Three Dimensional Biomechanics of the Hand and Wrist in Precision Grip

by

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A thesis submitted in accordance with the regulations governing the award of the Degree of Doctor of Philosophy in Bioengineering.

The Bioengineering Unit

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Glasgow, Scotland, U. K.

November, 2011

This thesis is the result of the author's original research. It has been composed by the author and has not been previously submitted for examination which has led to the award of a degree.

Signature: _______________

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To Professor Sandy Nicol

ΕΑΝ ΜΗ ΕΛΗΠΤΑΙ ΑΝΕΛΠΙΣΤΟΝ,
ΟΥΚ ΕΞΕΥΡΗΣΕΙ.

ΗΡΑΚΛΕΙΤΟΣ

Acknowledgments

I would like to thank my supervisors Dr Nicky K. Fowler and Dr Ben Stansfield for their advice and the valuable guidance at the beginning of this project, as well as Iain Tullis for his technical assistance.

I gratefully acknowledge the State Scholarships Foundation of Greece for the financial support.

Also, I am grateful to the University of Strathclyde and specifically the Bioengineering Unit for giving me the opportunity to undertake my research in order to complete this study for the degree of Ph.D. in Bioengineering.

During my postgraduate studies, Life did not treat me with kindness: I lost a baby, I found myself without financial support, homeless, far away from my country and my relatives, and my project was in jeopardy as my first supervisor abandoned academics and the second one changed university. I would not have managed not only to finish my project but even to survive without the three following persons.

Magnús K. Gíslason: although he is a Viking from Iceland he has a warm heart, always ready to advice, eager to help. I will never forget our conversations about mathematics, culture and good food. Maggi was constantly giving me strength to fight and finish this project.

Christos Kapatos: he supported me financially whenever he could. I remember him cooking for me, smiling and joking to give me strength: that was exactly what I was needing, an optimistic friend to tell me that it is just a bad period in my life, which sooner or later will finish.

Finally, but not lastly, Professor Sandy Nicol: he was standing by me when my supervisors left, and he was ready to spend his time to modify my project in the optimum way. He stood by me when I lost the baby, and gave to me -off the record- the necessary time to recover. He stood by me as my third supervisor to help me write down

my Thesis. It was not his *obligation*: Professor Nicol believed that it was his *duty* to assist me to recover and finish my project; that is why this work is dedicated to him. I will always remember –and miss!- not only his great scientific level and intelligence, but also his wisdom.

Table of Contents

Abstract

The purpose of the present study was to investigate the three-dimensional kinetic and kinematic characteristics of the whole hand during precision grip.

Fifty asymptomatic adults produced maximal gripping force in five different wrist orientations: neutral, flexion, extension, radial and ulnar deviation. A custom-built grip strength measuring tool containing five six-component force transducers was used to measure the three dimensional loads applied on the hand, while three dimensional kinematic data were obtained concurrently with an eight-camera VICON motion analysis system.

The functionally neutral position of the wrist was experimentally defined as 36 degrees extension of the joint, coupled with a statistically different ulnar deviation between the genders. In that neutral wrist position, the subjects provided their maximal resultant gripping force and in a flexed position the minimal gripping force.

Female subjects showed statistically significant smaller radial deviation. This is the carpal position where the scaphoid is compressed, which indicates the possibility of different type of wrists between the genders.

Significant shear force components are produced during simple grip activities and these can generate large moments at the finger joints. These loads tend to ulnar deviate and internal rotate the metacarpophalangeal joints of all the fingers except the little finger, a characteristic deformation in rheumatoid arthritis.

Finally, statistical analysis revealed the importance of palmar interossei muscles in the finger flexion force generation, a fact not known in the literature.

CHAPTER 1: **Introduction**

1.1 Background

Most of the time, when someone comes across the word “hand” in the literature, they comprehend the hand and wrist complex, and that is not without a reason. The ability of the fingers to interact with an object, by any means, directly depends on the capacity of the wrist to support this interaction. The wrist joint, as will be shown later, always takes a position that not only services the precise placement of the fingers around an object, but also optimises the length of the engaged muscles and optimises their lever arms. Therefore, any study of the fingers without embracing the wrist joint does not represent how the hand functions as an “organ”, and this is the prism under which this work was constructed.

1.1.1 The Wrist

The reader can find a brief anatomy and kinesiology of the hand and wrist in Appendix A. The importance of wrist kinematics in force generation of the hand has been investigated by several authors since the work of Hazelton et al (1975), demonstrating a heterogeneous group with quite different methodologies. Some authors follow the strategy of wrist immobilization in specific angles to examine how this affects the strength generation of the fingers (Hazelton et al, 1975; Ohtsuki 1981), while others allowed the subjects to find their own comfortable wrist joint position during the experiment (Brumfield and Champoux, 1984; Amis, 1987; Ryu et al, 1991; O'Driscoll et al, 1992; Lamoreaux and Hoffer, 1995; Talasnia and Kozin, 1998; Li, 2002a; Li et al, 2005). Although both strategies provide useful scientific results, only the second one represents the functionality of the wrist and delivers clinical important knowledge. Rheumatologists, orthopaedic surgeons as well as ergonomics and rehabilitation scientists are particularly interested in the wrist kinematic envelope, inside which the hand can provide its maximal strength. From the research done in the field, most of them did not use modern equipment to deliver accurate results (Brumfield and Champoux, 1984; Amis, 1987; Ryu et al, 1991; O'Driscoll et al, 1992; Lamoreaux and Hoffer, 1995; Talasnia and Kozin, 1998) while others examined either the unloaded (free) hand (Li et al, 2005), or investigated just the fingers and they were not including the thumb (Li, 2002a). Furthermore, any possible differences between the genders have not been investigated. As a result, the contribution of the wrist position in the force generation of the hand is not clear in the literature.

In addition, there is discussion in the literature on how each individual carpal bone moves in respect to each other, and how this movement affects the aforementioned “macroscopic” wrist kinematics. Classical anatomists divide the wrist bones in two rows, the proximal and the distal one, proposing the well-known “row type wrist” theory. However, Navaro (1921) (cited by Taleisnik, 1976) suggested the “column type wrist”: according this theory, the wrist is divided in 3 columns, representing better the functionality of the joint. By the middle of 90s, Craigen and Stanley (1995) examined with X-rays a large number of subjects and after a sophisticated methodology reported that the types of wrist are normally distributed, with the column and row types at the two sides, and between these two extremes there was a spectrum of combinations of wrist joint types. Additionally, their work indicates that there is a difference in the wrist type between genders, with females to be in general more of the column type wrist. Furthermore, all the researchers agree that mainly the scaphoid kinematics is the factor which defines the wrist type.

Larson et al (1987) observed that normal individuals not only show substantial variations in carpal kinematics but also variations in range of motion. Based on these results and motivated by the work of Craigen and Stanley (1995), Garcia-Elias et al (1995) tried to correlate the type of wrist with the global wrist laxity, a clinical examination that uses four clinical trials originally defined by the rheumatologists to assess and understand the so-called “hyper-mobility-syndrome” (Bulbena et al, 1992). They found that scaphoid kinematics, and therefore the type of wrist, is significantly correlated with the global wrist laxity, fully verified the normal distribution of the wrist types and their gender dependency described by Craigen and Stanley (1995), and provided a simple clinical tool to define the wrist type.

But in contradiction with the above, researchers who used in the late 90s Craigen and Stanley's (1995) two dimensional X-ray technique and methodology, were not always able to share the same results: Nuttal et al (1998) verified them, but Ferris et al (2000) did not. Facing these discrepancies and understanding the source of the problems, the researchers focused the last decade on wrist stability and almost abandoned the wrist type investigation. They used the three dimensional imaging techniques (CT, MRI etc.) to investigate how each individual carpal bone moved in relation to each other on one hand (Foumani et al, 2009; Moritomo et al, 2004; Moojen et al, 2002; Wolfe et al, 2000), and the role of the wrist ligaments on the other (Kijima and Viegas, 2009; Mitsuyasu et al, 2004; Viegas et al, 1999). Although the researchers have described with accuracy the kinematics of each individual carpal bone, they did not assume any wrist type as a conclusion. Hence, after almost nine decades of research, the wrist type model and the concept remains under question.

As regards wrist kinetics, there has been considerable debate about how load is transmitted through the joint. Back in 1984, Palmer and Werner carried out some of the first cadaveric measurements; they used a load cell in order to investigate the load transfer ratio between the radius and ulna. Other authors performed cadaveric experiments using pressure-sensitive films placed at the articular surface of the carpal bones in order to measure the contact pressures (Viegas et al, 1987a; Viegas et al, 1987b; Tencer et al, 1988). The results from these cadaveric studies have shed light on how the wrist responds under loading, but concerns can be raised about the measuring procedures: cadaveric measurements are difficult to perform. The wrist is a very delicate joint and by performing an invasive measurement it is possible that the researcher could be perturbing the joint as the dissection is carried out. Additionally, after the specimen has been dissected and set up for the experimental work, it is not possible to perform the experiment again with modified parameters.

Due to the above limitations, several theoretical models of the wrist have been created to investigate the joint load characteristics (Schuind et al, 1995; Nedoma et al, 2003). These have been developed mostly by creating a rigid body spring model to calculate the force transmission and displacement between multiple non-deformable bodies using a series of springs with known stiffnesses. The geometry of the wrist makes such theoretical models difficult to create. Finite Element models of the wrist have been created, but most have focused on a particular subregion of the joint. The exception to this is the work of Carrigan et al, (2003), who developed a three dimensional finite element analysis of the carpus (without metacarpals). However, none of the aforementioned models used physiologically realistic loading systems; theoretical or arbitrary loads were applied, just because there are no three dimensional whole hand loading data provided by the literature to feed these models.

1.1.2 The Hand

The study of the fingers interacting with an object is a very demanding and complicated task. Apart from the influence the wrist position has on the force generation of the hand, as discussed above, the fingers can grasp an object in several different ways, and therefore, the relevant studies in the literature can be divided by the kind of grip. As regards the whole handgrips, the precision grip involves a pinching action between the fingers and the thumb, while power grip is defined as grasp with an object held in contact with the palm (Napier, 1956).

Both of the aforementioned power grips have been used to investigate the function of the hand, not without problems. In power grips, the loads are distributed, apart from the fingertips, also on the area of the palm, which is in contact with the object. The main experimental ways to measure these loads involve the use of either strain-gauged cantilever beams or pressure sensitive films. Nevertheless, authors agree that there are numerous difficulties in both cases. According to the literature, the significant drawback of the gauging arrangement on the cantilever beam is the dependence of accuracy on finger position (Amis, 1987; Jensen et al, 1991; Fransson and Winkel, 1991). In addition, the pressure sensitive film has the main drawback of not measuring the out of plane loads, and therefore the results cannot be considered as representative for the power grip function of the hand.

Although precision grip avoids the above difficulties, the literature is limited in the study of how the thumb interacts with one finger in common everyday activities (Chang et al, 2008; Bourbonnais et al, 2008; Lin et. al, 2010), or how the thumb interacts with all the fingers without studying the wrist kinematics (Zatsiorsky et al, 2002; Zatsiorsky et al, 2003), or finally, how the wrist position affects the force generation of each individual finger, without studying the hand (Li, 2002a). There is no evidence of whole hand kinetic and kinematic precision grip results involving high-end equipment.

1.2 The Aim of the Research

The research presented in this thesis aims to investigate the three dimensional biomechanics of the hand during a precision grip, involving all five fingers. The experiment required a large number of subjects to provide their maximal grip force in five wrist orientations: neutral, flexion, extension, radial and ulnar deviation. Three-dimensional kinetic and kinematic data were collected and analysed for every finger and the wrist, fulfilling the following list of objectives:

- To determine the wrist kinematic envelope inside which the hand can generate its maximal grip force, to investigate any differences between the genders and to draw the clinical importance of the results. Additionally, to conclude about any “pattern” of the wrist kinematics, which could lead on “type of wrist” results.

- To define the “functional neutral” wrist position and search for any potential differences between the genders.
- To investigate the wrist joint laxity scores and verify any relation with genders or wrist kinematics.
- To measure the resultant maximal grip force for every wrist orientation, in the transducer axis system, and to define any gender differences.
- To examine the contribution of the shear forces in the resultant maximal force, in the transducer axis system.
- To calculate the percentage distribution of the resultant maximal grip force across the fingertips in every wrist orientation, to compare the results with those from the literature, and to define any differences between the genders.
- To transfer the three-dimensional loads on the metacarpal axis system and calculate the external metacarpophalangeal loads for every wrist orientation. To analyse the results and search for their clinical relevance, as well as to provide the finite element modellers with accurate data to feed the wrist models.
- To use sophisticated data reduction statistical tools in order to define the most important variables, which describe at least eighty percent of the functionality of the hand.

1.3 Thesis Structure

This thesis consists of seven chapters and eleven appendices; appendices contain important information and the reader is advised to refer to them when required. Chapter 2 contains the literature review in the fields related with the present research, meaning the wrist kinematics and the work done in the whole handgrip experiments. The methodology of the current study is presented analytically in Chapter 3. In Chapter 4 and 5 the reader can find respectively the kinematic and the kinetic results. Chapter 6 consists of the Principal Component Analysis of the hand, a data reduction statistical procedure. Finally, the thesis concludes with Chapter 7, which contains the conclusions and underlines the most important observations made throughout the entire research. For better reading of the thesis, the discussion is contained within the results chapters: 4,5 and 6.

CHAPTER 2: **Review of the Literature**

2.1 Introduction

This chapter is divided in two main sections: first, the study of the kinematics of the wrist, and second the kinetics of the whole hand grip, sub-divided according their methodology.

2.2 Wrist Kinematics

2.2.1 Methods of Kinematic Measurement

2.2.1.1 Introduction

There are several methods of kinematic measurement used in hand and wrist studies. These methods compose a heterogeneous group, with different accuracy, invasiveness and cost. In the following text, the main devices and methods used in kinematic measurements are investigated through the literature as regards –between others- their reliability, validity, accuracy and precision.

