distance(Left Shoulder Position::Right Hand Position)
e. RERHi = Distance(Right Elbow Position::Right Hip Position)
f. RWRHi = Distance(Right Wrist Position::Right Hip Position)
g. RWLH = Distance(Right Wrist Position::Left Hip Position)
h. LWHC = Distance(Left Wrist Position:: Hip Center Position)
i. LWLHi = Distance(Left Wrist Position::Left Hip Position)

Table 5: Discriminant Analysis for Key Inter-Joint Distances

		Wilks Lambda				Exact F			
Step	Entered	Statistic	df1	df2	df3	Statistic	df1	df2	Sig.
1	LWLHi	0.067	1	14	885	884.29	14	885.00	0.000
2	LHRH	0.005	2	14	885	852.52	28	1768.00	0.000
3	LWHC	0.001	3	14	885	710.96	42	2620.17	0.00
4	RWRHi	7.90E+05	4	14	885	633.49	56	3432.97	0.00
5	RSRH	1.40E+05	5	14	885	564.84	70	4198.49	0.00
6	RWLHi	3.00E+06	6	14	885	503.94	84	4911.23	0.00
7	LSRH	8.00E+07	7	14	885	462.69	98	5568.21	0.00
8	HRH	3.00E+07	8	14	885	425.43	112	6168.68	0.00
9	RERHi	1.00E+07	9	14	885	398.00	126	6713.71	0.00

The results of the discriminant analysis include 15 Fisher's Linear Discriminant functions consisting of a separate set of constants and variable coefficients for each posture. Cases are assigned by assessing each of the 15 functions with the function that produces the highest discriminant score, indicating which posture the case represents (see Appendix B). Table 6 is a subset of the discriminant function coefficients for the first five postures. Table 7 provides an example set of observed data for the nine key variables.

Table 6: Discriminant Function Coefficients

	Posture 1	Posture 2	Posture 3	Posture 4	Posture 5
LHRH	-42.1	2.5	-66.0	49.3	-90.5
HRH	213.1	323.7	274.5	175.9	258.9
RSRH	183.1	66.5	-35.9	3.5	23.4
LSRH	-220.4	-365.1	10.7	-98.3	-97.5
RERHi	58.1	71.0	103.1	92.8	77.2
RWRHi	-345.1	-63.9	400.4	-45.4	76.4
RWLHi	449.2	264.3	-368.0	171.6	59.6
LWHC	534.3	-290.3	76.3	47.2	65.0
LWLHi	-508.8	297.7	-51.2	-25.2	45.3
(Constant)	-142.5	-115.2	-123.0	-151.1	-153.7

Table 7: Key Inter-Joint Distance Observed Data

Posture	LHRH	HRH	RSRH	LSRH	RERHi	RWRHi	RWLHi	LWHC	LWLHi
1	0.47	0.89	0.56	0.68	0.20	0.21	0.33	0.28	0.18
2	0.28	0.40	0.33	0.23	0.38	0.53	0.51	0.37	0.43
3	0.09	0.78	0.51	0.48	0.20	0.26	0.23	0.24	0.22
4	1.35	0.71	0.51	0.82	0.50	0.67	0.79	0.68	0.66
5	0.31	0.69	0.60	0.60	0.47	0.62	0.64	0.68	0.69

A set of discriminant scores is obtained by solving each of the 15 discriminant functions using the above supplied coefficients, constant, and observed values. Taking the maximum value from the 15 discriminant scores produces the predicted posture for each case as listed in Table 8.

Table 8: Predicted Posture Max Values

Predicted Posture	Max Value	P1	P2	P3	P4	P5
1	125.67	125.67	22.49	69.95	36.91	57.36
2	101.60	-4.95	101.60	27.33	18.53	54.04
3	117.29	52.49	49.24	117.29	-2.30	79.81
4	127.69	44.54	49.30	23.47	127.69	51.07
5	149.73	79.78	98.42	112.16	68.16	149.73

An assessment of the models' accuracy was conducted by calculating the discriminant scores for each posture performed by the 60 participants, producing a predicted posture. Comparing the discriminant function model predictions against those of the actual values resulted in an overall accuracy of 97 percent as listed in Table 9.

Table 9: Model Prediction Accuracy

Posture	Model Prediction Accuracy
1	100.00%
2	98.21%
3	100.00%
4	93.65%
5	96.67%
6	93.55%
7	95.16%
8	93.75%
9	100.00%
10	94.92%
11	98.28%
12	100.00%
13	96.67%
14	98.33%
15	96.77%
Total	**97.00%**

6.2 Anthropometry Analysis of Key Posture Parameters

Following the discriminant analysis, an ANOVA was conducted for the key posture parameters using the following IVs:

a. Height
b. Gender
c. FTE = Fist-to-Elbow
d. ChestCir = Chest Circumference
e. BicepCir = Bicep Circumference
f. WaistCir = Waist Circumference
g. ETS = Elbow-to-Shoulder

The ANOVA results are presented in tables 10 and 11. Asterisks denote the significance ($p < .05$) in the inter-joint distance because of the given factor. Full ANOVA results are in Appendix C, and the Tukey results from the ANOVA analysis are in Appendix D. All of the Tukey results that were not significant were omitted, including significant factors in which the Tukey results didn't show a significant simple main effect difference. The following paragraphs break down the ANOVA results.

Gender had a significant impact on RSRH (12), LSRH (1, 9), and RWLH (5, 9) inter-joint distances. Even though LSRH (1, 9) and RWLH (9) were found to be significant for the gender effect, post-hoc analysis did not find a significant simple main effect differences owing to gender. The male's inter-joints distance for RWLH and RSRH were significantly larger that the female inter-joint distance for the equivalent key parameters.

Height had a significant impact on LHRH (9), RSRH (1, 5, 9, 12), LSRH (5, 9, 12), RWRHI (2, 12), RWLH (4, 9, 12), and LWHC (4, 15) inter-joint distances. The 95th percentile group for the key inter-joint distances was significantly larger than the 50th percentile group.

The 5th percentile group was not significantly different from either group.

BMI had a significant impact on LHRH (2), HRH (9), RSRH (5), and LSRH (9) inter-joint distances. The large BMI group for LSRH are significantly larger that the small and medium BMI groups. The results also reveal that the small and medium BMI groups' inter-joint distance for LHRH and RSRH are significantly larger than the large BMI group. The HRH results indicated three separate groups where the large BMI group key distance difference was significantly larger than the other two groups, and the medium BMI group key distance difference was significantly larger than the small BMI group.

FTE had a significant impact on LHRH (12), RSRH (14), and LSRH (12, 13) inter-joint distances. The 95th percentile group key distance differences were significantly larger than the 5th percentile group. The results also showed that the 95th percentile group key distance difference for the RSRH was significantly larger than the 50th percentile group. The ANOVA results indicated that ETS did not impact the key inter-joint distance for any of the static postures.

ChestCir had a significant impact on LHRH (5, 12), HRH (13), RSRH (9, 10, 12), LSRH (13), RERHi (11), RWRHi (11), and LWHC (3) inter-joint distances. The 50th and 95th percentile group key distances were significantly larger than the 5th percentile group.

BicepCir had a significant impact on HRH (8), and LSRH (8) inter-joint distances. The 5th percentile group key distance difference was significantly larger than the other two groups.

WaistCir had a significant impact on LHRH (1, 5), HRH (4, 9, 10, 13), RSRH (9, 10), LSRH (2, 13), RERHi (11), RWRHi (2, 9, 12, 13), RWLH (2, 9, 11, 13, 14), LWHC (13), and LWLHi (13) inter-joint distances. The 5th percentile group key distances were significantly larger than the other two groups. The 5th percentile group only had two individuals who represented the group, which is skewing the results. By excluding that group, the WaistCir factor would not be a significant factor.

Table 10: ANOVA Results (Part 1)

		Posture #														
Factor		**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**
Gender	LHRH															
	HRH															
	RSRH												*			
	LSRH	*								*						
	RERHi															
	RWRHi															
	RWLH					*				*						
	LWHC															
	LWLHi															
Height	LHRH									*						*
	HRH															
	RSRH	*				*				*			*			
	LSRH					*				*			*			
	RERHi												*			
	RWRHi		*										*			
	RWLH				*					*			*			
	LWHC				*											*
	LWLHi															
BMI	LHRH		*													

		Posture #														
Factor		**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**
	HRH									*						
	RSRH					*										
	LSRH									*						
	RERHi															
	RWRHi															
	RWLH															
	LWHC															
	LWLHi															
FTE	LHRH												*			
	HRH															
	RSRH														*	
	LSRH												*	*		
	RERHi															
	RWRHi															
	RWLH															
	LWHC															
	LWLHi															

Table 11: ANOVA Results (Part 2)

		Posture #														
Factor		**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**
ETS	LHRH															
	HRH															
	RSRH															
	LSRH															
	RERHi															
	RWRHi															
	RWLH															
	LWHC															
	LWLHi															
ChestCir	LHRH					*							*			
	HRH													*		
	RSRH									*	*		*			
	LSRH													*		
	RERHi											*				
	RWRHi											*				
	RWLH															
	LWHC			*												
	LWLHi															
BicepCir	LHRH															
	HRH								*							
	RSRH															
	LSRH								*							
	RERHi															
	RWRHi															
	RWLH															
	LWHC															
	LWLHi															
WaistCir	LHRH	*				*								*	*	
	HRH				*						*	*		*		
	RSRH									*	*					
	LSRH		*											*		
	RERHi											*				

Factor		Posture # 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
	RWRHi		*							*		*		*		
	RWLH		*							*		*		*	*	
	LWHC													*		
	LWLHi													*		

7.0 DISCUSSION AND CONCLUSION

The first overall objective of the research was to develop an approach to identify the key inter-joint distances for a given set of static postures. By using a discriminant analysis, we were able to identify 9 out of 400 possible key inter-joint distances for distinguishing the 15 postures used in the experiment. Comparing the discriminant function model predictions to the actual observed values for the 15 postures resulted in an overall prediction accuracy of 97 percent. This function has since been applied and tested in the HPL and has been demonstrated as an accurate and effective means of posture estimation. Anecdotal evidence seems to indicate that inaccuracies in postural identification may occur in cases where postures are closely related across the key postural parameters (e.g., P15/P4 and P7/P12). Further study is required to determine possible solutions for such conflicts.

A critical observation of the nine key inter-joint distances is the strong relationship between hand/wrist and hip joint locations. This relationship is not surprising; joint locations from the hip down remained relatively stable across postures with hand/wrist locations varying considerably. This is particularly true for the 15 postures used in this study, as participants were not required to bend or move their lower extremities when performing the postures. This may point to an important design element in the creation of future gestures, where lower joints, possibly the hips, act as key reference locations, with changes in the relative hand positions from these joints differentiating individual gestures. Overall, this approach for developing algorithms to identify selected postures seems to be very effective.

The second overall objective of the research was to determine if anthropometry and gender have an effect on the key inter-joint distance. The chart in Figure 2 indicates the number of occurrences across all postures were an anthropometric factor group based on Tukey pairwise comparisons of the key inter-joint distances were significantly different.

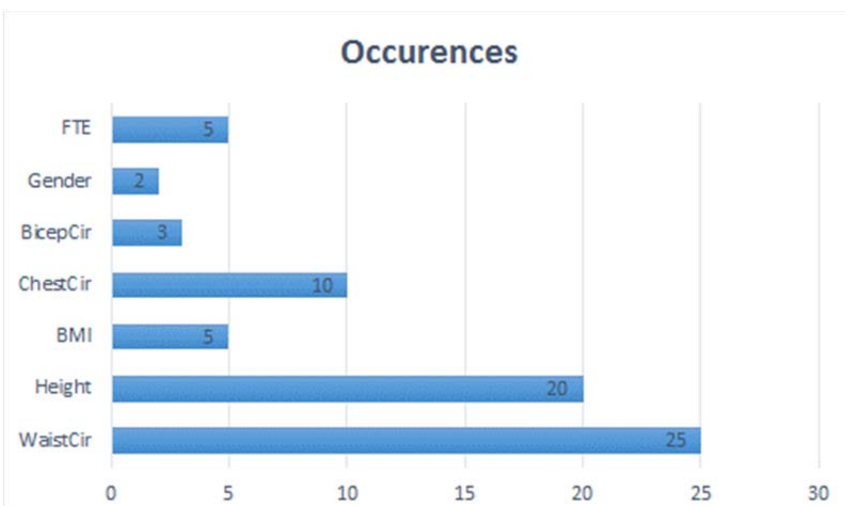

Figure 2: Number of Anthropometry Factor Impacts

Even though waist circumference showed to have a significant impact in joint distances, the group size of the 5th percentile group was only two participants. When omitting the 5th percentile group, the number of occurrences of waist circumference across the postures resulted in five counts.

Height seems to have an effect on all the postures that require the hands to be away from the center of the body (e.g., P1/4/5/9/12/15). The results were unusual in the sense that, in most cases, the 95th percentile and 5th percentile groups' key inter-joint distance means were larger than the 50th percentile group's. We expected the 50th percentile group mean distances would be larger than the 5th percentile group's for height because of larger limb lengths, but this was not the case. For all cases where BMI was significant, the small and medium groups' key distances were greater than a large group's. This is probably due to how the Kinect tracks joint positions using the disparity maps. We discovered that large individual joint locations are inaccurately placed by the Kinect sensor due to the individual mass. For instance, large individuals' shoulder positions were approximately two inches inward toward the chest than smaller individuals'. This technical flaw will result in shorter distances between some key joints.

Gender was only found to be significant for postures 9 and 12. In both cases, the male inter-joint distances were larger than the female inter-joint distances. Practically, gender does not seem to have a significant effect on posture detection. This finding is very important since both males and females use gestural control devices. Given these results, there does not appear to be a need to independently model for both genders.

The other anthropometric factors don't seem to have a significant impact on gesture detection in the current design of this study. Since the subjects were randomly selected, the number of participants in each group is insufficient in providing a definitive answer of the effect anthropometry with regard to gestural detection. Since detecting a gesture is based on a collection of key inter-joint distances, anthropometric effects seem to be minimized; anthropometry doesn't usually affect all key inter-joint distances concurrently for a given posture. There seems to be enough distinction between postures compared to anthropometric variability, especially given the high F values observed for the key posture parameters that provide a relative measure of the between posture variability over the subjects' variability.

While the above approach provides a valid method for detecting static postures, there is still a need for further studies developing an algorithmic approach for detecting dynamic gestures. Dynamic gestures are defined as gestures with kinematic properties occurring over a period of time. An example with two-dimensional devices would be swiping left to right or pinching or pulling to zoom in or out on a smartphone's map application. There is interest in defense applications to provide ways of communicating with robots or unmanned vehicles in a more humanistic manner using gestures. Dynamic gestures have the same problems as static gestures in regards to mutually exclusive gesture recognition.

Further studies should evaluate the biomechanical and physiological effects of interacting with gross motor gestural control devices over long periods of time. There are numerous static and dynamic muscular loading curves used to inform individuals of their muscular fatigue rate due to a given loading condition. In regard to 3D gestural devices, especially the ones that require standing, there is no data providing information on the muscular fatigue rate for prolonged gross motor gestural device interaction. This data could be used to determine what type of actions should be gestural controlled and to provide thresholds for informed design of gross motor gestural devices with respect to fatigue.

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APPENDIX A: STATIC POSTURES

Pictured below are the 15 postures used to collect the inter-joint distance data during the data acquisition period.

Posture	Demonstration	Description
1		Standing up straight, feet shoulder width apart, hands down by sides
2		Arms crossed in front of the body at chest level
3		Arms crossed and extended downward in front of the body

4		Arms extended to the side from shoulders, parallel to ground
5		Arms extended straight forward from the shoulders, parallel to ground
6		Arms extended forward from shoulders, elbows slightly bent
7		Arms extended above the head in a vertical position

8		Arms held out to the sides, elbows bent, fists at eye-level
9		Right arm extended above the head, forward of shoulder. Left arm extended straight out to the side, parallel to the ground.
10		Right arm bent at a 90° angle at the elbow, fist pointing to the left, forearm parallel to the ground.
11		Right arm held parallel to the ground, elbow bent at a 90° angle, forearm across chest-level, fist pointing to the left.

12		Hands over head with fingertips touching
13		Fists on hips, elbows out to the side
14		Arms held straight and downward at a 45° angle from hips
15		Right arm extended above the head, forward of shoulder, elbow slightly bent

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APPENDIX B: CLASSIFICATION FUNCTION COEFFICIENTS

Table B-1 lists classification function coefficients for each of the nine critical inter-joint distances.

Table B-1: Classification Function Coefficient

	Posture														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
LHRH	-42.1	2.5	-66.0	49.3	-90.5	-39.0	-82.4	-11.5	2.8	-25.5	-2.4	-82.6	-11.1	20.9	25.6
HRH	213.1	323.7	274.5	175.9	258.9	208.9	70.3	105.3	171.4	212.7	210.1	19.4	208.4	217.6	157.5
RSRH	183.1	66.5	-35.9	3.5	23.4	-83.1	109.0	-28.4	-19.9	191.2	215.3	110.3	113.4	108.8	176.3
LSRH	-220.4	-365.1	10.7	-98.3	-97.5	-82.9	-16.3	-18.2	-38.4	-203.1	-261.2	-2.3	-250.0	-217.9	-216.6
RERHi	58.1	71.0	103.1	92.8	77.2	-1.3	86.0	42.7	64.9	60.1	64.8	133.5	257.1	58.0	51.8
RWRHi	-345.1	-63.9	400.4	-45.4	76.4	30.8	-125.8	-44.0	-56.3	-378.1	-446.4	-197.9	-475.6	-269.3	-412.6
RWLHi	449.2	264.3	-368.0	171.6	59.6	134.5	224.4	169.7	145.8	488.7	510.8	241.8	480.7	408.1	378.8
LWHC	534.3	-290.3	76.3	47.2	65.0	-41.2	-96.4	-39.1	-176.3	-326.9	-368.5	-145.1	258.3	323.8	-129.9
LWLHi	-508.8	297.7	-51.2	-25.2	45.3	107.1	249.1	111.1	286.4	284.3	407.0	282.1	-255.0	-317.5	308.2
(Constant)	-142.5	-115.2	-123.0	-151.1	-153.7	-70.9	-168.8	-95.5	-155.5	-125.1	-134.2	-135.6	-118.8	-134.5	-161.8

APPENDIX C: ANOVA ANALYSES

These tables list ANOVA results of anthropometry effects on critical inter-joint distances.