In *reliability* studies the consistency, reproducibility and repeatability of a measurement procedure or an instrument is tested. In a hypothetical situation where an instrument is completely reliable, any variation in measurements reflects the actual variation in values (Portney and Watkins, 1993; Rothstein, 1985). *Validity*, on the other hand, is the capability of the instrument to measure what it is supposed to measure; then the valid data can be further described as precise or accurate (Rothstein, 1985). Precision and accuracy are different things according Sokal and Rohlf (1995): "*Accuracy* is the closeness of a measured or computed value, while *precision* is the closeness of repeated measurements of the same quantity to each other".

2.2.1.2 The Manual Goniometer

Back in the 70s, when electronic methods of measuring kinematics were not yet available in most of the researchers, the main ways to measure wrist angles were with the classic goniometer and the X-rays.

The manual goniometer is simple to use and cheap, but it has two disadvantages: it is not accurate (mainly due to visual inspection of the angle) and it is difficult to measure with it in situations where the position of the joint changes continually. Nussbaumer et al (2010) examined the validity and test-retest reliability of manual goniometers for measuring passive hip range of motion, by comparing their results with an electromagnetic tracking system. They concluded that, although manual goniometer results are quite accurate for clinical use, they considerably overestimate hip joint range of motion. Carter et al (2009) tested the accuracy and reliability of three different techniques for manual goniometry for wrist motion in cadavers. They found that radial and ulnar deviation measurement was less accurate than those of flexion-extension, although both can be used for clinical assessment. The interrater and intrarater reliability of finger goniometric measurements was investigated by Lewis et al (2010). They used a common manual goniometer and concluded that significant differences existed between raters for metacarpophalangeal, proximal interphalangeal and distal interphalangeal active finger range of motion (ROM) measurements and for metacarpophalangeal and proximal interphalangeal passive range of motion.

Apart from the accuracy of the specific method of angle measurement, it seems that the plethora of manual goniometers available in the market raises issues about the possible error generated from the different devices. Loder et al (2007) investigated the angular measurement error due to different measuring devices by testing three articulated and four fixed goniometers, and found significant differences between them. They also suggested that the clinicians should use the same goniometer at all times and this is important when faced with the question of a change in an angular measurement being a true change or simply a reflection of measurement error.

Furthermore, the fact that the manual goniometer cannot measure dynamic joint angle changes forced the researchers to stabilize the wrist in predefined angles measured as carefully as possible with a classic goniometer, and run afterwards their kinetic experiments in these positions, like in the studies of Hazelton et al (1975), Ohtsuki (1981), and Mathiowetz et al (1984).

2.2.1.3 X-rays

X-rays have been used in many studies, mainly in order to define how the carpal bones move in respect to each other (Savelberg et al, 1993; Craigen & Stanley 1995; Garcia-Elias et al, 1995; Kobayashi et al, 1997; Nuttall et al, 1998; Ferris et al, 2000). Although X-ray pictures are extremely accurate and relatively cheap, the procedure to define the angles relies on the lines drawn on them and the use of a classic goniometer. Additionally, it is an invasive technique and kinematic results cannot be taken for the same joint position in more than two dimensions concurrently. Modern technology allowed the coupling of X-rays and charged-couple device (CCD) video cameras, the well-known fluoroscopy. In the hand and wrist field, there are just a few papers examining the carpal bone kinematics with this method (Carelsen et al, 2009; Galley et al, 2007; Wolfe et al, 1997b; Ambrose and Posner, 1992), but this technique never became popular due to the risk of the long-time exposure of the subjects to X-rays.

2.2.1.4 Computer Tomography and Magnetic Resonance Imaging

In the last decade, many researchers have used modern technology, like Computer Tomography (CT), to acquire data about carpal bone kinematics (Wolfe et al, 1997a; Patterson et al, 1998; Feipel and Rooze, 1999; Sun et al, 2000; Wolfe et al, 2000; Moojen et al, 2002; Moore et al, 2007; Foumani et al, 2009). CT has the advantage of using software to construct from the tomographies a three dimensional image of the carpal bones and define with accuracy how they move in relation to each other. However, CT is relatively expensive, invasive and cannot be used in a clinical environment or a laboratory.

Magnetic Resonance Imaging (MRI) has also been used for the investigation of the complete carpal bone kinematics (Goto et al, 2005), the midcarpal joints (Moritomo et al, 2004; Moritomo et al, 2006) and the triquetrum-hamate joint (Moritomo et al, 2003). The main difference between MRI and CT, as regards the images, is that the former can also capture the soft tissue volume and therefore, as it is extremely expensive, has been mainly used for the investigation of the wrist ligaments (Moritomo et al, 2008) and the carpal tunnel (Bower et al, 2006). It is considered as extremely accurate non-invasive technique but, as with CT, it is static and cannot be used in a clinical environment or a laboratory.

2.2.1.5 Electrogoniometer

Because of the above, there was a need for a cheap, accurate and non-invasive electronic device to measure joint angles by clinicians and researchers. The first published paper regarding the electrogoniometry goes back in the middle 60s (Thomas and Long, 1964), but the electrogoniometer devices were not broadly available before the middle 80s. In 1978, Chao and Hoffman tested a triaxial electrogoniometer instrumented by three miniature precision potentiometers to evaluate the functionality of the patients with abnormal hip, knee and ankle joints as well as lower extremity amputees fitted with artificial limbs (Chao and Hoffman, 1978), and two years later, Chao et al (1980) constructed a similar device to measure the human elbow rotation. Those days, electrogoniometers were using potentiometers to calculate the joint angles and they were not flexible, but it was a revolutionary procedure compared with the manual and static goniometers or the invasive X-rays. By the late 80s the electrogoniometers became computer assisted and many joints started to be studied simultaneously, like in gait (Isacson and Brostrom, 1988).

The first research on the hand kinematics with the use of electrogoniometer goes back in 1984 and regards the normal functional wrist motion (Brumfield and Champoux, 1984). The same joint was investigated with the same equipment in several studies afterwards (Palmer et al, 1985; Mann et al, 1989; Romdhane et al, 1990; Ryu et al, 1991), as well as the complete kinematics of the upper extremity in everyday activities (Safaee-Rad et al, 1990). Nonetheless, there is no study regarding the accuracy, validity and reliability of the potentiometer-instrumented electrogoniometer. These types of electrogoniometers were somewhat bulky and were restricting patient movement. The instrument's precision could also be compromised due to its inability to follow any changes in the joint's axis of rotation.

By the beginning of 90s a strain-gauged electrogoniometer was available, also known as flexible electrogoniometer. Its strain gauge is a flexible spring with plastic end blocks on each end. The strain gauge mechanism is housed inside the spring, and changes its electrical resistance proportionally to the change in angle between the plastic end blocks' longitudinal axes. Strain gauged electrogoniometers are portable, lightweight, easily applied, adapt well to different body segments and do not restrict movements or interfere in patient activities.

Ojima et al (1992) were the first researchers to use the flexible electrogoniometer in the upper extremity in order to investigate the ranges of dynamic motion of the wrist. In the middle 90s this device was the most popular goniometry equipment (Carey et al, 1994; Barker et al, 1996; Hansson et al, 1996; Rawes et al, 1996; Buchholz and Wellman, 1997; Marshall et al, 1999; Salvia et al, 2000) and it is still, especially for simple clinical or laboratory experiments (Fagarasanu et al, 2004; Gustaffson et al, 2010; Wang et al, 2011).

Nevertheless, electrogoniometers are prone to errors. According the literature, a major source of error with the most widely used electrogoniometers is “crosstalk” (Buchholz and Wellman, 1997; Hansson et al, 1996). Crosstalk occurs when a movement in one anatomical plane (e.g. radial/ulnar deviation of the wrist) generates a false signal in the other anatomical plane (e.g. flexion/extension). Crosstalk can occur from two major sources. First, when the strain gauges inside the electrogoniometer are twisted with respect to the movement planes of the joint (Buchholz and Wellman, 1997); this is characterised as “intrinsic crosstalk”, and it is associated with the design of the goniometer transducer. Second, when the transducer of the goniometer is not located over the joint centres (Moore et al, 1993) and it is characterised as “extrinsic crosstalk”, associated with the anatomy and complex movement of the joint.

Christensen (1999) tested the precision and accuracy of an electrogoniometer and found that the device had a very high precision, its accuracy, however, was less than acceptable (up to 11.5% away from the present value). Jonsson and Johnson (2001) compared the measurement accuracy between two types of wrist goniometer systems: a biaxial single transducer and a biaxial two-transducer. They concluded that the single transducer goniometer had larger measurement errors and was more prone to crosstalk, and specifically intrinsic crosstalk. Additionally, they reported that the calibration procedures as well as slight, almost undetectable movements during calibration could substantially affect the offsets of both the electrogoniometers.

Hansson et al (2004) investigated the electrogoniometer crosstalk in five work tasks involving wrist and forearm positions and movements. They found that, although the error was in general small, in some combined movements of wrist and forearm the error could not be neglected. Jonnson et al (2007) examined the accuracy and feasibility of using an electrogoniometer for measuring simple thumb movements and reported an error of almost 4 degrees in maximal adduction/abduction of the thumb and almost 5 degrees in maximal flexion/extension. This accuracy is generally accepted for clinical use of the device but it is probably not acceptable for research purposes. That is the reason why Bronner et al (2010) suggest the use of electrogoniometer only when motion capture is unavailable.

In summary, the recent flexible electrogoniometers are valuable for clinical use, where the crosstalk error is acceptable for this purpose range. However, in order to run an experiment, which needs precise, accurate and reliable results, like in this study, electrogoniometer is not the device of choice. Furthermore, it would be nearly impossible to measure with electrogoniometers, concurrently and in three dimensions, the fifteen joints involved in the hand/wrist complex.

2.2.1.6 The motion capture systems

2.2.1.6.1 Historical background

The first attempt to record the human motion was via photography, with the legendary work of Eadweard Muybridge back in the 19th Century. In this monumental work, 318 different human tasks were presented in 4789 photographs. Taken at speeds ranging up to 1/6000th of a second, these photographs show bone and muscle positions against ruled backgrounds (Muybridge, 1955). Almost all subjects were undraped, and all actions were shown from three angles: front, rear, and three-quarter view. Therefore, this work is considered as the first human motion analysis.

2.2.1.6.2 Stereophotogrammetry

Introduction

Since the aforementioned work of Eadweard Muybridge, photogrammetry has been developed as a photography-oriented science, and is nowadays under continuous development with the aid of pattern recognition and artificial intelligence techniques. Stereophotogrammetric methods are used to reconstruct three-dimensional landmark coordinates from photographs (Greaves, 1995), radiographs (Selvik et al, 1983; Huiskes et al, 1985) and video images (Stevens, 1997).

Video images have several potential advantages over the other techniques in terms cost, potential image distortion of the development process and time consumption, so that video-based optoelectronic systems are nowadays the most popular in movement analysis (Chiari et al, 2005). These systems are used to track the three-dimensional position of a set of fiducial points, constituted from either retroreflective (passive) or light-emitting (active) markers, with the aid of a system of charged-couple device (CCD) cameras. Then, analytical photogrammetry allows the estimation of three-dimensional position data from digitised image data, using the geometrical properties of central projection from multi-camera observations.

Retroreflective passive markers are used together with infrared stroboscopic illumination produced by an array of light-emitting diodes mounted around the lens of each camera. Recognition of passive markers in the video frames can be performed either via dedicated hardware circuits, or by pattern recognition software (Taylor et al, 1982). Conversely, active markers are pulsed sequentially, so the system can detect automatically each marker by virtue of the pulse timing. The three-dimensional coordinates of each marker are finally computed by using the two-dimensional data from two or more cameras. More information regarding the principles underlying marker detection and identification can be found in the work of Medved (2001). It is important to be said here that, although optical sensing is one of the most convenient methods of human locomotion measurement, it has drawbacks due to marker visibility constraints. These drawbacks are practically overcome by using multiple cameras. In fact, for the three-dimensional coordinates reconstruction, each marker must be seen simultaneously by at least two cameras, but in practice more than two are recommended, since markers can become obscured from camera views because of walking aids, subject rotation, arm swinging, etc.

Background Theory and Procedure

The instantaneous positions of markers located on the skin surface are acquired using stereophotogrammetry (motion capture) either based on controversial photography or optoelectronic sensors. These markers are located on specific, predefined bony landmarks and aid in the construction of an anthropomorphic model in order to estimate the kinematic quantities that are not directly observable. This model consists of kinematic chain of links, where each link represents a portion of the human body referred to as a body segment. These segments are made of a bony part and soft tissue. Bony segments are considered non-deformable and, therefore, are represented using rigid bodies, according to classical mechanics. No author has disputed this choice so far, or assessed the inaccuracy that it may introduce in the analysis.

Afterwards, joints with their degrees of freedom connect bony segments. The number of bony segments and constraints imposed by the joints contribute to the number of degrees of freedom of the model and its structural accuracy to reality. Soft tissue around the bony segment may, or may not be considered deformable, although most of the literature chooses the latter option, that is, the entire body segment is regarded as a rigid body. In this case, analysis is straightforward and classical mechanics can solve any related problem. The reader can find more details in this three dimensional kinematics computation in the very informative review paper of Cappozzo et al, 2005.

Accuracy of the Photogrammetric Systems

Several sources of inaccuracy affect photogrammetric measurements, resulting in an error on marker coordinates. As regards instrumental errors, these are of two types: a) systematic and b) random. Systematic errors are in any case associated with a model of the measurement system of limited validity, due to photogrammetric calibration inaccuracies. Random errors may be due to electronic noise, marker flickering, i.e. the imprecision with which marker images are converted into image points, the digitising process itself that transforms marker image coordinates into their numerical values, and marker imaged shape distortion which can result from velocity effects, partially obscured marker images, merging of markers with each other or with phantom signals (Chiari et al, 2005). Nowadays, systematic errors are considered small, due to the improved and standarised calibration procedures used on the optoelectronic systems; random errors can be managed in most of the cases with improved software techniques. Detailed information about the progress done and future tasks in this field the reader can find in the Chiari et al (2005) work. However, there are two other types of errors that even nowadays can generate non-affordable errors if they are not considered carefully by the researchers: a) the soft tissue artifact and b) the anatomical landmark misplacement.