Table C-1: Posture 1 ANOVA Results

	LHIJRightHand		
Source	**DF**	**F**	**P**
Gender	1	0.16	.688
Height	2	0.55	.578
BMI	2	1.51	.233
FTE	2	0.21	.811
ETS	2	0.18	.837
ChestCir	2	3.17	.052
BicepCir	2	0.17	.843
WaistCir	2	5.59	.007

HIJRightHand				**RSIJRightHand**		
Source	**DF**	**F**	**P**	**DF**	**F**	**P**
Gender	1	0.92	0.34	1	0.95	0.33
Height	2	0.63	0.53	2	3.17	0.05
BMI	2	0.50	0.61	2	0.38	0.68
FTE	2	0.70	0.50	2	0.60	0.55
ETS	2	0.28	0.76	2	0.75	0.48
ChestCir	2	0.22	0.80	2	0.64	0.53
BicepCir	2	0.10	0.90	2	0.43	0.65
WaistCir	2	0.39	0.67	2	0.05	0.94
LSIJRightHand				REIJRightHip		
Source	**DF**	**F**	**P**	**DF**	**F**	**P**
Gender	1	2.99	0.09	1	0.03	0.86
Height	2	3.77	0.03	2	0.21	0.80
BMI	2	0.23	0.79	2	1.17	0.32
FTE	2	0.99	0.38	2	0.35	0.70
ETS	2	0.69	0.50	2	0.09	0.91
ChestCir	2	1.24	0.29	2	0.14	0.87
BicepCir	2	0.22	0.80	2	0.29	0.75
WaistCir	2	0.65	0.52	2	0.62	0.54
RWIJRightHip				RWIJLeftHip		
Source	**DF**	**F**	**P**	**DF**	**F**	**P**
Gender	1	0.01	0.91	1	0.19	0.66
Height	2	0.21	0.81	2	0.35	0.70
BMI	2	0.57	0.56	2	0.30	0.74
FTE	2	0.10	0.90	2	0.05	0.94
ETS	2	0.00	0.99	2	0.00	0.99
ChestCir	2	1.44	0.24	2	1.16	0.32
BicepCir	2	1.43	0.25	2	1.34	0.27
WaistCir	2	1.44	0.24	2	0.99	0.37
LWIJHipCenter				LWIJLeftHip		
Source	**DF**	**F**	**P**	**DF**	**F**	**P**
Gender	1	0.36	0.54	1	0.01	0.93
Height	2	0.30	0.74	2	0.15	0.86
BMI	2	1.47	0.24	2	1.88	0.16
FTE	2	0.47	0.62	2	0.41	0.66
ETS	2	0.07	0.93	2	0.03	0.96
ChestCir	2	2.20	0.12	2	2.21	0.12
BicepCir	2	1.56	0.22	2	1.18	0.31
WaistCir	2	1.30	0.28	2	1.99	0.14

Table C-2: Posture 2 ANOVA Results

	LHIJRightHand		
Source	**DF**	**F**	**P**
Gender	1	0.24	0.62
Height	2	0.60	0.55
BMI	2	4.05	0.02
FTE	2	0.10	0.90
ETS	2	0.28	0.75
ChestCir	2	3.11	0.052
BicepCir	2	0.74	0.48
WaistCir	2	1.87	0.16

HIJRightHand				**RSIJRightHand**		
Source	**DF**	**F**	**P**	**DF**	**F**	**P**
Gender	1	0.09	0.76	1	1.15	0.28
Height	2	0.43	0.65	2	1.01	0.37
BMI	2	0.29	0.74	2	2.05	0.14
FTE	2	0.71	0.49	2	1.11	0.33
ETS	2	0.05	0.94	2	0.33	0.72
ChestCir	2	0.28	0.75	2	0.60	0.55
BicepCir	2	0.27	0.76	2	0.14	0.87
WaistCir	2	1.21	0.30	2	2.42	0.10

LSIJRightHand				REIJRightHip		
Source	**DF**	**F**	**P**	**DF**	**F**	**P**
Gender	1	0.10	0.75	1	0.14	0.70
Height	2	0.53	0.59	2	0.82	0.44
BMI	2	0.40	0.67	2	0.17	0.84
FTE	2	0.47	0.62	2	0.36	0.69
ETS	2	0.08	0.92	2	0.27	0.76
ChestCir	2	1.61	0.21	2	0.43	0.65
BicepCir	2	0.13	0.88	2	0.09	0.91
WaistCir	2	4.30	0.02	2	2.47	0.09

RWIJRightHip				RWIJLeftHip		
Source	**DF**	**F**	**P**	**DF**	**F**	**P**
Gender	1	0.28	0.60	1	0.08	0.78
Height	2	1.62	.020	2	0.38	0.68
BMI	2	0.34	.071	2	0.67	0.51
FTE	2	0.31	0.73	2	0.22	0.80
ETS	2	0.03	0.97	2	0.15	0.86
ChestCir	2	1.59	0.21	2	1.95	0.15
BicepCir	2	0.07	0.93	2	0.10	0.90
WaistCir	2	8.42	0.001	2	4.63	0.01

LWIJHipCenter				LWIJLeftHip		
Source	**DF**	**F**	**P**	**DF**	**F**	**P**
Gender	1	1.04	0.31	1	0.61	0.43
Height	2	0.22	0.80	2	0.02	0.97
BMI	2	1.47	0.24	2	0.67	0.51
FTE	2	0.60	0.55	2	0.47	0.62
ETS	2	0.35	0.70	2	0.37	0.69
ChestCir	2	0.05	0.95	2	0.22	0.80
BicepCir	2	0.12	0.88	2	0.08	0.92
WaistCir	2	2.28	0.11	2	2.59	0.08

Table C-3: Posture 3 ANOVA Results

	LHIJRightHand		
Source	**DF**	**F**	**P**
Gender	1	0.16	0.69
Height	2	0.77	0.47
BMI	2	1.09	0.34
FTE	2	0.29	0.74
ETS	2	0.36	0.70
ChestCir	2	0.62	0.54
BicepCir	2	0.34	0.71
WaistCir	2	1.29	0.28

HIJRightHand				**RSIJRightHand**		
Source	**DF**	**F**	**P**	**DF**	**F**	**P**
Gender	1	0.48	0.49	1	1.35	0.25
Height	2	0.04	0.96	2	0.53	0.59
BMI	2	0.54	0.58	2	0.05	0.94
FTE	2	0.18	0.83	2	2.46	0.09
ETS	2	0.70	0.50	2	0.14	0.86
ChestCir	2	0.09	0.91	2	0.63	0.53
BicepCir	2	0.53	0.59	2	0.71	0.49
WaistCir	2	0.26	0.77	2	0.32	0.73

LSIJRightHand				REIJRightHip		
Source	**DF**	**F**	**P**	**DF**	**F**	**P**
Gender	1	0.45	0.50	1	0.00	0.95
Height	2	1.16	0.32	2	0.09	0.91
BMI	2	0.15	0.86	2	0.15	0.86
FTE	2	0.69	0.50	2	0.37	0.69
ETS	2	0.74	0.48	2	0.51	0.60
ChestCir	2	0.82	0.44	2	0.33	0.72
BicepCir	2	0.08	0.92	2	0.24	0.78
WaistCir	2	0.81	0.45	2	0.37	0.69

RWIJRightHip				RWIJLeftHip		
Source	**DF**	**F**	**P**	**DF**	**F**	**P**
Gender	1	2.37	0.13	1	0.60	0.44
Height	2	0.12	0.88	2	0.10	0.90
BMI	2	0.10	0.90	2	0.14	0.86
FTE	2	0.94	0.39	2	0.50	0.60
ETS	2	0.74	0.48	2	0.54	0.58
ChestCir	2	1.14	0.32	2	1.85	0.16
BicepCir	2	0.76	0.47	2	0.61	0.54
WaistCir	2	1.23	0.30	2	1.56	0.22

LWIJHipCenter				LWIJLeftHip		
Source	**DF**	**F**	**P**	**DF**	**F**	**P**
Gender	1	1.11	0.29	1	0.40	0.53
Height	2	0.04	0.95	2	0.20	0.81
BMI	2	0.04	0.95	2	0.09	0.91
FTE	2	0.53	0.59	2	0.42	0.65
ETS	2	0.22	0.80	2	0.46	0.63
ChestCir	2	3.25	0.04	2	1.81	0.17
BicepCir	2	0.01	0.98	2	1.02	0.37
WaistCir	2	2.53	0.09	2	1.80	0.17

Table C-4: Posture 4 ANOVA Results

	LHIJRightHand		
Source	**DF**	**F**	**P**
Gender	1	2.29	0.13
Height	2	1.72	0.19
BMI	2	2.33	0.10
FTE	2	1.09	0.34
ETS	2	0.68	0.51
ChestCir	2	0.09	0.91
BicepCir	2	1.53	0.22
WaistCir	2	0.56	0.57

HIJRightHand				**RSIJRightHand**		
Source	**DF**	**F**	**P**	**DF**	**F**	**P**
Gender	1	0.17	0.68	1	1.40	0.24
Height	2	1.06	0.35	2	3.09	0.055
BMI	2	2.61	0.08	2	1.18	0.31
FTE	2	1.00	0.37	2	0.45	0.64
ETS	2	0.11	0.89	2	0.80	0.45
ChestCir	2	2.12	0.13	2	0.63	0.53
BicepCir	2	0.92	0.40	2	0.93	0.40
WaistCir	2	4.36	0.01	2	0.12	0.89

LSIJRightHand				REIJRightHip		
Source	**DF**	**F**	**P**	**DF**	**F**	**P**
Gender	1	2.31	0.13	1	0.25	0.61
Height	2	2.30	0.11	2	1.40	0.25
BMI	2	2.80	0.07	2	0.44	0.64
FTE	2	0.76	0.47	2	0.48	0.62
ETS	2	0.39	0.67	2	0.10	0.90
ChestCir	2	0.61	0.54	2	1.10	0.34
BicepCir	2	1.32	0.27	2	0.08	0.92
WaistCir	2	1.06	0.35	2	3.04	0.58

RWIJRightHip				RWIJLeftHip		
Source	**DF**	**F**	**P**	**DF**	**F**	**P**
Gender	1	0.56	0.45	1	1.44	0.23
Height	2	2.88	0.06	2	3.72	0.03
BMI	2	0.62	0.54	2	1.88	0.16
FTE	2	0.25	0.77	2	0.52	0.59
ETS	2	0.47	0.63	2	0.46	0.63
ChestCir	2	1.26	0.29	2	1.25	0.29
BicepCir	2	0.27	0.76	2	0.48	0.62
WaistCir	2	1.54	0.22	2	1.56	0.22

LWIJHipCenter				LWIJLeftHip		
Source	**DF**	**F**	**P**	**DF**	**F**	**P**
Gender	1	2.30	0.13	1	1.79	0.18
Height	2	3.08	0.05	2	2.83	0.07
BMI	2	1.20	0.31	2	1.21	0.30
FTE	2	1.27	0.29	2	0.88	0.42
ETS	2	0.34	0.71	2	0.28	0.75
ChestCir	2	0.69	0.50	2	0.68	0.51
BicepCir	2	0.18	0.83	2	0.08	0.92
WaistCir	2	2.42	0.10	2	2.23	0.11

Table C-5: Posture 5 ANOVA Results

	LHIJRightHand		
Source	**DF**	**F**	**P**
Gender	1	0.36	0.55
Height	2	0.99	0.38
BMI	2	0.11	0.89
FTE	2	0.99	0.38
ETS	2	0.75	0.47
ChestCir	2	5.64	0.007
BicepCir	2	0.36	0.70
WaistCir	2	14.54	< .0001

HIJRightHand				**RSIJRightHand**		
Source	**DF**	**F**	**P**	**DF**	**F**	**P**
Gender	1	0.50	0.48	1	0.26	0.61
Height	2	0.66	0.52	2	5.32	0.009
BMI	2	0.98	0.38	2	3.74	0.03
FTE	2	0.51	0.60	2	1.60	0.21
ETS	2	0.26	0.77	2	0.18	0.83
ChestCir	2	0.16	0.85	2	0.03	0.96
BicepCir	2	0.18	0.83	2	0.05	0.95
WaistCir	2	0.70	0.50	2	0.34	0.71

LSIJRightHand				REIJRightHip		
Source	**DF**	**F**	**P**	**DF**	**F**	**P**
Gender	1	1.67	0.20	1	0.53	0.46
Height	2	4.60	0.01	2	0.22	0.80
BMI	2	0.80	0.45	2	0.13	0.87
FTE	2	0.64	0.53	2	0.34	0.71
ETS	2	0.31	0.73	2	0.34	0.71
ChestCir	2	0.00	0.99	2	0.83	0.44
BicepCir	2	0.06	0.94	2	0.05	0.95
WaistCir	2	0.06	0.94	2	0.71	0.49

RWIJRightHip				RWIJLeftHip		
Source	**DF**	**F**	**P**	**DF**	**F**	**P**
Gender	1	2.67	0.10	1	3.92	0.05
Height	2	2.05	0.14	2	2.42	0.10
BMI	2	0.26	0.77	2	0.23	0.79
FTE	2	0.20	0.81	2	0.23	0.79
ETS	2	0.69	0.50	2	0.65	0.52
ChestCir	2	0.43	0.65	2	0.30	0.74
BicepCir	2	0.65	0.52	2	0.59	0.55
WaistCir	2	3.00	0.06	2	2.08	0.13

LWIJHipCenter				LWIJLeftHip		
Source	**DF**	**F**	**P**	**DF**	**F**	**P**
Gender	1	0.33	0.57	1	0.52	0.47
Height	2	0.13	0.87	2	0.09	0.91
BMI	2	2.41	0.10	2	2.38	0.10
FTE	2	0.09	0.91	2	0.13	0.88
ETS	2	0.99	0.38	2	0.93	0.40
ChestCir	2	0.05	0.94	2	0.04	0.95
BicepCir	2	0.52	0.59	2	0.40	0.67
WaistCir	2	1.72	0.19	2	1.80	0.17

Table C-6: Posture 6 ANOVA Results

LHIJRightHand			
Source	**DF**	**F**	**P**
Gender	1	1.19	0.28
Height	2	0.32	0.73
BMI	2	1.00	0.37
FTE	2	0.04	0.96
ETS	2	0.15	0.85
ChestCir	2	0.25	0.78
BicepCir	2	0.79	0.45
WaistCir	2	1.00	0.37

HIJRightHand				**RSIJRightHand**		
Source	**DF**	**F**	**P**	**DF**	**F**	**P**
Gender	1	0.03	0.87	1	0.34	0.56
Height	2	1.57	0.22	2	1.09	0.34
BMI	2	0.72	0.49	2	0.30	0.74
FTE	2	0.97	0.38	2	0.93	0.40
ETS	2	1.69	0.19	2	1.39	0.26
ChestCir	2	0.46	0.63	2	0.59	0.55
BicepCir	2	1.25	0.29	2	0.98	0.38
WaistCir	2	0.61	0.54	2	0.04	0.96
LSIJRightHand				REIJRightHip		
Source	**DF**	**F**	**P**	**DF**	**F**	**P**
Gender	1	0.04	0.83	1	0.16	0.68
Height	2	0.90	0.41	2	0.95	0.39
BMI	2	0.32	0.72	2	0.74	0.48
FTE	2	0.52	0.59	2	0.87	0.42
ETS	2	0.55	0.58	2	0.32	0.72
ChestCir	2	0.30	0.74	2	0.18	0.83
BicepCir	2	0.57	0.56	2	0.57	0.56
WaistCir	2	0.63	0.53	2	0.14	0.87
RWIJRightHip				RWIJLeftHip		
Source	**DF**	**F**	**P**	**DF**	**F**	**P**
Gender	1	1.48	0.23	1	2.46	0.12
Height	2	0.53	0.59	2	0.59	0.55
BMI	2	0.87	0.42	2	0.55	0.58
FTE	2	0.29	0.75	2	0.29	0.75
ETS	2	0.05	0.95	2	0.05	0.95
ChestCir	2	0.11	0.89	2	0.17	0.84
BicepCir	2	0.95	0.39	2	1.08	0.34
WaistCir	2	1.94	0.15	2	2.54	0.09
LWIJHipCenter				LWIJLeftHip		
Source	**DF**	**F**	**P**	**DF**	**F**	**P**
Gender	1	0.50	0.48	1	0.67	0.41
Height	2	0.51	0.60	2	0.31	0.73
BMI	2	0.42	0.65	2	0.32	0.72
FTE	2	0.08	0.92	2	0.05	0.95
ETS	2	0.11	0.89	2	0.04	0.95
ChestCir	2	0.41	0.66	2	0.47	0.63
BicepCir	2	0.80	0.45	2	0.71	0.49
WaistCir	2	1.05	0.36	2	1.12	0.33

Table C-7: Posture 7 ANOVA Results

	LHIJRightHand		
Source	**DF**	**F**	**P**
Gender	1	0.48	0.49
Height	2	2.47	0.09
BMI	2	0.52	0.59
FTE	2	0.30	0.74
ETS	2	0.88	0.42
ChestCir	2	0.23	0.79
BicepCir	2	0.49	0.61
WaistCir	2	1.16	0.32