In optoelectronic stereophotogrammetry, the markers are associated with the underline bone in a procedure where, by seeing the marker coordinates to interpret the position of the underline bone (bony segment) in three-dimensions. However, skin deformation and displacement causes marker movement with respect to the underlying bone. This movement represents an artifact (the well-known Soft Tissue Artifact- STA), which affects the estimation of the skeletal system kinematics, and is regarded as the most critical source of error in human movement analysis. STA magnitude has been assessed in several studies, with techniques based a) on intra-cortical pins and X-ray fluoroscopy (Reinschmidt et al, 1997a; Reinschmidt et al, 1997b; Houck et al, 2004), b) on external fixators and X-ray fluoroscopy (Cappozzo et al, 1996), c) on percutaneous trackers (Manal et al, 2000; Manal et al, 2002) and finally d) on Roentgen photogrammetry (Tranberg and Karlsson, 1998). The results from the previous studies can be drawn in the following conclusions: a) errors from the STA are much larger than stereophotogrammetric errors; b) the pattern of the artifact is task depended; c) the STA associated with the thigh is greater than any other lower limb segment. Several techniques have been proposed and used successfully in order to eliminate the errors from the STAs, a review of which the reader can find in the paper of Leardini et al, 2005.

The last source of error is the anatomical landmark misplacement, by means of precision in determining the location of both palpable and internal anatomical landmarks. As regards the palpable anatomical landmarks, a considerable amount of research has been done in especially the lower extremities (Piazza and Cavanagh, 2000; Rabuffetti et al, 2002). These studies have provided the biomechanics audience with the most accurate palpable anatomical landmarks of the lower extremities to use in biomechanical modelling and optoelectronic stereophotogrammetric kinematic analysis in general.

Those anatomical landmarks not representing palpable bony prominences are referred to as “internal”. Among the internal anatomical landmarks, the calculation of the geometric centres of the joints are those that have attracted the interest of the researchers, and a review of the work done in the field can be found in the work of Della Croce et al (2005). In general, there is no technique better than the other, as regards the geometric joint centre calculation, and it is well known that all the papers published in the field of kinematic analysis with stereophotogrammetric methods are based more or less on assumptions and carry this error.

As said previously, most of the work done in the field of stereophotogrammetry regards the lower extremities and especially gait. Lower extremities have large bones, large muscles and therefore are probably more prone to errors relative to STAs than that of the upper extremities. The feasibility of using surface markers and stereophotogrammetry for measuring thumb kinematics (Kuo et al, 2002) and assessing the motion of the thumb trapeziometacarpal joint (Kuo et al, 2003) has been examined by using fluoroscopy. In both cases, researchers found very small errors and concluded that the application of a video-based motion analysis system with surface markers to thumb kinematics is warranted. These two studies show that the hand is probably an ideal part of the body to be studied with this method, since there is less STAs than that in the lower extremities and therefore minimum errors related to them.

2.2.1.7 Comparison of the Kinematic Measurement Methods

In the following table the main pros and cons of each method of the kinematic measurement described above is summarized.

	Cost	**Invasive**	**3-D**	**Accuracy**	**Dynamic capture**	**Lab-usability**
Manual goniometer	Low	No	No	Small	No	Yes
X-rays	Low	Yes	No	High	No	No
Fluoroscopy	High	Yes	Yes	Very high	Yes	No
CT	High	Yes	Yes	Very high	No	No
MRI	Very high	No	Yes	Extremely high	No	No
Electrogoniometer	Low	No	Yes	high	Yes	Yes
Stereophotogrammetry	Low	No	Yes	Very high*	Yes	Yes

*with the use of the appropriate software

2.2.2 Wrist Range of Motion

The movements that take place in the wrist joint (Appendix A2.4) are flexion-extension (FEM) and radial-ulnar deviation (RUD), in the sagittal plane and the coronal plane respectively. The range of motion of the wrist is affected by gender and race (Gunal et al, 1996), as well as by cultural differences (Ahlberg et al, 1988). Gunal et al (1996) measured 1000 male subjects and found a statistically significant difference in the range of motion of the wrist between the left and the right side. Due to these variations, there is a wide range of published results for wrist joint range of motion, i.e. in flexion-extension: 95° (Youm et al, 1978), 112° (Ruby et al, 1988), 121.9° (Sarrafian et al, 1977), 124.5° (Ferris et al, 2000) and 150° (Linscheid, 1986).

In contrast with the maximal range of motion of the wrist, it is the functionality of the joint during everyday activities that is of clinical importance, and a series of studies have been conducted in the field. Brumfield and Champoux (1984) used a uniaxial electrogoniometer to determine the range of wrist motion required to accomplish 15 activities of daily living. They found that activities for personal care requiring placing the hand at various locations on the body were accomplished by motion of 10 degrees of flexion to 15 degrees of extension. Other necessary activities, such as eating, drinking, reading and using a telephone, were accomplished by motion of 5 degrees of flexion to 35 degrees of extension. Therefore, they concluded that the optimum functional motion for the wrist to accomplish most activities is from 10 degrees of flexion to 35 degrees of extension.

A triaxial electrogoniometer was used by Palmer et al (1985) in order to measure functional wrist motion in 10 normal subjects who performed 52 standardized tasks. They found that the normal functional range of wrist motion was 5 degrees of flexion, 30 degrees of extension, 10 degrees of radial deviation, and 15 degrees of ulnar deviation. Ryu et al (1991) examined 40 normal subjects with a biaxial electrogoniometer and found that during everyday activities, the majority of hand placement and range of motion could be accomplished with 70 per cent of the maximal range of wrist motion. That is 40° of both flexion and extension and 40° of combined radial-ulnar deviation. The entire battery of evaluated tasks could be achieved with 60 degrees of extension, 54 degrees of flexion, 40 degrees of ulnar deviation, and 17 degrees of radial deviation, which reflects the maximum wrist motion required for daily activities. Additionally, Safaee-Rad et al (1990) used triaxial electrogoniometers and reported that for feeding tasks the required range of motion is from 10° wrist flexion to 25° wrist extension and from 20° ulnar deviation to 5° radial deviation.

The discrepancy in the above results may be for several reasons. First, all the aforementioned authors used a potentiometer electrogoniometer, the accuracy of which was never measured and published in the literature. Second, the wrist range of motion seems to be related with other important variables and mainly with the way that the carpal bones move in relation to each other. The scientific community suspected that this carpal bones movements may be different between the individuals and started examining them thoroughly.

2.2.3 How the individual carpal bones move: Row-Column theories

There are two main theories, which attempt to explain how the individual carpal bones move. The classical anatomists divided the wrist into two rows with the scaphoid treated as a bridge between them. The proximal row consisted of the triquetrum, lunate and the proximal scaphoid pole, and the distal row consisted of the hamate, capitate, trapezium, trapezoid and the distal pole of the scaphoid (Appendix A2.2). According to this 'row type' theory, flexion and extension occurs at the midcarpal joint and radial-ulnar deviation at the joint between the scaphoid and the distal radius (Figure 2.1).

The column theory was originally proposed by Navaro in 1921. Navaro suggested that the wrist was made up of three columns. The central column consisted of the lunate, capitate and hamate and it was the place where flexion and extension occurred. The lateral column consisted of the scaphoid, trapezium and trapezoid. Finally, the medial column was formed by the triquetrum and pisiform (Taleisnik, 1976).

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Figure 2.1: *The row (left) and column type wrist (right)*

Taleisnik (1976), agreed with this ‘column type’ theory, but suggested that the whole distal row acted as a single unit with the lunate, building the central column. Thus, the lateral column was defined by the scaphoid and the medial column as the triquetrum. According to the Taleisnik theory, the central column controlled flexion and extension and radioulnar deviation occurred with rotation of the scaphoid and triquetrum about the central column.

Craigen and Stanley (1995) claimed that the major disadvantage of each of the afore-mentioned studies was the small number of wrists examined. In order to investigate the kinematic behaviour of the normal wrist they took radiographs of 52 subjects in radial and ulnar deviation. The distance from the proximal and ulnar point on the scaphoid to the central crest on the distal pole was measured (Figure 2.2). The value obtained in the radial deviation was divided by the value in ulnar deviation in order to normalize it.

The values of this ratio of the length in radial deviation and ulnar deviation (RD/UD), or *CR index*, appeared to follow an approximated normal distribution, with a mean of 0.81 and SD of 0.1. A perfect row type wrist would have a *CR index*=1, while a column type wrist would have a *CR index* of approximately 0.5. Between these two extremes, there was a spectrum of combinations of wrist joint type (Craigen and Stanley, 1995).

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Figure 2.2: *The measurement of the scaphoid length in radial (left) and ulnar (right) deviation of the wrist (from Craigen and Stanley, 1995).*

In the same key study, the authors also measured a value named *translation ratio*: a vertical line was drawn from the radial styloid to the most ulnar point on the scaphoid and the distance measured between them in radial and ulnar deviation (Figure 2.3). The difference between the two values was divided by the length of the scaphoid in ulnar deviation to normalize the final value.

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Figure 2.3: *Measurement of the "translation ratio" of the scaphoid (From Craigen and Stanley, 1995).*

The scaphoid translation ratio also approximated to a normal distribution with mean of 0.26 and SD 0.09. Regression analysis showed a significant relationship between the CR index and translation ratio; the more the scaphoid shortened, the less it translated and vice versa. No statistical difference was evident between the right and left wrists, but the female subjects had a significantly lower CR index and translation ratio, which indicates that women were generally of the column type wrist (Craigen and Stanley, 1995).

Most of the results of the above study were confirmed by the paper of Nuttall et al (1998). Using the same methods, the authors examined 30 normal wrists and found a spectrum of movements of the scaphoid in the two planes. They conclude that the scaphoid can flex, translate or supinate on the radius, but commonly moves by combination of two or these during radio-ulnar deviation. Furthermore, although CR index can determine the type of wrist, the correlation is not clear for values above 0.8, for reasons that were uncertain. There did not appear to be gender or age related differences in any of the calculated values.

Ferris et al (2000) examined 34 normal wrist joints by using a radiographic technique combined with the methods described in the Craigen and Stanley (1995) paper. The authors were unable to find any correlation between the CR index and the translation ratio. Comparing the two studies; although the correlation between the CR index and the translation ratio in Craigen and Stanley (1995) is not strong (r=0.498), there were more subjects than in the study of Ferris et al. Thus, no conclusions could yet be drawn about the existence of a 'row-column' wrist type model and the concept remains under question.

Meanwhile, the idea of a clinical method, instead of the use of invasive X-rays, that would be possibly used to distinct the type of the wrist in the population had arose with the work of Garcia-Elias et al (1995).

2.2.4 Wrist joint laxity and scaphoid kinematics

Wrist joint laxity was previously investigated by rheumatologists in order to assess and understand the so-called ‘hyper-mobility syndrome’ (Bulbena et al, 1992). Garcia-Elias et al (1995) used the 4 clinical trials originally defined by the rheumatologists to investigate any correlation between the wrist joint laxity and scaphoid movement patterns. The basis for the study was the previously published observation that normal individuals not only show substantial variations in carpal kinematics but also variations in range of motion (Larsson et al, 1987).

The four clinical manoeuvres described by Garcia-Elias et al (1995) were as follows: with the wrist and thumb in maximum passive extension and radial deviation, the shortest distance (D1, Fig 2.4a) in millimetres between the centre of the thumb and the radius was measured. With the wrist flexed and the thumb passively approximated toward the palmar aspect of the forearm, the shortest distance (D2) between the centre of the thumb nail and the longitudinal axis of the radius was measured (Figure 2.4a).

Maximum passive wrist flexion was measured using a standard clinical goniometer, taking as references the dorsum of the forearm and the distal aspect of the third metacarpal (Figure 2.4b). Maximum passive wrist extension (D4) was measured, using as references the midline of the palm and the palmar aspect of the forearm (Figure 2.4b). In order to compensate for individual variations in shape of the hand, the two distance measurements (D1 and D2) were normalized by the length of the third metacarpal.

Based on these determinations, a scoring system was devised according to which each individual was given a number of points, from 0 to 25, for each of the four parameters, for each hand. These were calculated proportionally to a scale in which the person with the shortest D1 or D2 or the smallest D3 or D4 was given 25 points, while the person with the longest D1 or D2, or the largest D3 or D4 was given 0 points. The summation of the four measurements was interpreted as representing the amount of global laxity of each wrist (Garcia-Elias et al, 1995).

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Figure 2.4: *The wrist joint laxity measurement protocol (from Garcia-Elias et al, 1995).*

Garcia-Elias et al (1995) found that scaphoid kinematics showed a significant correlation with the global wrist laxity. During RUD motion the scaphoid of very lax wrists move preferentially in flexion-extension while in the less mobile wrists, the scaphoid moves preferentially in radio-ulnar deviation. They also found a spectrum of normal carpal bone motion, from a true 'column' wrist, (with flexion of the scaphoid without translation), to a 'row' wrist (with little or no scaphoid flexion), as Craigen and Stanley published in their paper. Additionally, they claimed a significant difference in global wrist laxity between genders, with women showing higher global mobility than men (male: 48.5 ±15, female 56.7±15; p=0.045).

Garcia-Elias et al (1995) indicate the existence of a specific pattern of carpal kinematics for more lax wrists, which is different from the pattern observed in tighter wrist joints. The authors concluded that in lax individuals, the scaphoid appears to be less tightly bound to the distal carpal row. That allows greater rotation in the sagittal plane (flexion-extension), requiring less lateral deviation to achieve maximal wrist RUD. The opposite is true for individuals with 'tighter' wrist joints. The whole proximal carpal row must deviate more laterally in order to compensate for the lack of scaphoid flexion-extension. There is an assumption that the less constrained the scaphoid is in the sagittal plane, the higher the incidence of periscaphoid ligamentous injuries will be. Thus, the authors suggest that this may be one reason why lax wrists are so frequently symptomatic if overloaded, because they have relatively more vulnerable carpal kinematics.

In conclusion, lax wrists not only appear to be more mobile but also more vulnerable to overwork or injury than the normal wrists (Acasuso et al, 1993; Garcia-Elias et al, 1995). Additionally, wrist laxity seems to be directly related to the type of wrist, as described by Craigen and Stanley (Garcia-Elias et al, 1995). The studies that confirmed the existence of the spectrum of wrist type are two-dimensional (Craigen and Stanley, 1995; Garcia-Elias et al, 1995; Nuttall et al, 1998) and need verification using three-dimensional methods. Furthermore, female individuals in general appear to have greater joint laxity (Garcia-Elias et al, 1995), as well as being of column type wrist (Craigen and Stanley, 1995). If this is correct, then women must have the majority of wrist joint injuries; an interesting hypothesis which requires further investigation.