HIJRightHand				**RSIJRightHand**		
Source	**DF**	**F**	**P**	**DF**	**F**	**P**
Gender	1	0.43	0.51	1	0.14	0.70
Height	2	1.03	0.36	2	0.51	0.60
BMI	2	0.31	0.73	2	0.15	0.86
FTE	2	0.86	0.42	2	2.00	0.14
ETS	2	1.24	0.30	2	1.34	0.27
ChestCir	2	0.34	0.71	2	0.33	0.72
BicepCir	2	0.15	0.86	2	0.06	0.94
WaistCir	2	0.72	0.49	2	0.26	0.77

LSIJRightHand				REIJRightHip		
Source	**DF**	**F**	**P**	**DF**	**F**	**P**
Gender	1	1.05	0.31	1	0.16	0.69
Height	2	2.82	0.07	2	0.02	0.97
BMI	2	0.32	0.72	2	0.86	0.43
FTE	2	1.55	0.22	2	0.13	0.88
ETS	2	1.34	0.27	2	0.25	0.78
ChestCir	2	0.47	0.63	2	0.57	0.56
BicepCir	2	0.45	0.63	2	0.11	0.89
WaistCir	2	0.44	0.64	2	1.76	0.18

RWIJRightHip				RWIJLeftHip		
Source	**DF**	**F**	**P**	**DF**	**F**	**P**
Gender	1	0.01	0.90	1	0.07	0.79
Height	2	0.10	0.90	2	0.02	0.97
BMI	2	0.56	0.57	2	0.43	0.65
FTE	2	0.21	0.81	2	0.38	0.68
ETS	2	0.17	0.84	2	0.11	0.89
ChestCir	2	0.13	0.88	2	0.19	0.83
BicepCir	2	0.02	0.97	2	0.01	0.99
WaistCir	2	1.43	0.25	2	1.35	0.27

LWIJHipCenter				LWIJLeftHip		
Source	**DF**	**F**	**P**	**DF**	**F**	**P**
Gender	1	0.92	0.34	1	1.00	0.32
Height	2	1.73	0.18	2	1.63	0.20
BMI	2	0.50	0.61	2	0.36	0.70
FTE	2	0.79	0.46	2	0.73	0.48
ETS	2	0.55	0.58	2	0.64	0.53
ChestCir	2	0.28	0.76	2	0.18	0.83
BicepCir	2	0.05	0.94	2	0.11	0.89
WaistCir	2	0.21	0.81	2	0.26	0.77

Table C-8: Posture 8 ANOVA Results

	LHIJRightHand					
Source	**DF**	**F**	**P**			
Gender	1	0.00	0.95			
Height	2	0.76	0.47			
BMI	2	3.01	0.06			
FTE	2	1.53	0.22			
ETS	2	1.03	0.36			
ChestCir	2	0.23	0.79			
BicepCir	2	2.99	0.06			
WaistCir	2	1.53	0.22			
HIJRightHand				**RSIJRightHand**		
Source	**DF**	**F**	**P**	**DF**	**F**	**P**
Gender	1	0.09	0.76	1	2.68	0.10
Height	2	0.45	0.63	2	0.22	0.80
BMI	2	0.60	0.55	2	2.92	0.06
FTE	2	1.73	0.19	2	2.71	0.07
ETS	2	0.65	0.52	2	0.61	0.54
ChestCir	2	1.30	0.28	2	0.15	0.86
BicepCir	2	3.97	0.02	2	1.26	0.29
WaistCir	2	2.03	0.14	2	0.73	0.48
LSIJRightHand				REIJRightHip		
Source	**DF**	**F**	**P**	**DF**	**F**	**P**
Gender	1	0.17	0.68	1	0.45	0.50
Height	2	0.53	0.59	2	0.71	0.49
BMI	2	2.20	0.12	2	0.25	0.77
FTE	2	3.10	0.05	2	0.83	0.44
ETS	2	0.50	0.61	2	0.51	0.60
ChestCir	2	0.20	0.82	2	0.86	0.43
BicepCir	2	3.68	0.03	2	0.02	0.97
WaistCir	2	2.09	0.13	2	1.87	0.16
RWIJRightHip				RWIJLeftHip		
Source	**DF**	**F**	**P**	**DF**	**F**	**P**
Gender	1	1.01	0.32	1	0.74	0.39
Height	2	0.47	0.62	2	0.68	0.51
BMI	2	0.90	0.41	2	1.08	0.34
FTE	2	1.47	0.24	2	2.15	0.12
ETS	2	0.59	0.55	2	0.66	0.51
ChestCir	2	0.68	0.51	2	0.68	0.51
BicepCir	2	0.17	0.84	2	0.65	0.52
WaistCir	2	1.66	0.20	2	2.48	0.09
LWIJHipCenter				LWIJLeftHip		
Source	**DF**	**F**	**P**	**DF**	**F**	**P**
Gender	1	1.15	0.28	1	1.22	0.27
Height	2	0.09	0.91	2	0.14	0.87
BMI	2	0.71	0.49	2	0.42	0.66
FTE	2	1.77	0.18	2	1.82	0.17
ETS	2	0.38	0.68	2	0.36	0.70
ChestCir	2	0.45	0.64	2	0.49	0.61
BicepCir	2	0.42	0.65	2	0.36	0.70
WaistCir	2	2.51	0.09	2	2.50	0.09

Table C-9: Posture 9 ANOVA Results

	LHIJRightHand		
Source	**DF**	**F**	**P**
Gender	1	0.63	0.43
Height	2	3.60	0.03
BMI	2	1.29	0.28
FTE	2	1.45	0.24
ETS	2	1.17	0.32
ChestCir	2	0.50	0.61
BicepCir	2	2.22	0.12
WaistCir	2	0.14	0.87

HIJRightHand				**RSIJRightHand**		
Source	**DF**	**F**	**P**	**DF**	**F**	**P**
Gender	1	1.18	0.28	1	0.68	0.41
Height	2	3.78	0.03	2	11.84	< .001
BMI	2	7.98	0.001	2	1.75	0.18
FTE	2	1.18	0.31	2	1.49	0.23
ETS	2	0.29	0.74	2	0.56	0.57
ChestCir	2	1.46	0.24	2	3.77	0.03
BicepCir	2	1.00	0.37	2	0.39	0.67
WaistCir	2	0.85	0.43	2	3.92	0.02

LSIJRightHand				REIJRightHip		
Source	**DF**	**F**	**P**	**DF**	**F**	**P**
Gender	1	3.80	0.05	1	0.49	0.48
Height	2	6.31	0.004	2	1.31	0.28
BMI	2	4.48	0.01	2	0.61	.54
FTE	2	0.73	0.48	2	0.14	0.86
ETS	2	0.65	0.52	2	0.08	0.92
ChestCir	2	1.42	0.25	2	0.76	0.47
BicepCir	2	0.94	0.40	2	0.55	0.58
WaistCir	2	2.46	0.09	2	1.91	0.16

RWIJRightHip				RWIJLeftHip		
Source	**DF**	**F**	**P**	**DF**	**F**	**P**
Gender	1	2.79	0.10	1	5.48	0.02
Height	2	2.41	0.10	2	3.85	0.02
BMI	2	0.70	0.50	2	0.10	0.90
FTE	2	0.10	0.90	2	0.14	0.87
ETS	2	0.54	0.58	2	0.83	0.44
ChestCir	2	0.00	0.99	2	0.10	0.90
BicepCir	2	0.53	0.59	2	0.84	0.43
WaistCir	2	4.20	0.02	2	5.51	0.007

LWIJHipCenter				LWIJLeftHip		
Source	**DF**	**F**	**P**	**DF**	**F**	**P**
Gender	1	0.01	0.90	1	0.05	0.82
Height	2	1.33	0.27	2	1.12	0.33
BMI	2	0.23	0.79	2	0.32	0.73
FTE	2	0.83	0.44	2	0.69	0.50
ETS	2	0.08	0.92	2	0.19	0.82
ChestCir	2	0.10	0.90	2	0.08	0.92
BicepCir	2	0.22	0.80	2	0.27	0.76
WaistCir	2	0.27	0.76	2	0.28	0.75

Table C-10: Posture 10 ANOVA Results

	LHIJRightHand		
Source	**DF**	**F**	**P**
Gender	1	0.23	0.63
Height	2	1.68	0.19
BMI	2	0.83	0.44
FTE	2	0.17	0.84
ETS	2	0.13	0.87
ChestCir	2	0.06	0.94
BicepCir	2	0.03	0.96
WaistCir	2	1.76	.018

HIJRightHand				**RSIJRightHand**		
Source	**DF**	**F**	**P**	**DF**	**F**	**P**
Gender	1	1.75	0.19	1	1.58	0.21
Height	2	0.60	0.55	2	2.56	0.08
BMI	2	0.27	0.76	2	0.70	0.50
FTE	2	0.38	0.68	2	0.12	0.89
ETS	2	0.49	0.61	2	0.89	0.41
ChestCir	2	1.48	0.23	2	3.99	0.02
BicepCir	2	0.35	0.70	2	0.01	0.98
WaistCir	2	6.11	0.005	2	10.11	< .001
LSIJRightHand				REIJRightHip		
Source	**DF**	**F**	**P**	**DF**	**F**	**P**
Gender	1	1.09	0.30	1	0.48	0.49
Height	2	2.71	0.07	2	0.31	0.73
BMI	2	1.18	0.31	2	1.03	0.36
FTE	2	0.38	0.68	2	0.04	0.96
ETS	2	0.23	0.79	2	0.00	0.99
ChestCir	2	0.29	0.75	2	0.05	0.95
BicepCir	2	0.20	0.82	2	0.52	0.59
WaistCir	2	1.72	0.19	2	0.10	0.90
RWIJRightHip				RWIJLeftHip		
Source	**DF**	**F**	**P**	**DF**	**F**	**P**
Gender	1	0.18	0.67	1	0.00	0.99
Height	2	0.27	0.76	2	0.48	0.62
BMI	2	0.23	0.79	2	0.56	0.57
FTE	2	0.34	0.71	2	0.31	0.73
ETS	2	0.06	0.94	2	0.07	0.92
ChestCir	2	1.40	0.25	2	1.26	0.29
BicepCir	2	0.46	0.63	2	0.35	0.70
WaistCir	2	2.15	0.12	2	1.63	0.20
LWIJHipCenter				LWIJLeftHip		
Source	**DF**	**F**	**P**	**DF**	**F**	**P**
Gender	1	0.04	0.84	1	0.01	0.91
Height	2	0.53	0.59	2	0.64	0.53
BMI	2	0.32	0.72	2	0.09	0.91
FTE	2	0.17	0.84	2	0.18	0.84
ETS	2	0.17	0.84	2	0.09	0.91
ChestCir	2	0.77	0.47	2	0.66	0.52
BicepCir	2	0.48	0.62	2	0.41	0.66
WaistCir	2	2.84	0.06	2	2.52	0.09

Table C-11: Posture 11 ANOVA Results

	LHIJRightHand		
Source	**DF**	**F**	**P**
Gender	1	0.24	0.62
Height	2	1.03	0.36
BMI	2	0.64	0.53
FTE	2	0.26	0.77
ETS	2	0.47	0.62
ChestCir	2	1.11	0.33
BicepCir	2	0.00	0.99
WaistCir	2	2.91	0.06

HIJRightHand				**RSIJRightHand**		
Source	**DF**	**F**	**P**	**DF**	**F**	**P**
Gender	1	2.38	0.13	1	0.02	0.89
Height	2	0.25	0.77	2	2.95	0.06
BMI	2	0.27	0.76	2	0.47	0.62
FTE	2	0.97	0.38	2	1.91	0.16
ETS	2	0.93	0.40	2	1.22	0.30
ChestCir	2	1.59	0.21	2	2.17	0.12
BicepCir	2	0.40	0.67	2	0.08	0.92
WaistCir	2	8.52	0.001	2	0.93	0.40
LSIJRightHand				REIJRightHip		
Source	**DF**	**F**	**P**	**DF**	**F**	**P**
Gender	1	1.22	0.27	1	1.09	0.30
Height	2	3.01	0.059	2	0.20	0.82
BMI	2	1.81	0.17	2	1.59	0.21
FTE	2	0.39	0.60	2	1.98	0.15
ETS	2	1.39	0.26	2	0.66	0.52
ChestCir	2	0.16	0.85	2	3.71	0.03
BicepCir	2	1.56	0.22	2	0.15	0.86
WaistCir	2	0.53	0.59	2	9.58	< .001
RWIJRightHip				RWIJLeftHip		
Source	**DF**	**F**	**P**	**DF**	**F**	**P**
Gender	1	1.44	0.23	1	0.64	0.42
Height	2	0.29	0.75	2	0.54	0.58
BMI	2	0.45	0.64	2	0.82	0.44
FTE	2	1.58	0.21	2	1.49	0.23
ETS	2	0.58	0.56	2	0.57	0.56
ChestCir	2	5.44	0.008	2	4.45	0.01
BicepCir	2	0.08	0.92	2	0.02	0.98
WaistCir	2	13.58	< .001	2	11.28	< .001
LWIJHipCenter				LWIJLeftHip		
Source	**DF**	**F**	**P**	**DF**	**F**	**P**
Gender	1	0.56	0.46	1	1.10	0.30
Height	2	0.30	0.73	2	0.41	0.66
BMI	2	0.05	0.95	2	0.0	0.81
FTE	2	0.05	0.95	2	0.05	0.94
ETS	2	0.06	0.93	2	0.08	0.92
ChestCir	2	0.47	0.62	2	0.34	0.71
BicepCir	2	0.35	0.70	2	0.30	0.74
WaistCir	2	0.94	0.39	2	1.02	0.37

Table C-12: Posture 12 ANOVA Results

	LHIJRightHand		
Source	**DF**	**F**	**P**
Gender	1	3.11	0.08
Height	2	0.31	0.73
BMI	2	0.25	0.78
FTE	2	3.89	0.02
ETS	2	0.10	0.90
ChestCir	2	0.11	0.89
BicepCir	2	0.81	0.45
WaistCir	2	1.72	0.19

HIJRightHand				**RSIJRightHand**		
Source	**DF**	**F**	**P**	**DF**	**F**	**P**
Gender	1	0.01	0.91	1	6.45	0.01
Height	2	1.64	0.20	2	4.66	0.01
BMI	2	2.97	0.06	2	2.33	0.10
FTE	2	2.77	0.07	2	1.20	0.31
ETS	2	0.46	0.63	2	0.63	0.53
ChestCir	2	1.53	0.22	2	3.02	0.05
BicepCir	2	0.56	0.57	2	2.80	0.07
WaistCir	2	1.23	0.30	2	3.00	0.06

LSIJRightHand				REIJRightHip		
Source	**DF**	**F**	**P**	**DF**	**F**	**P**
Gender	1	.025	0.61	1	2.46	0.12
Height	2	4.03	0.02	2	5.80	0.006
BMI	2	2.44	0.09	2	0.09	0.91
FTE	2	3.14	0.05	2	0.25	0.78
ETS	2	0.14	0.86	2	0.29	0.75
ChestCir	2	0.55	0.58	2	0.61	0.54
BicepCir	2	0.58	0.56	2	0.33	0.72
WaistCir	2	0.82	0.44	2	0.71	0.49

RWIJRightHip				RWIJLeftHip		
Source	**DF**	**F**	**P**	**DF**	**F**	**P**
Gender	1	3.51	0.06	1	2.47	0.12
Height	2	4.85	0.01	2	5.43	0.008
BMI	2	1.32	0.27	2	1.47	0.24
FTE	2	1.21	0.30	2	1.58	0.21
ETS	2	0.29	0.74	2	0.19	0.82
ChestCir	2	0.33	0.72	2	0.23	0.79
BicepCir	2	1.59	0.21	2	1.19	0.31
WaistCir	2	0.82	0.44	2	0.59	0.56

LWIJHipCenter				LWIJLeftHip		
Source	**DF**	**F**	**P**	**DF**	**F**	**P**
Gender	1	1.37	0.24	1	1.42	0.24
Height	2	1.22	0.30	2	1.26	0.29
BMI	2	1.64	0.20	2	1.11	0.33
FTE	2	0.07	0.93	2	0.05	0.94
ETS	2	0.06	0.94	2	0.07	0.93
ChestCir	2	0.12	0.88	2	0.18	0.83
BicepCir	2	0.96	0.39	2	0.84	0.44
WaistCir	2	2.09	0.13	2	2.58	0.08

Table C-13: Posture 13 ANOVA Results

	LHIJRightHand		
Source	**DF**	**F**	**P**
Gender	1	0.77	0.38
Height	2	1.56	0.22
BMI	2	0.53	0.59
FTE	2	1.82	0.17
ETS	2	1.10	0.34
ChestCir	2	3.62	0.03
BicepCir	2	0.03	0.97
WaistCir	2	7.86	0.001

HIJRightHand				**RSIJRightHand**		
Source	**DF**	**F**	**P**	**DF**	**F**	**P**
Gender	1	0.08	0.77	1	0.20	0.65
Height	2	2.84	0.06	2	1.99	0.14
BMI	2	1.82	0.17	2	0.12	0.88
FTE	2	2.58	0.08	2	1.82	0.17
ETS	2	1.24	0.29	2	1.10	0.34
ChestCir	2	4.87	0.01	2	6.80	0.003
BicepCir	2	0.63	0.53	2	0.06	0.93
WaistCir	2	3.63	0.03	2	6.64	0.003
LSIJRightHand				REIJRightHip		
Source	**DF**	**F**	**P**	**DF**	**F**	**P**
Gender	1	0.15	0.70	1	0.04	0.84
Height	2	2.71	0.07	2	1.09	0.34
BMI	2	2.18	0.12	2	0.28	0.75
FTE	2	3.73	0.03	2	0.24	0.78
ETS	2	1.47	0.24	2	0.53	0.59
ChestCir	2	7.10	0.002	2	0.04	0.96
BicepCir	2	0.72	0.49	2	0.70	0.50
WaistCir	2	10.65	< .001	2	0.08	0.92
RWIJRightHip				RWIJLeftHip		
Source	**DF**	**F**	**P**	**DF**	**F**	**P**
Gender	1	1.05	0.31	1	0.83	0.36
Height	2	0.46	0.63	2	0.71	0.49
BMI	2	0.22	0.80	2	0.39	0.67
FTE	2	1.03	0.36	2	1.65	0.20
ETS	2	0.20	0.81	2	0.35	0.70
ChestCir	2	1.77	0.18	2	2.58	0.08
BicepCir	2	0.52	0.59	2	0.43	0.65
WaistCir	2	5.29	0.009	2	6.62	0.003
LWIJHipCenter				LWIJLeftHip		
Source	**DF**	**F**	**P**	**DF**	**F**	**P**
Gender	1	0.77	0.38	1	0.72	0.40
Height	2	1.54	0.22	2	1.36	0.26
BMI	2	0.17	0.84	2	0.07	0.93
FTE	2	1.84	0.17	2	1.50	0.23
ETS	2	0.94	0.39	2	0.65	0.52
ChestCir	2	2.81	0.07	2	1.92	0.15
BicepCir	2	0.15	0.85	2	0.14	0.87
WaistCir	2	6.14	0.004	2	5.51	0.007