2.2.5 Carpal bone kinematics

The aforementioned investigations of normal wrist kinematics mainly used planar radiographs to study both cadaver specimens and living subjects (Kauer, 1986). Later investigators, recognizing the limitations of planar radiographs, used various other methods to analyze the three-dimensional (3D) properties of wrist kinematics: cineradiography, sonic digitizers, stereoscopic radiographs and computer imaging.

One of the first issues examined with the available 3D methods was the contribution of the radiocarpal and midcarpal joints to the total arc of the wrist motion. This has been a controversial issue since the work of Sarrafian et al (1977), who used X-rays to investigate maximal flexion and extension trials, and found that the contribution in the maximum flexion was 40% radiocarpal and 60% mid-carpal, while in maximum extension was 66.5% radiocarpal and 33.5% midcarpal. Using a high-speed video data acquisition technique, Patterson et al (1998), concluded exactly the opposite: during global wrist motion, the radiocarpal joint contributes more motion in flexion than the midcarpal joint and the midcarpal joint contributes more motion in extension than the radiocarpal joint. Wolfe et al (1997a) examined the contribution of midcarpal and radiocarpal joints to the total arc of wrist motion by using CT. They concluded that normal wrist movement occurred equally at the midcarpal and radiocarpal joints, while Sun et al (2000), using ultrafast CT, found that the contribution of the radiocarpal joint was equal to that of the midcarpal joint during flexion, but during extension, there was a greater contribution from the midcarpal joint. Specifically, between 30 and 70 degrees of volar flexion 45-50% of wrist flexion occurred at the midcarpal joint whereas between 30-80 degrees of wrist extension, 54-61% of wrist extension occurred at the midcarpal joint.

According to Kobayashi et al (1997), one source of controversy stems from the confusion regarding which regions of the radiocarpal and midcarpal joints are to be compared. Kobayashi et al demonstrated that the contribution of the radiocarpal joint to global wrist motion is different depending on which of the radiocarpal relationships is used as the reference (radioscaphoid or radiolunate). Similar discrepancies were evident comparing scaphocapitate and lunocapitate joint contributions to midcarpal joint motion. Using radiolunate and capitolunate motions for radiocarpal and midcarpal contributions, and biplanar radiographic method, Kobayashi et al found that extension of the wrist was almost equally divided between the radiolunate and lunocapitate joints and in flexion the contribution of the lunocapitate joint was larger than that of the radiolunate joint. Finally, in radial-ulnar deviation of the wrist, ulnar deviation was equally divided between the radiolunate and lunocapitate joint and radial deviation occurred mainly in the lunocapitate joint as far as the primary rotation is concerned (Kobayashi et al, 1997).

Wolfe et al (2000) used computer tomography to investigate in vivo the kinematics of scaphoid, lunate and capitate in flexion and extension, and found that the scaphoid contributed 73% of capitate motion and the lunate contributed 46%, while in extension the contribution was 99% and 68% respectively. He concluded that in extension the scaphoid, capitate and lunate are relatively “engaged” and found no differences between the genders. Moojen et al (2002), in a key in vivo study, used computer tomography to investigate the kinematics of all the carpal bones, in eleven subjects in radial-ulnar deviation and in five of them also in flexion extension. They found that there is more than one kinematic pattern for the scaphoid. Recent studies have found similar results (Foumani et al, 2009; Moritomo et al, 2004) verifying the important conclusions of Moojen et al (2002) regarding the scaphoid kinematics.

These results in the carpal bone kinematics, and especially the many patterns of scaphoid kinematics, have made the researchers to doubt about any wrist type theory, or to admit that may be more than two. In any case, no conclusions have been drawn in the field, and the authors prefer to leave the issue in uncertainty.

2.3 The Metacarpophalangeal Joint Kinematics

There is little evidences in the literature regarding the kinematics of the metacarpophalangeal joints and most of them concern dynamic activities. Fowler and Nicol (2001) used a glove instrumented with flexible goniometers to monitor MCP joint usage in patients with rheumatoid arthritis. The same year, Speirs et al (2001) proposed a three-dimensional method of measuring the metacarpophalageal joint kinematics with retroreflective markers, and four years later Degeorges et al (2005) used retroreflective markers and an optoelectronic device to investigate the rotations of human three-joint fingers. Since then, there are only two papers in the field, investigating the angular patterns of the MCP joints during a grip of everyday objects (Bazański, 2010) and piano playing (Furuya et al, 2011), and the reader should refer to them for further information.

2.4 Hand and Wrist Kinetics

2.4.1 Introduction

The study of the kinetics of the hand is a demanding task, mainly due to the number of the joints involved, the multivariate positions the fingers may take and the numerous tasks the hand is called upon to perform. Under this high biomechanical complexity, some limitations must be imposed in order to study the hand adequately.

The functions of the hand are divided according Napier (1956) into prehensile and non-prehensile movements. The term prehensile is used to define any activity which involves grip of an object or objects, whereas non-prehensile movement refers to other activities not using counter pressure between the fingers, i.e. pushing an object. Prehensile grip is further divided into precision grip and power grip. Precision grip involves a pinching action between the thumb and one or more fingers. Power grip is defined as grasp where the object is held generally in contact with the palm and encircled by thumb and fingers.

It is the study of the hand kinetics in precision grip (due to the design of the gripping tool used in this experiment) that this work is concerned with.

2.4.2 Methods of Force Measurement

Analysis of the force distribution across the fingers is necessary for the resolution of moments at the wrist as well as at the metacarpophalangeal joints. Resolution of muscle-tendon and ligament forces and the calculation of the joint reaction force depend on the ability to define the external moments at the joint to feed the equilibrium equations. The external forces and moments are best calculated by the measurement of the force and moments produced by the digits as well as the co-ordinate positions of both the point of action of the forces and the centre of rotation of the joint.

Several methods are available and have been used and described in the literature for the measurement of the forces with varying degrees of accuracy. A rubber ball connected to a mercury sphygmomanometer was used by Wright (1959) in one of the first described methods, but with the disadvantage of measuring only pressure. Dickson et al (1972) were one of the first who tried to measure forces at the individual digits with their "digital cybernometer". This was a cantilever beam attached at the free end of a clock gauge, and it was used to assess finger flexion force and pinch grip.

Hazelton et al (1975) studied the influence of wrist position on the force produced by the finger flexors. Isolated finger flexion was measured using an assembly containing strain gauged proving rings which were attached, via straps, to each finger (Figure 2.5). Forces applied to the proving rings caused their distortion, creating changes in the electrical resistance of the strain gauges. Ohtsuki (1981) used similar apparatus to examine the inhibition of individual fingers during grip strength exertion. In this study, the wrist and forearm were constrained by a plaster cast and simultaneous electromyographic activity of the finger flexor muscles was determined.

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Figure 2.5: *The apparatus used by Hazelton et al, 1975.*

Amis (1987) describes apparatus for the simultaneous measurement of both normal and shear forces imposed by each of the three phalangeal segments of a finger during gripping actions. Three strain gauged cantilevered beams were mounted inside a cylinder. A slot in the cylinder exposed the beams as individual pads for each finger segment. Finger force variation with a range of cylinder diameters was investigated. According to the literature, the significant drawback of the gauging arrangements is the dependence of accuracy on finger position. In this type of transducer, the error is linearly proportional to the deviation of centre of pressure of the finger from the point of calibration.

Interposition of sensors between the finger and grasped surface allows the instrumentation of more difficult objects and tools. This method of force measurement has been done using three methods described in the literature. In the first one, an interdigitated flat wire layer is separated from a conductive polymer by a spacer. Applied pressure causes reduction in electrical resistance, which may be picked up by a bridge circuit (Jensen et al, 1991). The calibration curves of this sensor are non-linear and show large hysteresis, probably due to the viscoelastic behaviour of the polymer.

Small conductive polymer force sensors have been developed by Radwin et al (1991,1992) to measure individual finger forces during controlled lifting and pinching tasks (Figure 2.6). The sensors were taped to the distal phalangeal pads of each finger and calibrated on the hand by pinching a strain gauge dynamometer. The useful range of the sensors was between 0 and 30 N, with an accuracy of 1N for both static loading and normal dynamic grasping activities.

The second interposition type is a piezoresistive sensor or load cell, which generates a potential difference on loading. This has been used by Fransson and Winkel (1991) for the assessment of finger strength in pliers grip. According to the authors, although sensitivity is good with a resolution of about 0.5N for finger sensors, their large size and fragility limit their usefulness. In another two-dimensional study, Rempel et al (1994) used piezoelectric loadcells to measure fingertip loading during keyboard use. The loadcell, incorporated into a standard computer keyboard, was used to record contact force between the fingertip and key. Fingertip motion during the key strike was measured with a video motion analysis system.

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Figure 2.6: *Radwin et al (1992) experimental apparatus*

The last one used is a pressure sensitive film. Pressure causes a permanent change in colour of the film, and variation in colour across the spectrum is pressure dependent. This generates a picture of maximum pressure only and as such is a static measurement with limited use. Pressure sensitive film combined with ball mats were employed by Lee and Rim (1991) in a study of maximal finger forces during cylinder grip activities. Finger joint angles were measured concurrently with multi-camera photogrammetry.

The above research studies were the first attempts to discover a way of accurate measurements of hand grip strength, with limited success though. However, during the last decade, very sensitive, 6DoF strain gauges are used in several custom made equipment to measure the loads in various types of grip. These works are discussed in the following section.

2.4.3 Methodology of the previous studies

Studies of force actions in individual fingers have been well described. Most work on grip has been performed on precision pinch, however many authors have focused on the neurological control aspects. The studies are a heterogeneous group, demonstrating quite different methodologies, and may generally be divided into three broad categories: a) linear or uniaxial measurement, which usually involves a plier's type grip apparatus or a sling around a phalanx attached to a transducer, b) the two dimensional measurement technique involves a cylinder grip, and c) the three dimensional measurements of the applied loads, like this work, by using six- channel force transducers.

Hazelton et al (1975) and Ohtsuki (1981) looked at uniaxial force generation by the fingers using slings around the middle or distal phalanges. In both studies, forearm and upper arm were solidly immobilized in strapping/plaster. Strain gauged force transducers were used to measure the force actions. Hazelton et al (1975) focused his study on the influence of wrist position on the forces, while Ohtsuki (1981) investigated the synergistic muscle inhibition. None of the authors provide positional data to allow assessment of internal force actions.

Radwin et al (1991, 1992), measured fingertip force in pinch grip across the fingers by using pressure sensitive resistors. These sensors, as mentioned above, are not as reliable as strain gauging and again, no positional data is provided.

Fransson and Winkel (1991) gauged pliers with a load cell to assess distribution of finger grip. Their study had an ergonomic emphasis and again did not record joint position data. Similar in construction was Talsania and Kozin's (1998) study. They used a hand dynamometer, strain gauged, to assess individual finger contribution to grip in one dimension. Each subject was allowed to find their own comfortable position, which was not controlled. Kinoshita et al (1995) built their own dynamometer with strain gauged keys and used similar with the previous study methodology.

Baud-Bovy and Soechting (2001,2002) run two experiments to determine the factors that influence the variability in the load force during a precision grip. Although they used high-end force transducers, the subjects used only the thumb, index and middle fingers (tripod grasp) in neutral wrist position only. Li, (2002b) investigated inter-digit co-ordination and object-digit interaction during sustained object holding tasks by using five, six-component force/torque sensors. In this study, he compared only the nominal to the object forces between the fingers. The shear forces were not taken into account probably because there was no interest of transferring these loads on other hand joints. Additionally, only the neutral wrist position was used.

Zatsiorsky et al (2002) used a similar with the present study tool to investigate the force and torque production in static multifinger prehension. He used four uniaxial force transducers for the fingers, and one 6DoF force transducer for the thumb. The scope of the study was to determine the force generated by each finger when different loads were mounted in different positions on the tool, in order to produce torque, and therefore the results are not comparable with the present study. Similar objectives are found in the studies of Zatsiorsky et al (2003), and Pataky et al (2004).

In conclusion, there is no one study available in the literature investigating the synchronized kinetics and kinematics of the whole hand during a precision grip. Additionally, there is no evidence in the literature of transferring the loads on the metacarpophalangeal joints and the metacarpals.

The influence of wrist position on maximal grip strength

Another important variance with regard to the assessment of finger grip strength is the position of the wrist. It has been reported in the literature that the position of the wrist has a profound effect on the magnitude of maximum grip force when it is in the anatomical sagittal plane.

With regard to the flexor muscles, movement at the wrist joint in the sagittal plane has the effect of lengthening the effective length of the muscle in dorsiflexion and of shortening it in volar flexion. The potential for force generation by muscle fibre is dependent on its initial length (Crago, 1992).

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Figure 2.7: *Length-Tension Curve of a muscle.The L_0 defines the rest position of the muscle.*

When the initial length of a muscle fibre is increased, its ability to generate force is also increased (Figure 2.7). Therefore, a wrist in volar flexion has less capacity to generate force than a wrist in neutral position, due to shortening of the fibres. Full dorsiflexion has the effect of stretching the fibres beyond their ideal working length and will also compromise force generation. Furthermore, wrist position changes the moment arms of the tendons, which affects the moments generated around each joint (Horii et al, 1993; Youm et al, 1984).

Many of the authors on the subject of the power grip have ignored the position of the wrist in their experiments, allowing the wrist to find its ideal position for the generation of maximum grip force (Amis, 1987; Ohtsuki, 1981), without measuring its kinematics. However, Hazelton et al (1975) focused on this and found that the greatest total finger flexion force was achieved in wrist ulnar deviation, followed in order by the wrist positions of anatomic neutral, radial deviation, extension, and flexion. The drawback of the Hazelton et al work is that they stabilised the wrist in predefined angles, which may be not the functional one for all the subjects.

Radhakrishnan and Nagaravindra (1993) measured the fingers force generation in different wrist positions, using neutral, full extension and full flexion in 20 subjects, but using cylinder grip. They found average grip strength of 64.9N when fully flexed compared with 125.9N in neutral and 89.1N in fully extended positions. Lamoreaux and Hoffer (1995) measured eleven subjects and found a significant loss of total grip strength with the wrist in maximal radial and maximal ulnar deviation as compared with the anatomic neutral position. The maximal pinch strength in these deviated wrist positions was reduced by up to 33%, as reported by Halpern and Fernandez (1996).