Table C-14: Posture 14 ANOVA Results

	LHIJRightHand		
Source	**DF**	**F**	**P**
Gender	1	0.69	0.41
Height	2	1.05	0.35
BMI	2	0.10	0.90
FTE	2	2.57	0.08
ETS	2	1.03	0.36
ChestCir	2	2.11	0.13
BicepCir	2	0.14	0.86
WaistCir	2	3.10	0.05

HIJRightHand				**RSIJRightHand**		
Source	**DF**	**F**	**P**	**DF**	**F**	**P**
Gender	1	0.45	0.50	1	0.03	0.85
Height	2	1.27	0.29	2	2.97	0.06
BMI	2	2.43	0.10	2	0.09	0.91
FTE	2	2.91	0.06	2	4.72	0.01
ETS	2	0.11	0.89	2	0.07	0.93
ChestCir	2	0.32	0.72	2	0.75	0.47
BicepCir	2	1.07	0.35	2	0.12	0.88
WaistCir	2	0.66	0.52	2	1.44	0.24
LSIJRightHand				REIJRightHip		
Source	**DF**	**F**	**P**	**DF**	**F**	**P**
Gender	1	0.24	0.62	1	0.43	0.51
Height	2	2.87	0.06	2	0.37	0.69
BMI	2	1.57	0.21	2	0.33	0.72
FTE	2	3.22	0.050	2	0.71	0.49
ETS	2	0.04	0.95	2	0.69	0.50
ChestCir	2	0.47	0.63	2	1.20	0.31
BicepCir	2	0.50	0.61	2	0.31	0.73
WaistCir	2	1.37	0.26	2	3.17	0.05
RWIJRightHip				RWIJLeftHip		
Source	**DF**	**F**	**P**	**DF**	**F**	**P**
Gender	1	0.36	0.55	1	0.02	0.90
Height	2	0.80	0.45	2	1.44	0.24
BMI	2	0.12	0.88	2	0.02	0.98
FTE	2	1.01	0.37	2	1.32	0.27
ETS	2	0.67	0.51	2	0.68	0.51
ChestCir	2	1.07	0.35	2	1.73	0.19
BicepCir	2	0.71	0.49	2	0.41	0.66
WaistCir	2	2.80	0.07	2	4.39	0.01
LWIJHipCenter				LWIJLeftHip		
Source	**DF**	**F**	**P**	**DF**	**F**	**P**
Gender	1	0.98	0.32	1	1.51	0.22
Height	2	1.30	0.28	2	0.95	0.39
BMI	2	0.50	0.61	2	0.66	0.52
FTE	2	2.45	0.09	2	1.93	0.15
ETS	2	1.54	0.22	2	1.50	0.23
ChestCir	2	1.64	0.20	2	1.64	0.20
BicepCir	2	0.45	0.63	2	0.54	0.58
WaistCir	2	2.90	0.06	2	2.56	0.08

Table C-15: Posture 15 ANOVA Results

	LHIJRightHand		
Source	**DF**	**F**	**P**
Gender	1	0.50	0.48
Height	2	3.61	0.03
BMI	2	1.14	0.33
FTE	2	0.96	0.39
ETS	2	0.30	0.74
ChestCir	2	0.41	0.66
BicepCir	2	0.04	0.96
WaistCir	2	0.42	0.66

HIJRightHand				**RSIJRightHand**		
Source	**DF**	**F**	**P**	**DF**	**F**	**P**
Gender	1	0.00	0.96	1	0.05	0.82
Height	2	0.42	0.66	2	2.37	0.10
BMI	2	0.51	0.60	2	1.17	0.32
FTE	2	2.01	0.14	2	2.64	0.08
ETS	2	0.02	0.97	2	0.17	0.84
ChestCir	2	0.58	0.56	2	2.23	0.11
BicepCir	2	0.41	0.66	2	0.51	0.60
WaistCir	2	0.65	0.52	2	0.46	0.63

LSIJRightHand				REIJRightHip		
Source	**DF**	**F**	**P**	**DF**	**F**	**P**
Gender	1	0.21	0.64	1	0.22	0.64
Height	2	2.56	0.08	2	0.12	0.88
BMI	2	2.37	0.10	2	1.44	0.24
FTE	2	2.53	0.09	2	0.38	0.68
ETS	2	0.40	0.67	2	0.12	0.88
ChestCir	2	0.51	0.60	2	0.22	0.80
BicepCir	2	0.27	0.76	2	0.00	0.99
WaistCir	2	0.22	0.80	2	0.52	0.59

RWIJRightHip				RWIJLeftHip		
Source	**DF**	**F**	**P**	**DF**	**F**	**P**
Gender	1	0.09	0.77	1	0.53	0.47
Height	2	0.21	0.81	2	0.32	0.72
BMI	2	0.06	0.94	2	0.41	0.66
FTE	2	0.17	0.84	2	0.24	0.78
ETS	2	0.07	0.84	2	0.24	0.78
ChestCir	2	0.27	0.93	2	0.05	0.95
BicepCir	2	0.05	0.76	2	0.04	0.95
WaistCir	2		0.94	2	0.07	0.93

LWIJHipCenter				LWIJLeftHip		
Source	**DF**	**F**	**P**	**DF**	**F**	**P**
Gender	1	2.93	0.09	1	3.02	0.08
Height	2	7.06	0.002	2	6.23	0.004
BMI	2	0.30	0.74	2	0.92	0.40
FTE	2	0.50	0.61	2	0.58	0.56
ETS	2	0.30	0.74	2	0.42	0.65
ChestCir	2	0.10	0.90	2	0.05	0.95
BicepCir	2	2.13	0.13	2	1.86	0.16
WaistCir	2	0.81	0.45	2	0.87	0.42

APPENDIX D: TUKEY RESULTS

Below are the Tukey results for the significant anthropometric factors identified in the ANOVA results.

Table D-1: Posture 1 Tukey Results

LHIJRighthand

WaistCir	N	Mean	Grouping	
5th	2	0.628	A	
95th	19	0.443		B
50th	39	0.4231		B

RSIJRighthand

Height	N	Mean	Grouping	
95th	42	0.569	A	
5th	3	0.546	A	B
50th	15	0.535		B

LSIJRighthand

Height	N	Mean	Grouping	
95th	42	0.695	A	
5th	3	0.661	A	B
50th	15	0.660		B

Table D-2: Posture 2 Tukey Results

LHIJRighthand

BMI	N	Mean	Grouping	
Small	18	0.41	A	
Medium	36	.394	A	
Large	6	.244		B

LSIJRightHand

WaistCir	N	Mean	Grouping	
5th	2	0.480	A	
50th	39	0.191		B
95th	19	0.170		B

RWIJRighthip

WaistCir	N	Mean	Grouping	
5th	2	0.536	A	B
95th	19	0.527	A	
50th	39	0.437		B

RWIJLefthip

WaistCir	N	Mean	Grouping	
5th	2	0.575	A	
95th	19	0.449	A	B
50th	39	0.395		B

Table D-3: Posture 4 Tukey Results

HIJRighthand

WaistCir	N	Mean	Grouping	
5th	2	0.913	A	
95th	19	0.743		B
50th	39	0.737		B

RSIJRighthand

Height	N	Mean	Grouping	
95th	42	0.538	A	
5th	3	0.530	A	B
50th	15	0.505		B

REIJRighthip

WaistCir	N	Mean	Grouping	
5th	2	0.633	A	
95th	19	0.539	A	B
50th	39	0.533		B

RWIJLefthip

Height	N	Mean	Grouping	
5th	3	0.881	A	B
95th	42	0.870	A	
50th	15	0.833		B

LWIJHipCenter

Height	N	Mean	Grouping	
95th	42	0.742	A	
5th	3	0.736	A	B
50th	15	0.711		B

Table D-4: Posture 5 Tukey Results

LHIJRighthand				
ChestCir	N	Mean	Grouping	
50th	5	0.543	A	
95th	53	0.476	A	
5th	2	0.249		B

LHIJRighthand				
WaistCir	N	Mean	Grouping	
5th	2	0.746	A	
50th	39	0.261		B
95th	19	0.261		B

RSIJRighthand				
Height	N	Mean	Grouping	
95th	42	0.580	A	
50th	15	0.535		B
5th	3	0.513	A	B

RSIJRighthand				
BMI	N	Mean	Grouping	
Small	18	0.569	A	
Medium	36	0.556	A	
Large	6	0.503		B

LSIJRighthand				
Height	N	Mean	Grouping	
95th	42	0.637	A	
50th	15	0.590		B
5th	3	0.561	A	B

Table D-5: Posture 8 Tukey Results

LHIJRighthand				
BMI	N	Mean	Grouping	
Small	18	0.884	A	
Medium	36	0.882	A	B
Large	6	0.795		B

LHIJRighthand				
BicepCir	N	Mean	Grouping	
5th	1	0.991	A	
50th	19	0.798	A	B
95th	40	0.773		B

HIJRighthand				
BicepCir	N	Mean	Grouping	
5th	1	0.532	A	
50th	19	0.407		B
95th	40	0.402		B

LSIJRighthand				
BicepCir	N	Mean	Grouping	
5th	1	0.798	A	
50th	19	0.654		B
95th	40	0.641		B

Table D-6: Posture 9 Tukey Results

LHIJRighthand				
Height	N	Mean	Grouping	
95th	42	1.323	A	
5th	3	1.283	A	B
50th	15	1.232		B

HIJRighthand				
Height	N	Mean	Grouping	
95th	42	0.804	A	
5th	3	0.775	A	B
50th	15	0.759		B

HIJRighthand				
BMI	N	Mean	Grouping	
Large	6	0.832	A	
Medium	36	0.779		B
Small	18	0.727		

RSIJRighthand					
Height		N	Mean	Grouping	
	95th	42	0.550	A	
	5th	3	0.510	A	B
C	**50th**	15	0.506		B

RSIJRighthand				
ChestCir	N	Mean	Grouping	
5th	2	0.555	A	
50th	5	0.514	A	B
95th	53	0.497		B

RSIJRighthand				
WaistCir	N	Mean	Grouping	
50th	39	0.546	A	
95th	19	0.538	A	B
5th	2	0.482		B

LSIJRighthand				
Height	N	Mean	Grouping	
95th	**42**	0.916	A	
5th	**3**	0.873	A	B
50th	**15**	0.856		B

LSIJRighthand				
BMI	N	Mean	Grouping	
Large	6	0.919	A	
Medium	36	0.885	A	
Small	18	0.841		B

RWIJRighthip				
WaistCir	**N**	**Mean**	**Grouping**	
95th	**19**	0.681	A	
50th	**39**	0.644	A	B
5th	**2**	0.572		B

RWIJLefthip				
Gender	**N**	**Mean**	**Grouping**	
M	30	0.810	A	
F	30	0.717		B

RWIJLefthip				
Height	**N**	**Mean**	**Grouping**	
95th	42	0.792	A	
5th	3	0.752	A	B
50th	15	0.748		B

RWIJLefthip				
WaistCir	**N**	**Mean**	**Grouping**	
95th	19	0.819	A	
50th	39	0.783	A	B
5th	15	0.690		B

Table D-7: Posture 10 Tukey Results

HIJRighthand				
WaistCir	**N**	**Mean**	**Grouping**	
95th	19	0.920	A	
50th	39	0.899	A	
5th	2	0.686		B

RSIJRighthand				
ChestCir	**N**	**Mean**	**Grouping**	
5th	2	0.570	A	
50th	5	0.501	A	B
95th	53	0.476		B

RSIJRighthand				
WaistCir	**N**	**Mean**	**Grouping**	
95th	19	0.574	A	
50th	39	0.5692	A	
5th	2	0.404		B

Table D-8: Posture 11 Tukey Results

HIJRighthand				
WaistCir	**N**	**Mean**	**Grouping**	
95th	19	0.928	A	
50th	39	0.894	A	
5th	2	0.641		B

REIJRighthip				
ChestCir	**N**	**Mean**	**Grouping**	
50th	5	0.377	A	
95th	53	0.349	A	B
5th	2	0.206		B

REIJRighthip				
WaistCir	**N**	**Mean**	**Grouping**	
5th	2	0.504	A	
50th	39	0.218		B
95th	19	0.210		B

RWIJRighthip				
ChestCir	**N**	**Mean**	**Grouping**	
50th	5	0.424	A	
95th	53	0.376	A	
5th	2	0.120		B

RWIJRighthip				
WaistCir	**N**	**Mean**	**Grouping**	
5th	2	0.644	A	
50th	39	0.159		B
95th	19	0.118		B

RWIJLeftHip				
ChestCir	**N**	**Mean**	**Grouping**	
50th	5	0.5252	A	
95th	53	0.490	A	
5th	2	0.263		B

RWIJLeftHip				
WaistCir	**N**	**Mean**	**Grouping**	
5th	2	0.722	A	
50th	39	0.293		B
95th	19	0.261		B

Table D-9: Posture 12 Tukey Results

LHIJRightHand				
FTE	N	Mean	Grouping	
95th	20	0.433	A	B
50th	10	0.412	A	
5th	30	0.265		B

RSIJRighthand				
Gender	N	Mean	Grouping	
M	30	0.426	A	
F	30	0.349		B

RSIJRighthand				
Height	N	Mean	Grouping	
95th	42	0.406	A	
5th	3	0.389	A	B
50th	15	0.369		B

LSIJRighthand				
Height	N	Mean	Grouping	
95th	42	0.557	A	
5th	3	0.543	A	B
50th	15	0.518		B

LSIJRighthand				
FTE	N	Mean	Grouping	
50th	10	0.562	A	
95th	20	0.559	A	B
5th	30	0.499		B

REIJRighthip				
Height	N	Mean	Grouping	
95th	42	0.646	A	
5th	3	0.614	A	B
50th	15	0.600		B

RWIJRighthip				
Height	N	Mean	Grouping	
95th	42	0.780	A	
5th	3	0.736	A	B
50th	15	0.726		B

RWIJLefthip				
Height	N	Mean	Grouping	
95th	42	0.828	A	
5th	3	0.785	A	B
50th	15	0.775		B

Table D-10: Posture 13 Tukey Results

LHIJRighthand				
ChestCir	N	Mean	Grouping	
50th	5	0.828	A	
95th	53	0.785	A	
5th	2	0.775		B

LHIJRighthand				
WaistCir	N	Mean	Grouping	
5th	2	0.949	A	
50th	39	0.497		B
95th	19	0.429		B

HIJRighthand				
ChestCir	N	Mean	Grouping	
50th	5	0.799	A	
95th	53	0.779	A	
5th	2	0.668		B

HIJRighthand				
WaistCir	N	Mean	Grouping	
5th	2	0.827	A	
95th	19	0.712		B
50th	39	0.707		B

RSIJRighthand				
ChestCir	N	Mean	Grouping	
50th	5	0.475	A	
95th	53	0.446	A	
5th	2	0.332		B

RSIJRighthand				
WaistCir	N	Mean	Grouping	
5th	2	0.516	A	
50th	39	0.372		B
95th	19	0.366		B

LSIJRighthand				
FTE	N	Mean	Grouping	
95th	20	0.688	A	
50th	10	0.636	A	B
5th	30	0.577		B

LSIJRighthand				
ChestCir	N	Mean	Grouping	
50th	5	0.694	A	
95th	53	0.666	A	
5th	2	0.541		B

LSIJRighthand				
WaistCir	N	Mean	Grouping	
5th	2	0.764	A	
50th	39	0.570		B
95th	19	0.567		B

RWIJRighthip				
WaistCir	N	Mean	Grouping	
5th	2	0.440	A	
50th	39	0.202		B
95th	19	0.193		B

RWIJLeftHip				
WaistCir	N	Mean	Grouping	
5th	2	0.583	A	
50th	39	0.360		B
95th	19	0.355		B

LWIJHipCenter				
WaistCir	N	Mean	Grouping	
5th	2	0.548	A	
50th	39	0.289		B
95th	19	0.249		B

LWIJLefthip				
WaistCir	N	Mean	Grouping	
5th	2	0.496	A	
50th	39	0.219		B
95th	19	0.182		B

Table D-11: Posture 14 Tukey Results

RSIJRighthand				
FTE	N	Mean	Grouping	
95th	20	0.607	A	
50th	10	0.551		B
5th	30	0.531		B

LSIJRighthand				
FTE	N	Mean	Grouping	
95th	20	0.890	A	
50th	10	0.836	A	B
5th	30	0.797		B

RWIJLefthip				
WaistCir	N	Mean	Grouping	
95th	19	0.632	A	
50th	39	0.585		B
5th	2	0.554	A	B

Table D-12: Posture 15 Tukey Results

LHIJRighthand				
Height	N	Mean	Grouping	
95th	42	1.208	A	
5th	3	1.155	A	B
50th	15	1.12		B

LWIJHipCenter				
Height	N	Mean	Grouping	
95th	42	0.796	A	
5th	3	0.742	A	B
50th	15	0.733		B

LWIJLefthip				
Height	N	Mean	Grouping	
95th	42	0.822	A	
5th	3	0.767	A	B
50th	15	0.758		B

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