O'Driscoll et al (1992) measured twenty healthy subjects and found that the maximal grip strength output was at a self-selected optimal wrist position of 35° of extension and 7 ° of ulnar deviation. They also reported that with the wrist in 15° of extension or 0° of radial-ulnar deviation, grip strength was reduced two thirds to three fourths of the strength found at the self-selected position. Pryce (1980) examined the power grip strength in flexion/extension and ulnar deviation (measured with manual goniometer) and found that the maximal grip force occurred at 15° of wrist extension and 0° deviation whereas changes in directions in either flexion/extension or radial/ulnar deviation resulted in a significant decrease in grip forces.

Recently, Li (2002a) investigated in nine subjects the influence of wrist orientations in power grip by using not static positions, like the previous studies, but a dynamic one. He used a biaxial electrogoniometer and four uniaxial force transducers and reported that the wrist position where the fingers can generate their maximal force was at 20° of wrist extension, combined with 5° of ulnar deviation. He also found that as the wrist was moved farther away from this position, the forces produced by individual fingers decreased incrementally.

The above discrepancy in the literature, is partially because of the low accurate equipment used in most of the cases (elecrtogoniometers) and the small number of subjects. More investigation in the field is required, with more subjects and high-end equipment, in order to clarify the influence of wrist orientation on fingers force generation. Finally, any gender differences are not taken under considerations in the literature.

2.4.4 Wrist Kinetics

Back in 1984, Palmer and Werner conducted one of the first experiments to investigate how the carpal loads are transmitted to radius and ulna. They used a cadaveric specimen and a pressure sensitive film in order to investigate the load transfer ratio between the radius and ulna. They found that 42.8% of the total load distributed between radius and scaphoid, 39% between radius and lunate and only 18.2% of the total load between ulna and lunate, in the anatomical neutral wrist position (Palmer and Werner, 1984). Tencer et al (1988) tested ten cadaveric specimens with pressure sensitive film to determine the pressure distribution properties of the normal radio-carpal joint. Five of the specimens were tested in 36 positions, combining flexion/extension and ulnar/radial deviation of the wrist, as well as supination/pronation of the forearm. They concluded that, overall, the scaphoid contact area was 1.47 times that of the lunate, although variations occurred with position, as in flexion, in which the scaphoid/lunate area ratio was 0.83. Viegas et al (1989) examined the effects of various load paths and different loads on the load transfer characteristics of the wrist. They also used cadaveric specimens and pressure sensitive film in their study and they found a non-linear relationship between increasing loads and greater overall contact areas.

Hara et al (1992) used pressure-sensitive conductive rubber sensors in order to investigate the force distribution across the wrist. Pressure was measured in seven different wrist orientations under increasing load. They found that the peak pressure ratio between the scaphoid and lunate was 1.7 in the neutral wrist position, 2.9 in radial deviation and 0.8 in ulnar deviation. The force transmission ratio was 50% through the scaphoid, 35% through the lunate and 15% through the triangular fibrocartilage in the neutral wrist position.

Although the above cadaveric studies have added significant knowledge regarding the load distribution in the wrist joint, concerns can be raised about the measuring procedures. According to Tencer et al (1988), the electronic transducer systems are difficult to position flush in the articular surface and may change its local compliance. Additionally, the plastic films may alter the joint contact characteristics and they can be used only for single, static measurements. Furthermore, error sources include inadvertent exposure of the pressure-sensitive film during fabrication of the transducer, variability in the position of the joint and the loading mechanism, variability in the tissues of the cadaveric specimens themselves, alteration in the lighting conditions during photography and projection of the transducers, and variations in the video imaging system.

Due to the above limitations, several theoretical models of the wrist have been created to investigate the joint load characteristics. Schiind et al (1995) conducted a two-dimensional study to measure the force and pressure transmission through the normal wrist by using rigid body spring modeling technique. They found that the force transmission ratio at the radio-ulno-carpal joint was 55% through the radio-scaphoid, 35% through the radio-lunate and the remaining 10% through the triangular fibrocartilage. Similar techniques and results presented by Nedoma et al (2003) and

Majima et al (2008). However, concerns exist regarding the accuracy of these works as the geometry of the wrist makes such theoretical models difficult to create.

Finite Element models of the wrist have been created, but most have focused on a particular subregion of the joint. The exception to this is the work of Carrigan et al, (2003), who developed a three dimensional finite element analysis of the carpus (without metacarpals), but theoretical or arbitrary loads were applied.

Although finite element models seem to be the most promising technique to determine the load distribution across the wrist there are no three-dimensional whole hand loading data provided by the literature to feed these models. An ambitious task of the present work is to provide the scientific community with these data, from a large sample size.

2.5 Conclusions and Project Design.

The research done in the hand and wrist biomechanics is enormous, and the authors, in most of the cases, have added very important knowledge in the scientific field. The present research is essential because attempts to fill the gap in the knowledge regarding the three dimensional whole hand and wrist kinetic and kinematic data. Specifically, the the present study aims to define the optimum wrist kinematic envelope inside which the hand can produse its maximal gripping force, an important knowledge for orthopaedic surgeons, and rehabilitation scientists. Furthermore, to calculate the external loads on the MCP joints, which will allow in the future the calculation of the internal loads on the joints, and will provide the industry with essential information in order to design better implants. Finally, the three dimensional kinetic data on the wrist and the other finger joints will be used, as future task, for the study of these joints.

However, the concurrent three-dimensional kinetic and kinematic study of the hand and wrist complex is a difficult path to walk through, and this is the explanation of why it is not yet done. The examination of the kinetics and kinematics of the whole hand is very special compared with the lower extremities study, i.e. in gait. Specifically:

i. Hand and wrist together compose a sum of no less than 15 joints.
ii. These joints are small and delicate.
iii. The fingers maximal grip force is related with the wrist orientation.
iv. There is no standard strength grip tool available in the market to study all the individual fingers and give information for each one of them.
v. The position of the grip tool is not fixed (in most of the cases) during the experiments (like i.e. the force plates in gait analysis), but is handled by the hand in the air.

In order to set up the experiment the aforementioned features should be confronted. Therefore:

(i) The kinematics of these joints are all related and therefore none excluded from the analysis in the present whole hand experiment. However, the decision which made was to analyse the loads on the fingertips, and to transfer them as external loads on the metacarpophalangeal joints. The calculation and the clinical relevance of the loads on the interphalangeal joints was set as a future task.

(ii) As the joints are small, extra care should be taken as regards the choice of the kinematic measurement device and procedure. The electrogoniometers were rejected as a candidate device because it was impossible to implement them in so many joints and simultaneously in so little volume. Therefore the stereophotogrammetry, and specifically the optoelectronic motion analysis system chosen. It is non-invasive, very accurate when used with the appropriate software, and it was available in the biomechanics laboratory of the University so the cost was minimised. The drawback of this choice was that a great amount of work would be needed by means of creating special small passive retroreflective markers to fit on the hand and wrist. Additionally, the optimum camera set up should be defined, a time consuming task, because the cameras should be close enough to capture the markers, but not very close due to camera focus limitations. Furthermore, the camera positions should permit the capture of the markers in different grip tasks under the same calibration.

(iii) As the maximal finger grip force is dependent on the orientation of the wrist, the decision made was to investigate this force in five different wrist positions. The plan was to examine the functionality of the hand and wrist in order to draw clinical relevance conclusions and therefore the subjects were free to choose their own maximal wrist orientations in every gripping task.

(iv) As there is no standard grip strength tool available in the market for these kind of experiments, a custom one should be designed and made. This apparatus should be able to enclose the five, 6DoF force transducers, one for each finger, which accordingly were purchased.

(v) The fact that the grip tool should be handled in the air and not in a fixed position added more difficulties in the project procedure. In gait analysis, where the force transducers are fixed to the ground (forceplates) and the joints involved are much less than these of the present study, the processing is more or less standardised and several script codes can be found online for almost every task. In the present experiment though, these scripting codes are useless and therefore all the script code and data processing should be designed, written and accomplished from the scratch.

In the following chapter the methodological aspects of the aforementioned experimental design are given in detail.

CHAPTER 3: **Methodology**

3.1 Introduction and Participants

In the present study, a large sample of asymptomatic adults required to generate maximal gripping force in five different wrist orientations: neutral, flexion, extension, radial and ulnar deviation. A custom-built grip strength tool containing five six-component force transducers was used to measure the three-dimensional loads applied on the hand. Three-dimensional kinematic data were obtained concurrently with an eight-camera VICON motion analysis system, and wrist joint laxity measured by methodology obtained from the literature.

The experiment was set up in three stages: a) the wrist joint laxity and anthropometric measurements of the hands and forearms, b) the equipment calibration including the pointing trials and c) the gripping force measurements (kinetic and kinematic data collection). Fifty right-handed volunteer subjects, without any previous or recent trauma or pathology of their hand or wrist, participated in the study. Twenty five (25) were males and twenty five (25) females, with a mean age of 30.8 years (SD 8.4 years) and 29.5 years (SD 9.1 years) respectively.

3.2 Wrist Joint Laxity and Anthropometric Measurements

Wrist laxity was determined in both hands by means of four clinical manoeuvres as described previously by Garcia-Elias et al (1995) and presented in the literature review. In the whole cohort of the fifty subjects, three anthropometric characteristics of the right arms were measured: a) with the forearm in supine position, the distance between the olecranon and the styloid process of the ulna (representing the length of the forearm), b) the circumference of the forearm at the proximal one third of the total ulnar length that measured as described above (representing the cross section of the extrinsic muscles of the hand and wrist), and c) the length of the third metacarpal (representing the size of the hand). A standard measuring tape was used for this purpose.

3.3 Equipment and Calibrations

3.3.1 Kinematics

3.3.1.1 Set Up of the Motion Analysis System

Kinematic data were captured under the same VICON (Oxford Metrics Ltd.) motion analysis system setup. Eight cameras were used for this task, operating at 120 Hz. The procedure dictated that every marker had to be visible from at least three cameras all the time and thus the cameras were set up by taking into consideration the gripping force trials, the most demanding procedure. Three cameras were set up on the right side of the table, on which the trials were to take place, capturing data from the markers placed on the dorsal side of the hands (Figure 3.2). Two cameras were placed in front of the table in such a way, providing enough space between them for the examiner to conduct the pointing trials. Two cameras were placed in a bar above the table covering all the area of the trials. The last camera was set up on the left of the table which, together with the front left one and the cameras on the bar, would be able to capture data from the thumb and the flexed distal phalanxes.

All the cameras, apart from those on the bar, were placed on two different levels, with those at the lower level as close as possible to the table in order to capture data from the small markers used on the hands. After preliminary trials, the minimum optimum distance between the cameras and the markers was determined at about 0.5m. Finally, the set up was tested to ensure the capturing of the markers in the five positions that the gripping trials were going to take place.

Figure 3.2: *The VICON motion analysis system set-up.*

3.3.1.2 Calibration Procedures

3.3.1.2.1 VICON Calibration

The camera sensitivity was agreed at 6-7 up to 10 (VICON units) in order to eliminate any reflections. Before every session, a new calibration of the VICON system was conducted: a static one, by using a calibration “L” frame and a dynamic one, by using a wand, giving always calibration residuals of less than 0.1mm.

3.3.1.2.2 Pointing Trials and Markers’ Set Up

The raw data from the pointing trials were to provide input into a biomechanical model (Fowler, 2003) described below. All the fingers of the right hand were marked using a 0.1mm pen in specific positions and the pointing trials were then conducted using the VICON system (Figure 3.3).

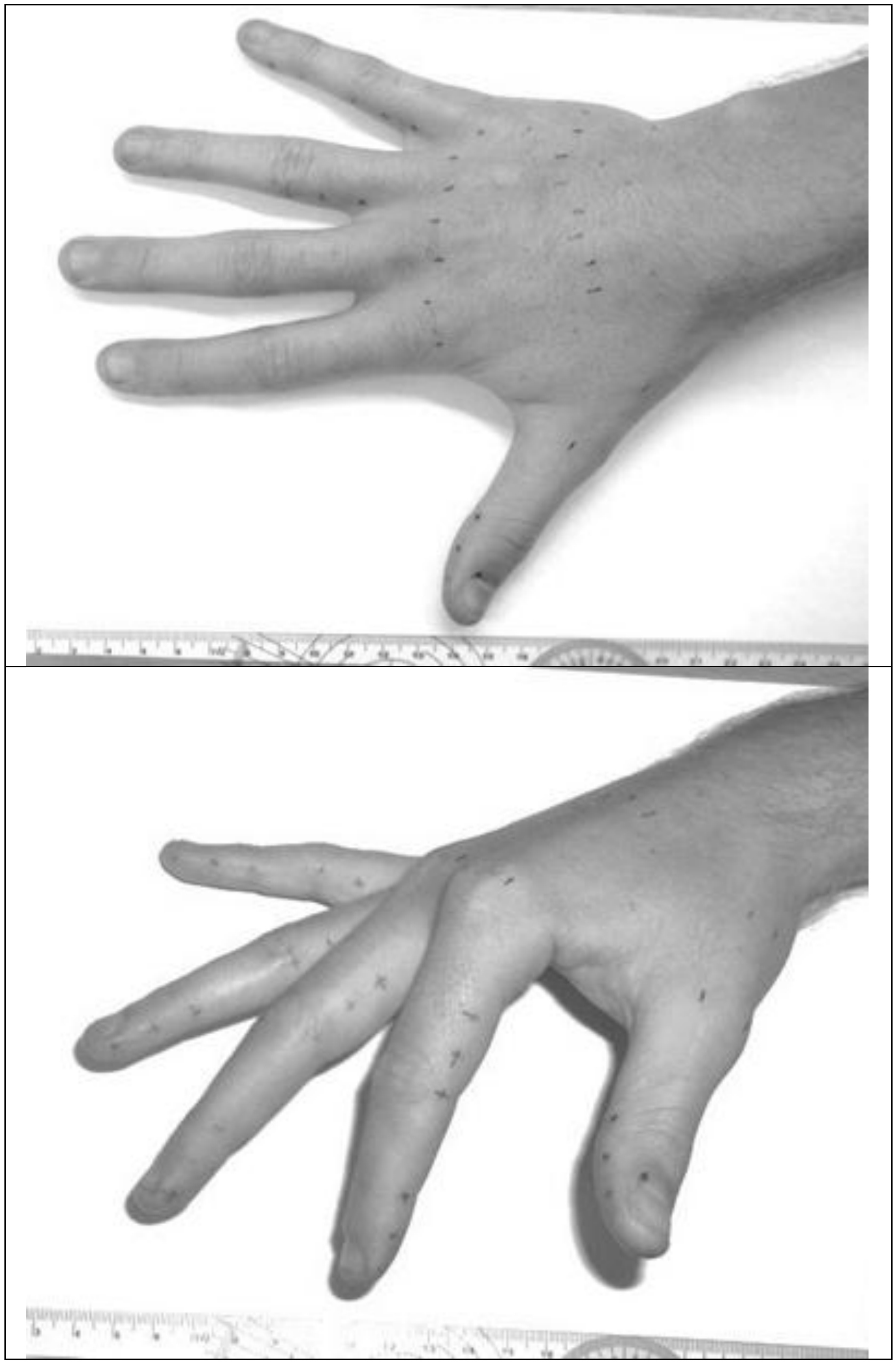


Figure 3.3: *Two views of a fully marked hand.*

Distant phalanx: A point estimating the position of the joint centre on the radial and ulnar side was marked; two further points were marked on each side, equidistant and distal to the joint. The distance between the dots was 5mm in most of cases, but in small fingers this was reduced to 3mm. The absolute value of this distance was not important for the experiment, only the equality of the distances between the marks for every phalanx was crucial.

Proximal phalanx: This was marked under the same procedure but marking started at the proximal interphalangeal (PIP) joint on both sides and taking equidistantly the other points proximal to the joint.

Metacarpals: four points were taken for these phalanxes defining the orientation of the bones. The first two marks defined the radial and ulnar condylar heads of the metacarpals. The distance between the points was not important, but there had to be consistency between the points on the ulnar and radial side.

A special wand with two static retro-reflective markers on it and predefined distances between them and its apex was used to acquire the pointing trials of the above described hand marks. Additionally to that, five pointing trials of the gripping tool were taken after each experiment, one for the centre of each transducer, in order to determine their orientation during the trials (Figure 3.4).

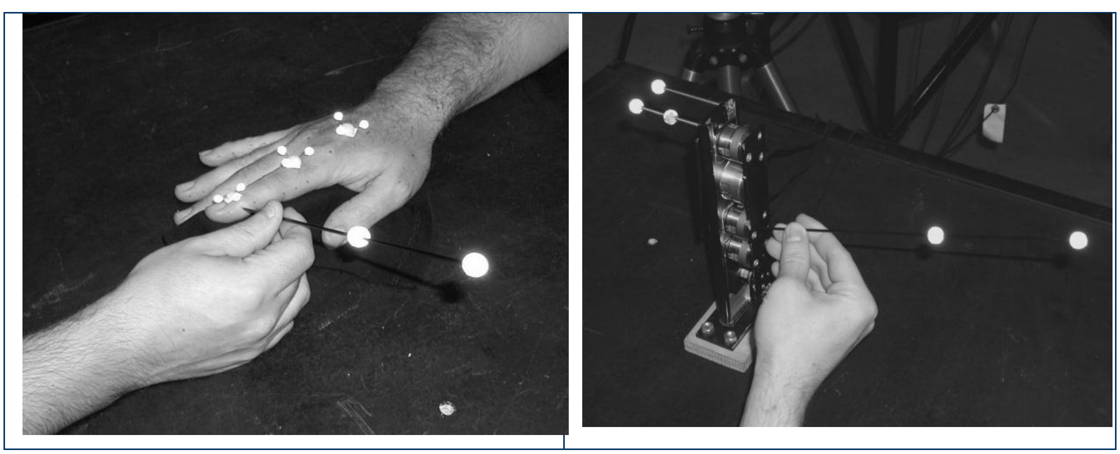


Figure 3.4: *Pointing trials of the finger (left) and of the transducer (right).*

Digital photographs of the hands placed beside a rule were taken for every hand in order to record the lengths and the thicknesses of the distal and proximal phalanxes and the metacarpals (Figure 3.3). This procedure significantly reduced the duration of each experiment.

Retro-reflective marker clusters (3mm in diameter) were used as a whole-hand marker system. Two of them were placed on the thumb and three on every finger as shown in Figure 3.5. Specific placement of the marker clusters was not important, although it was necessary to be on the dorsal part of the hand. The type of marker cluster and their specific positions on the fingers were chosen by the logic of providing optimum visibility for the cameras and, at the same time, reducing their proximity. The second condition was of high importance, because when two markers were very close, the VICON system recognized them as one; in addition, they were uncomfortable for the subjects and inhibited the movement.

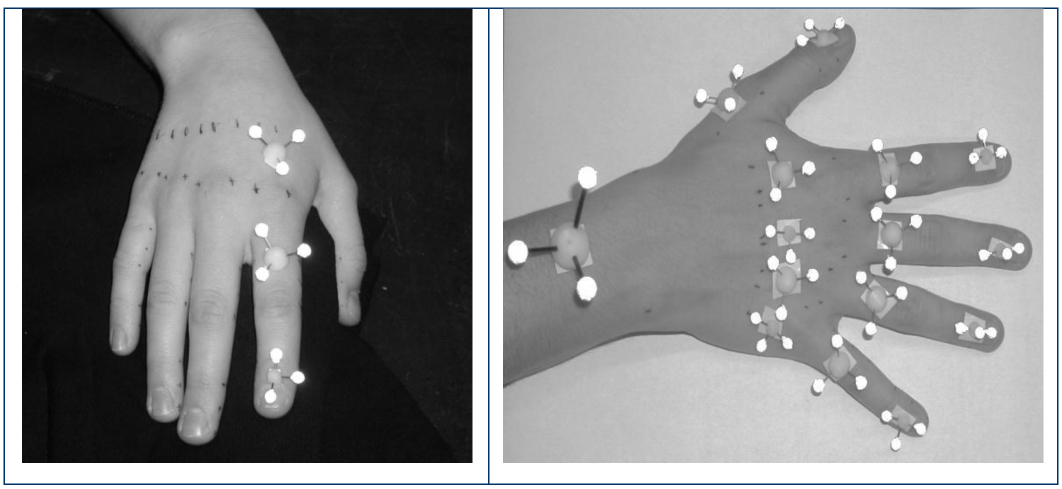


Figure 3.5: *The placement of the marker clusters on the hand.*

Two bigger markers (4mm in diameter) were placed, one on the dorsal part of the radius just above the wrist level and the other on the distal lateral part of the humerus, permitting later interpretations of the pronation-supination of the elbow during the trials. Furthermore, additional pointing trials were taken above the wrist (styloid process of the radius and styloid process of the ulnar), on the elbow (lateral epicondyle, medial epicondyle) and on the greater tubercle of humerus.

3.3.2 Kinetics

3.3.2.1 The Gripping Tool

A special tool was designed and afterwards manufactured in the mechanical engineering department of the University of Strathclyde to be used for the gripping trials (Figure 3.6). It consisted of an aluminium body and 5 individual aluminium sliders, onto which the force transducers were fitted. A curved steel pad was mounted onto each transducer providing enough space for comfortable gripping. Each steel pad was not in contact with anything else than its respective transducer. The index finger platform was bigger than the pads for the other fingers for fitting reasons, as well as to bring the index finger closer to the others (Appendix D). The gripping tool was painted in a matt black colour in order to avoid any reflections from the VICON system.

Five, six-axis force transducers (F_x, F_y, F_z, M_x, M_y, M_z) (Appendix B) (ATI Industrial Automation Inc.) were used to measure the forces and the moments for each individual digit (the axes on the transducers are shown in Appendix E). These force transducers use semi-conductor strain gauges, which are significantly more sensitive than traditional foil gauges, allowing the transducer volume to be minimised. For thumb, index, middle and ring finger the Nano25 force transducer was used, while for the little finger the Nano17 (Appendix B). The minimum transducer resolution was 0.031N and 0.379Nmm for transducers 1 to 4 (thumb, index, middle, ring) and 0.006N with 0.016Nmm for transducer 5 (little finger).

For this study, the grip span was fixed at 50mm. The complete grip tool (with transducers) had a mass of 0.756kg. The transducers were connected with their amplifiers, one for each specific transducer, as they came from the manufacturer (Figure 3.7). The amplified signal was transferred via a custom-built patch panel (Figure 3.7) to the analog to digital converter card in the VICON data station. This was absolutely crucial, because the kinetic and kinematic data had to be synchronized.

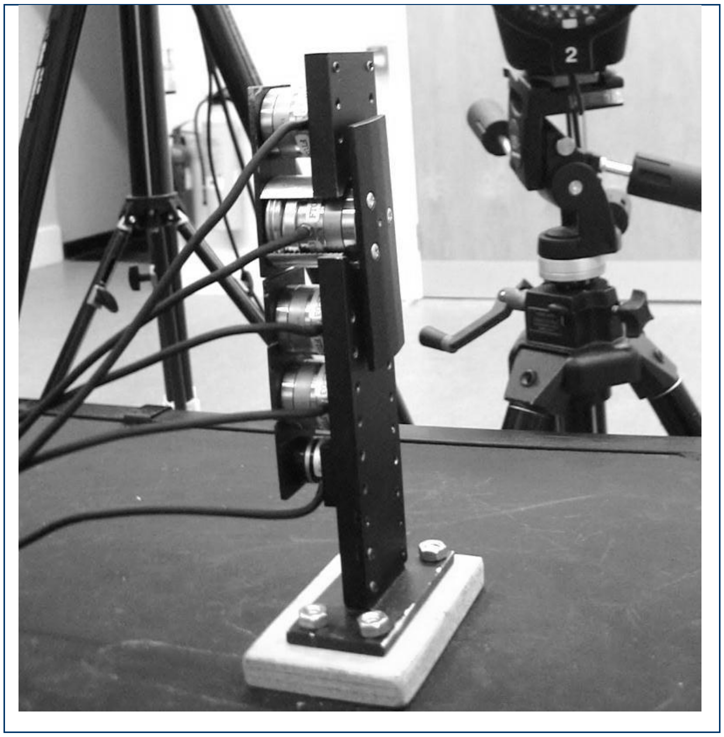


Figure 3.6: *The custom-built grip strength tool. From the top to the bottom, the force transducers of the index, thumb, middle, ring and little finger are shown.*

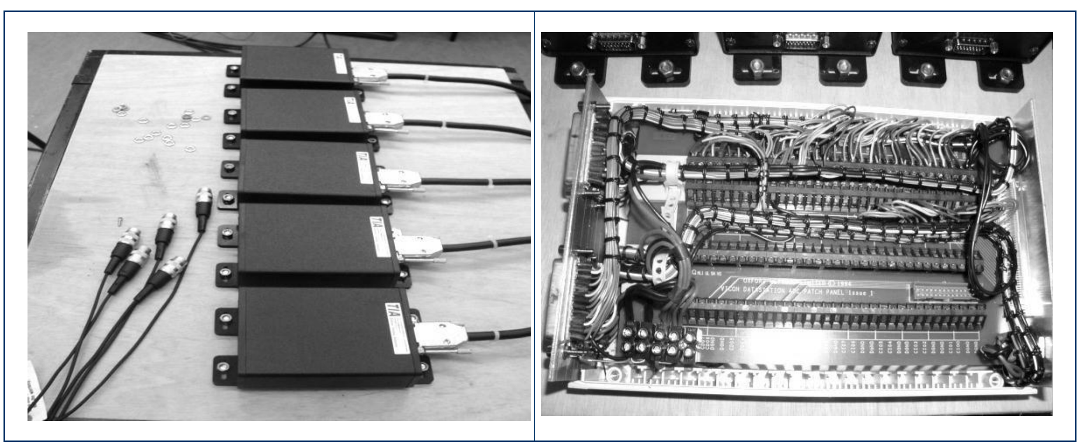


Figure 3.7: *The transducers amplifiers (left) and the custom-built patch panel (right).*

3.3.2.2 Testing and Calibration

The transducers came calibrated from the manufacturer, with the calibration diagrams given in Appendix C, and had not been used previously. The signals from the transducers were verified by placing known weights on each transducer in one axis (the F_z) and taking measurements from the patch panel and the PC simultaneously. After converting the measured force signal with the aid of the calibration data sheets provided by the manufacturer, the results were compared with the known applied weight value.

Furthermore, the connections from the patch panel to the data station were confirmed by applying a known voltage signal (5V) and verifying the measurement by using the PC.

3.4 Gripping Force Trials Procedure

Kinetic data were collected in five different wrist positions: normal, flexion, extension, ulnar and radial deviation, simultaneously with the kinematic data obtained with the VICON system. The subjects were asked for three trials in every position, providing their maximal force. Between the three trials the one with the maximal grip force and accurate kinematic envelope was chosen for analysis. In order to avoid soft tissue fatigue, the subjects were tested by changing the wrist position after every trial with a minimum relaxation time of one minute, and then the cycle was repeated again. None of the subjects complained of fatigue or pain during the trials.

Every trial lasted a fixed duration of seven seconds. The subjects were advised to place their fingers carefully during the first 2-3 seconds, then to provide their maximal grip force and finally to release the tool with the examiner’s advice, about one second before the end of the time envelope. Thus, it was ensured that a zero before and after the trial would be obtained and the whole kinetic information would be enclosed in the data collected.

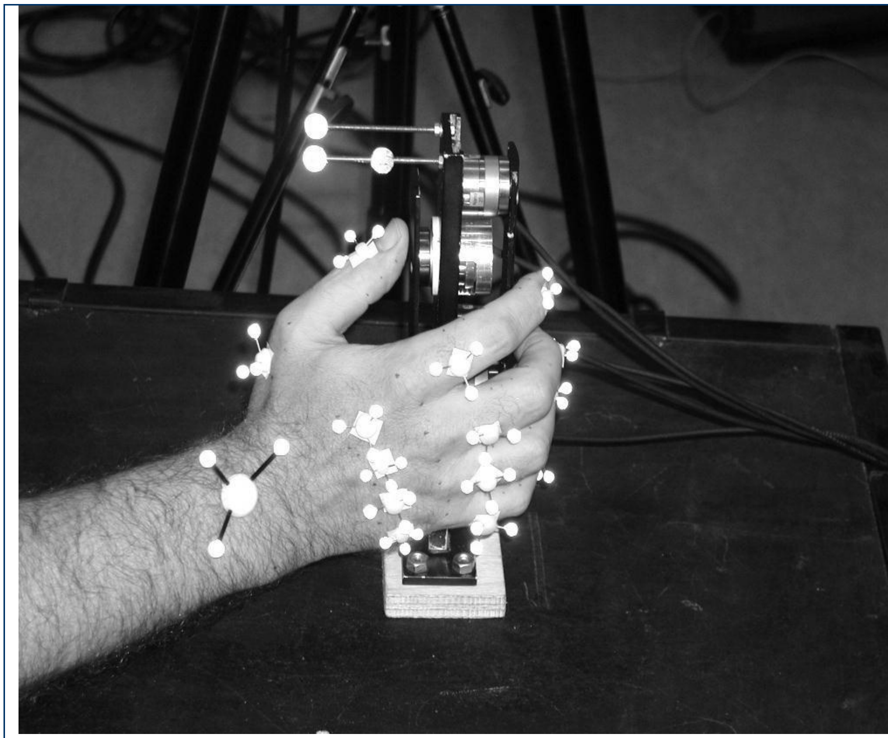


Figure 3.8: *Gripping force trial in neutral wrist position.*

The correct placement of the fingers and the position of the wrists were supervised by a second examiner. For the flexion, extension, radial and ulnar deviation the subjects were asked for their maximal comfortable angles, as the data collected was to be representative of functional positions of the wrist rather than positions rarely used in everyday life, and also to avoid any serious fatigue or injury in extreme positions.

The flexion, extension and neutral trials took place with the gripping tool fixed on the table, on a base which permitted only rotation about the vertical axis. For the radial and ulnar deviation, the gripping tool was lifted from its base and it was given to the pre-positioned by the subject right hand by the left one (Figures 3.8, 3.9, 3.10). In this way, the wrist position was controlled.

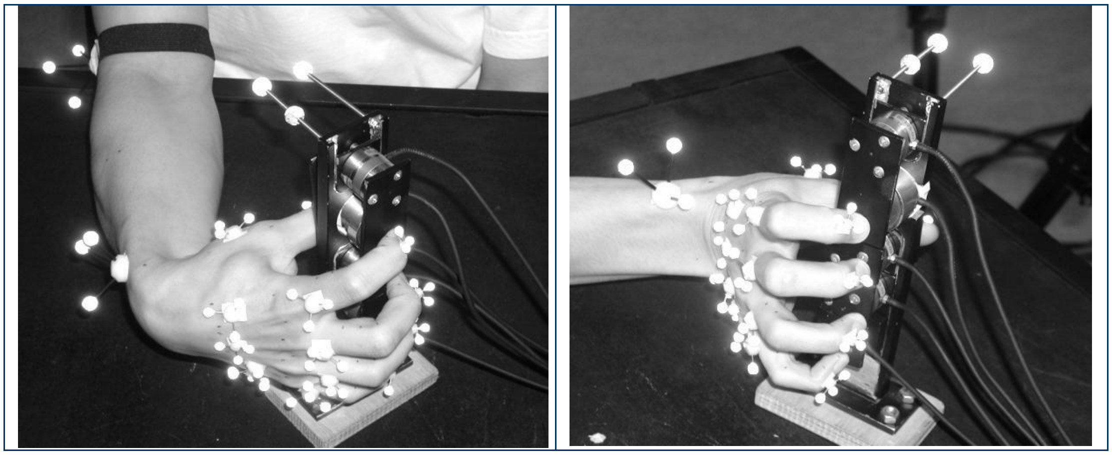


Figure 3.9: *Gripping force trials with the wrist in flexion (left) and extension (right).*

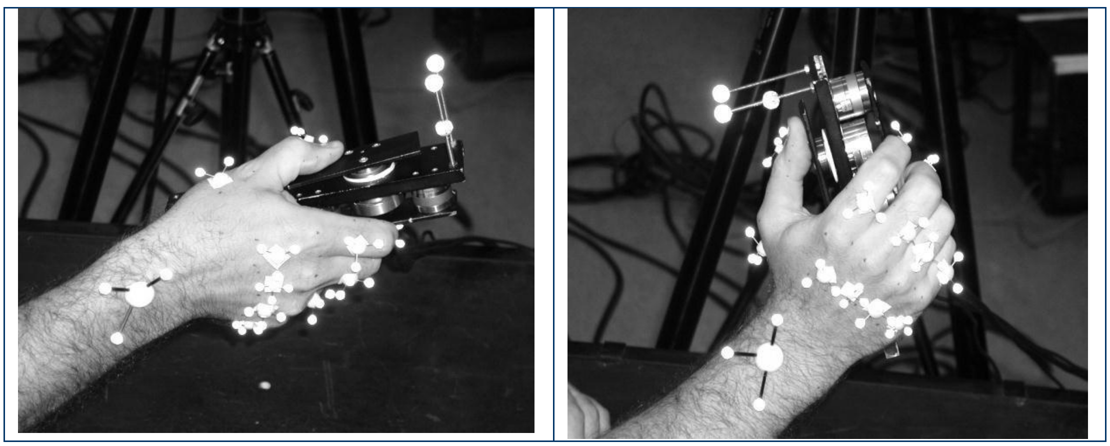


Figure 3.10: *Gripping force trials with the wrist in ulnar (left) and radial (right) deviation.*

The neutral position was allowed to be freely chosen by the subjects rather than imposed at the anatomical zero degrees. Any divergences between these chosen positions were correlated later in the processing with the wrist joint laxity. Small changes in the wrist angle during the trials were permitted as it could be recorded from the motional analysis system and would be used later in the investigation of the optimum angle for the maximal gripping force in every position. For the same reason, the elbow and shoulder positions were freely managed by the subjects but always supervised by the second examiner, avoiding any extremes.

Figure 3.11: *Gripping trial that shows the whole upper limb position.*

As it is shown in Figure 3.11, the upper extremity was not lying on the table during the experiment, and all the subjects chose a combination of a small flexion and abduction for the shoulder, and a middle position between pronation and supination for the forearm. A slightly flexed elbow position was also chosen from all the subjects, as the most comfortable one during the experiment.

3.5 Data Processing

3.5.1 Basic Principles

The positions and the three dimensional orientation of each finger segment relative to each other, as well as to the force transducer's origin was required as input into the biomechanical model. The output data from the motion analysis system contains co-ordinates of marker clusters attached to distal, proximal and metacarpal segments and the radius and ulnar as well. Each marker co-ordinate is referenced to the origin and co-ordinate system of the VICON system. The pointing trials described previously are part of the calibration procedure, which is used to define the constant relationship between the axis systems of the fixed marker clusters and the finger segments (Fowler, 1997).

3.5.1.1 Segment Axis System Definitions

The definition of each segment axis system in relation to the reference co-ordinate system is provided by the calibration of the system. The pointing trials described in the previous chapter are used to define each marked point on the finger segment. With reference to the Figure 2.11 the long axis of the distal segment, Y_d, is described by

$$Y_d = \left[\frac{S_3 + S_4}{2}\right] - \left[\frac{S_1 + S_2}{2}\right]$$

where S_1, S_2, S_3, and S_4 are the sets of co-ordinates for each point (taken by the pointing trials), as shown in Figure 3.11.

The X_d axis is defined by the vector cross product of $\hat{Y}_d$ and the temporary axis $\hat{Z}'$, where

$$Z' = (S_6 - S_5)$$

Then, the Z_d axis is equal to the vector cross product of X_d and Y_d. Hence

$$X_d = \hat{Y}_d \wedge \hat{Z}' \quad \text{and} \quad Z_d = \hat{X}_d \wedge \hat{Y}_d$$

The origin of the distal segment axis system is taken as the centre of rotation of the distal interphalangeal joint. Vector $\{X_{ds}, Y_{ds}, Z_{ds}\}_{ref}$ defines the translation vector which relates the distal segment axis system origin to the reference co-ordinate system origin.

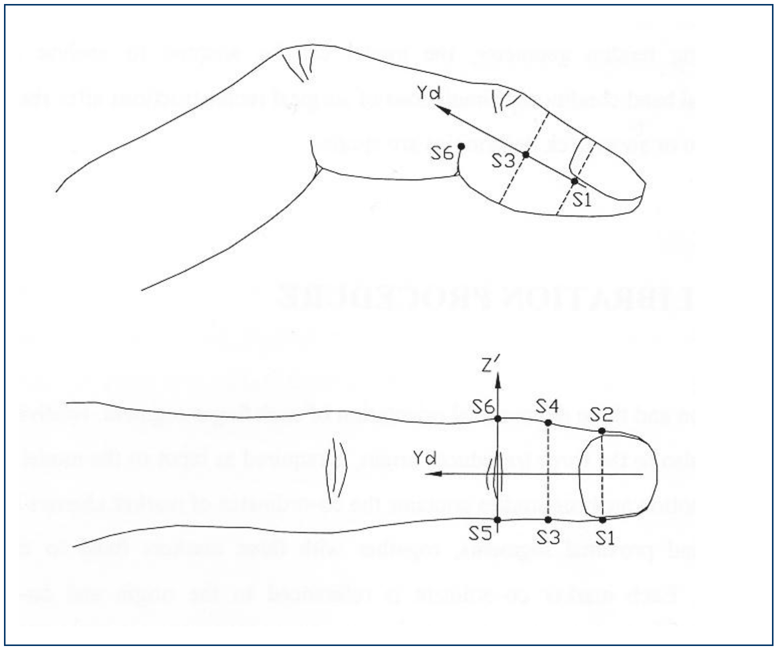


Figure 3.11: *Definition of the finger segment axis system.*
(From Fowler, 1997)

The proximal segment axis and the metacarpophalangeal segment axis are characterised in the same way, resulting in formation of three cosine matrices $[R_s]$

$$\{X_d, Y_d, Z_d\}_{dseg} = \underset{ref\rightarrow dseg}{[R_{ds}]} * [\{X_d, Y_d, Z_d\}_{ref} - \{X_{ds}, Y_{ds}, Z_{ds}\}_{ref}] \quad \text{(Eq. 3.1)}$$

$$\{X_p, Y_p, Z_p\}_{pseg} = \underset{ref\rightarrow pseg}{[R_{ps}]} * [\{X_p, Y_p, Z_p\}_{ref} - \{X_{ps}, Y_{ps}, Z_{ps}\}_{ref}] \text{ and}$$

$$\{X_c, Y_c, Z_c\}_{cseg} = \underset{ref\rightarrow cseg}{[R_{cs}]} * [\{X_c, Y_c, Z_c\}_{ref} - \{X_{cs}, Y_{cs}, Z_{cs}\}_{ref}]$$

where “dseg”, “pseg” and “cseg” denote distal, proximal and metacarpophalangeal segment axis systems respectively, and “ref” represents the reference co-ordinates system. The notation of $\underset{ref\rightarrow dseg}{[R_{ds}]}$ describes the direction cosine matrix which is used to convert co-ordinates from the reference co-ordinate system into that of the distal segment.

3.5.1.2 Marker Axis System Definitions

Each marker cluster contains three markers and its co-ordinate is output during the calibration procedure with respect to the reference co-ordinate system. The marker axes systems are defined from these three co-ordinates.

Axis Y_d is aligned approximately along the long axis of the distal segment (Figure 3.12) and is defined by

$$Y_d = (m_3 - m_1)$$

The X_d axis is described by the vector cross product of $\hat{Y}_d$ and the temporary axis $\hat{Z}'$, where

$$Z' = \left[m_2 - \left[\frac{m_1 + m_3}{2}\right]\right]$$

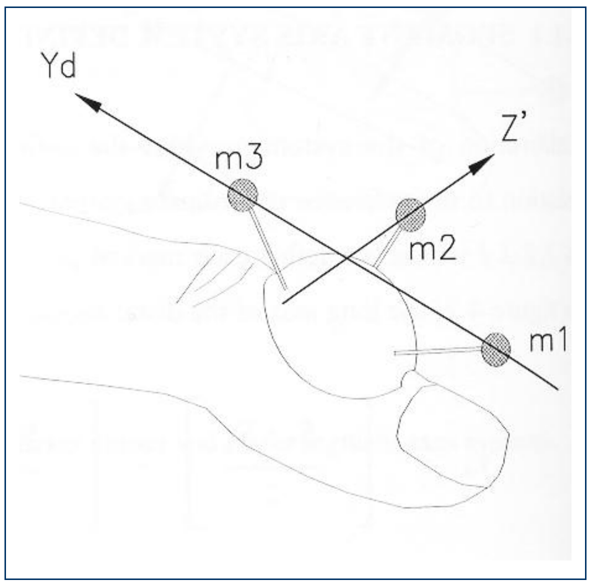


Figure 3.12: *Marker system definitions (from Fowler, 1997)*

Axis Z_d is equal to the vector cross product of $\hat{X}_d$ and $\hat{Y}_d$, hence

$$X_d = \hat{Y}_d \wedge \hat{Z}' \text{ and } Z_d = \hat{X}_d \wedge \hat{Y}_d$$

The origin of the distal marker axis system in terms of the reference co-ordinate system, $\{X_{dmk}, Y_{dmk}, Z_{dmk}\}_{ref}$, is defined as the geometric centre of the three marker co-ordinates.

The marker clusters axis systems give the direction cosine matrices [R_{mk}], such that

$$\{X_d, Y_d, Z_d\}_{dmrk} = \underset{ref \rightarrow dmrk}{[R_{dmk}]} * [\{X_d, Y_d, Z_d\}_{ref} - \{X_{dmk}, Y_{dmk}, Z_{dmk}\}_{ref}] \quad \text{(Eq. 3.2)}$$

$$\{X_p, Y_p, Z_p\}_{pmrk} = \underset{ref \rightarrow pmrk}{[R_{pmk}]} * [\{X_p, Y_p, Z_p\}_{ref} - \{X_{pmk}, Y_{pmk}, Z_{pmk}\}_{ref}] \text{ and}$$

$$\{X_c, Y_c, Z_c\}_{cmrk} = \underset{ref \rightarrow cmrk}{[R_{cmk}]} * [\{X_c, Y_c, Z_c\}_{ref} - \{X_{cmk}, Y_{cmk}, Z_{cmk}\}_{ref}]$$

where "dmk", "pmk" and "cmk" represent the distal, proximal and metacarpophalangeal marker cluster axis systems. $\underset{ref \rightarrow dmrk}{[R_{dmk}]}$ is the direction cosine matrix which transfers co-ordinates from the reference axis system into co-ordinates expressed in the distal marker axis system.

Because the marker and segment axis systems are both defined in terms of the reference co-ordinate system, from equations 3.1 and 3.2, the following relationships are derived:

$$\{X_d, Y_d, Z_d\}_{dmrk} = \underset{ref \rightarrow dmrk}{[R_{dmk}]} * \underset{ref \rightarrow dseg}{[R_{ds}]}^{-1} * \{X_d, Y_d, Z_d\}_{dseg} + \underset{ref \rightarrow dmrk}{[R_{dmk}]} * [\{X_{ds}, Y_{ds}, Z_{ds}\}_{ref} - \{X_{dmk}, Y_{dmk}, Z_{dmk}\}_{ref}]$$

giving distal segment co-ordinates in terms of the distal marker axis system, and

$$\{X_d, Y_d, Z_d\}_{dseg} = \underset{ref \rightarrow dseg}{[R_{ds}]} * \underset{ref \rightarrow dmrk}{[R_{dmk}]}^{-1} * \{X_d, Y_d, Z_d\}_{dmrk} + \underset{ref \rightarrow dseg}{[R_{ds}]} * [\{X_{dmk}, Y_{dmk}, Z_{dmk}\}_{ref} - \{X_{ds}, Y_{ds}, Z_{ds}\}_{ref}]$$

giving distal marker co-ordinates in terms of the distal segment axis.

Since the relationship between the marker and segment axes systems is constant these equations can be written as

$$\{X_d, Y_d, Z_d\}_{dmrk} = \underset{dseg \rightarrow dmrk}{[R_d]} * \{X_d, Y_d, Z_d\}_{dseg} + \{X_{dsm}, Y_{dsm}, Z_{dsm}\}_{dmrk} \quad \text{and}$$

$$\{X_d, Y_d, Z_d\}_{dseg} = \underset{dmrk \rightarrow dseg}{[R_d]} * \{X_d, Y_d, Z_d\}_{dmrk} + \{X_{dms}, Y_{dms}, Z_{dms}\}_{dseg} \quad \text{(Eq. 3.3)}$$

respectively. The $\underset{dseg \rightarrow dmrk}{[R_d]}$, $\underset{dmrk \rightarrow dseg}{[R_d]}$, $\{X_{dsm}, Y_{dsm}, Z_{dsm}\}_{dmrk}$, $\{X_{dms}, Y_{dms}, Z_{dms}\}_{dseg}$ are constant values. Similar relationships exist for the proximal segment axis system and marker cluster and the metacarpophalangeal segment system and marker cluster as well. Now, both of them are independent of the reference co-ordinate system and relate marker and segment axis systems regardless of the finger position and orientation.

3.5.1.3 Middle phalanx axis system

The position and the orientation of the middle phalanx can be obtained by interpolation, as the distal and proximal phalanx location and orientation are known (Figure 3.13).

The direction cosine matrix which gives proximal segment co-ordinates in terms of the middle segment axis system is:

$$\{X_d, Y_d, Z_d\}_{mseg} = \underset{pseg \rightarrow mseg}{[R_{mp}]} * \{X_p, Y_p, Z_p\}_{pseg}$$

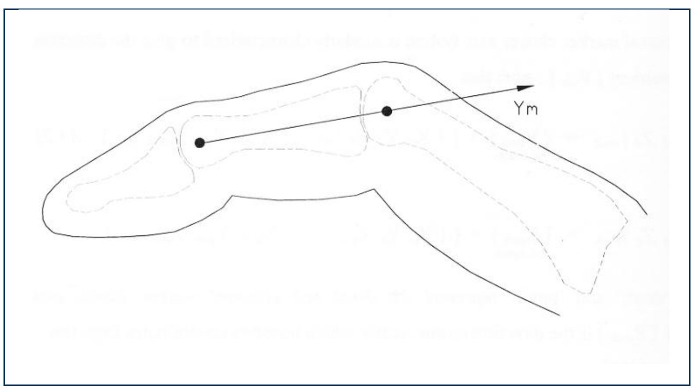


Figure 3.13: *Definition of axis Y_m (from Fowler,1997)*

3.5.1.4 Transducer Axis System

The gripping tool markers were permanently mounted as shown in the Appendix D. The transducer axis system is defined according the directions of positive measured forces. The Z axis of the transducer, Z_t, is described by

$$Z_t = (m_3 - m_2)$$

The Y_t axis is the vector cross product of $\hat{Z}_t$ and the temporary axis $\hat{X}'$, where

$$X' = (m_1 - m_2)$$

$$\text{Axis } X_t = \hat{Y}_t \wedge \hat{Z}_t$$

The origin for every one of the five transducers is located by the pointing trials taken. The equation which gives the position and orientation for every transducer in the reference co-ordinate system is defined as

$$\{X_t, Y_t, Z_t\}_{ref} = \underset{trans \rightarrow ref}{[R_t]} * \{X_t, Y_t, Z_t\}_{trans} + \{X_{tr}, Y_{tr}, Z_{tr}\}_{ref} \qquad \text{(Eq. 3.4)}$$

where "trans" denotes the transducer axis system (the same with the gripping tool) and $\underset{trans \rightarrow ref}{[R_t]}$ is the direction cosine matrix which describes the conversion of co-ordinates from the transducer axis system to the reference co-ordinate system. Translation vector $\{X_{tr}, Y_{tr}, Z_{tr}\}_{ref}$ describes the location of each transducer origin, taken with the pointing trials, in terms of the reference co-ordinate system.

3.5.1.5 Load Conversion to the Segment Axis System

External forces and moments are to be calculated at the origin of the metacarpophalangeal (MCP) axis system; that is, at their respective joint centres of rotation. In order to determine the moments applied at these joints, the relevant moment arms must first be found. For the metacarpal segment, the moment arm is the vector connecting the MCP joint centre of rotation and the force transducer origin. This is the location of the transducer origin, expressed in terms of the metacarpal segment co-ordinate system. The position vector {0,0,0} describes the position of the transducer origin in the transducer frame of reference. By using equation 3.4, the vector is first converted to the reference co-ordinate system. Equation 3.2 describes the vector in terms of the marker co-ordinate system. Use of equation 3.3 then, converts the position vector to the metacarpal segment co-ordinate system and the moment arm can be found.

Forces $\{F_{Xt}, F_{Yt}, F_{Zt}\}$ and moments $\{M_{Xt}, M_{Yt}, M_{Zt}\}$ measured at the transducer are also expressed in terms of the metacarpal segment co-ordinate system. In this case, only the rotational element of each equation is used and equation 3.4 becomes

$$\{X_t, Y_t, Z_t\}_{ref} = \underset{trans \rightarrow ref}{[R_t]} * \{X_t, Y_t, Z_t\}_{trans}$$

Taking moments about joint centres then provides the external moments in terms of each segment axis system.

3.5.1.6 Radius axis system and wrist joint angle calculation

According the International Society of Biomechanics recommendation on definitions of joint coordinate systems (Wu et al, 2005), the origin of the radius (Figure 3.14) is located midway between the proximal radius at the level of the depression in the proximal radial head and the distal radius at the level of the ridge between the radioscaphoid fossa and the radiolunate fossa.

However, these points are not easily palpable and therefore, in the present study, the depression of the radial head was calculated as a virtual point located at the lateral one forth (1/4) of the distance between the lateral epicondyle and the medial epicondyle. In the same way, the ridge between the radioscaphoid fossa and radiolunate fossa was calculated as a virtual point located at the lateral one third (1/3) of the distance between the radial and ulnar styloid. The exact positions of the lateral and medial epicondyles, as well as of the radial and ulnar styloids had been acquired for every subject with the pointing trials during the calibration procedure.

The image is removed due to Copyright restrictions.

Figure 3.14: *The radius and ulna axis systems according the ISB recommendations (from Wu et al, 2005)*

The Y axis of the radius, is the line parallel to the long shafl of the bone from the origin to intersect with the ridge between the radioscaphoid fossa and radiolunate fossa (Wu et al, 2005) (Figure 3.14). According the ISB recommendations, position of the wrist relative to the radius is defined as in neutral radial/ulnar deviation (0°) and neutral flexion/extension (0°) when the third metacarpal long axis (Y) is parallel to the Y axis of the radius (Wu et al, 2005).

3.5.2 Data Analysis

The Workstation 4.4 software (Oxford Metrics Ltd.) was used for the processing of the data collected from the VICON cameras. The three markers of every marker cluster were linked together (Figure 3.15) in order for the system to be able to recognize them as one co-ordinate system.

The processed kinematic data, together with the kinetic data and the pointing trials were used as input into the BodyBuiler software (Oxford Metrics Ltd.) for further kinetic and kinematic analysis. Thus, the wrist joint angles, the loads applied at each individual finger in the transducer axis system as well as the external loads in the metacarpal axis system were calculated.

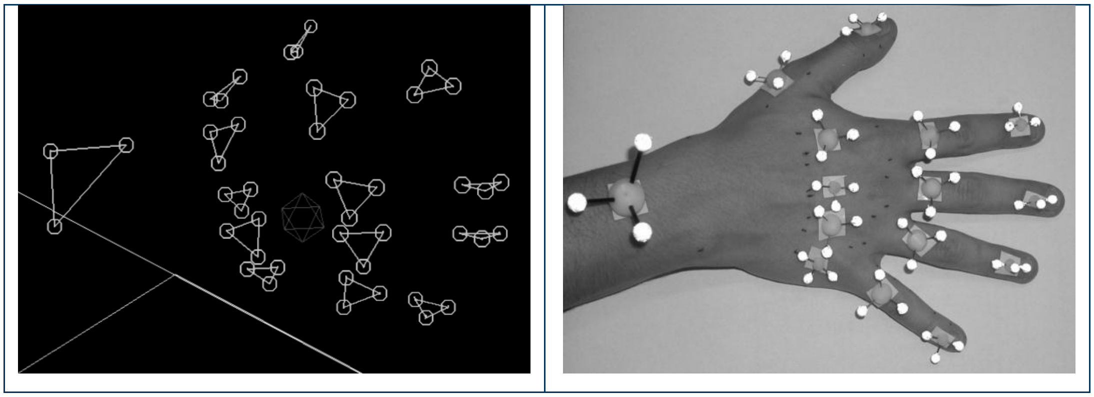


Figure 3.15: *The hand with the markers as it is shown after processing in the Workstation 4.4 software*

3.5.3 Statistical Analysis

The Statistica 7.0 (StatSoft Corp.) software was used in order to perform the standard statistical analysis of the results and the SPSS 14.0 (IBM Corp.) for the Principal Component Analysis of the hand and wrist complex. The statistical significance was calculated at 95% Confidence Intervals (CI) ($p \leq 0.05$).

CHAPTER 4: **Kinematics: Results and Discussion**

4.1 Wrist Joint Laxity Scores

4.1.1 Introduction

The wrist joint laxity score (WJLS), as studied by Garcia-Elias et al (1995) and Craigen and Stanley (1995), seems to express the kinematics of the wrist, to be related with the joint type and to differ between the genders. In this study, the joint laxity scores (Appendix F1) were first compared between gender groups for every hand, to determine if there were any statistical differences between them. This was done to determine if it was necessary to compare right and left wrist joint laxities between gender groups or between whole populations.

The distribution of the WJLS for every population was normal, as shown in Appendix F2. There were some outliers though, shown in the Boxplots in Appendix F2 for some of the groups and therefore non-parametric statistical tests were used in this study, as they are robust against them. For both the Mann-Whitney W test (used to compare the WJLS between the genders) and the Wilcoxon Matched Pairs test (used to determine difference between the hands), the null hypothesis was H_0=equal medians.

4.1.2 Differences in the Wrist Joint Laxity Scores by Gender

4.1.2.1 Right Hand Groups

The descriptive statistics of the right wrists joint laxity scores (WJLS-R) by the variable of gender (male=M, female=F) are as follows:

	Gender	N	Mean	Median	Standard Deviation
WJLS-R	M	25	51.44	54.0	19.11
WJLS-R	F	25	55.24	58.0	16.22

The Mann-Whitney W test showed no statistical difference in the right hands WJLS between the genders (W=594.0, p=0.4).

4.1.2.2 Left Hand Groups

The descriptive statistics of the left wrists joint laxity scores (WJLS-L) by the variable of gender (male=M, female=F) are as follows:

	Gender	N	Mean	Median	Standard Deviation
WJLS-L	M	22	49.91	50.0	14.90
WJLS-L	F	23	54.65	53.0	18.97

The Mann-Whitney W test showed no statistical difference in the left hands WJLS between the genders (W=456.5, *p*=0.266).

In conclusion, the wrist joint laxity scores between genders were investigated in both hands and there was no evidence of differences in 95% Confidence Intervals. Thus, any differences in the wrist joint laxity scores between the two hands were investigated considering the whole population for each hand regardless of gender.

4.1.3 Differences in the Wrist Joint Laxity Scores between the hands

The Wilcoxon Matched Pairs test was used to indicate any differences in wrist joint laxity scores between the two hands, with the wrist joint laxity to be considered as the dependent variable. Consistent with the aforementioned Mann-Whitney W test, the Wilcoxon Matched Pairs test is non-parametric, as powerful and sensitive as the two sample t-test, and robust against the population distribution or the existence of outliers. It compares between two medians to suggest whether both samples come from the same population or not (Ho=equal medians).

Variables	**Wilcoxon Matched Pairs Test** Significant at p <0.05		
	N	**Z**	***p*-level**
WJLS-R vs. **WJLS-L**	45	-0.985	0.325

The results show that there is no evidence that the two samples come from different populations in 95% C.I.

4.2 Kinematic Results

The distribution of the wrist positions (whole raw data set) chosen by the subjects is shown graphically in the Figure 4.1. The signs in all positions have been inverted and thus, the right wrist is assumed to be in the centre of the axes, with the fingers showing the positive direction of the Y and the thumb the positive direction of the Z axis.

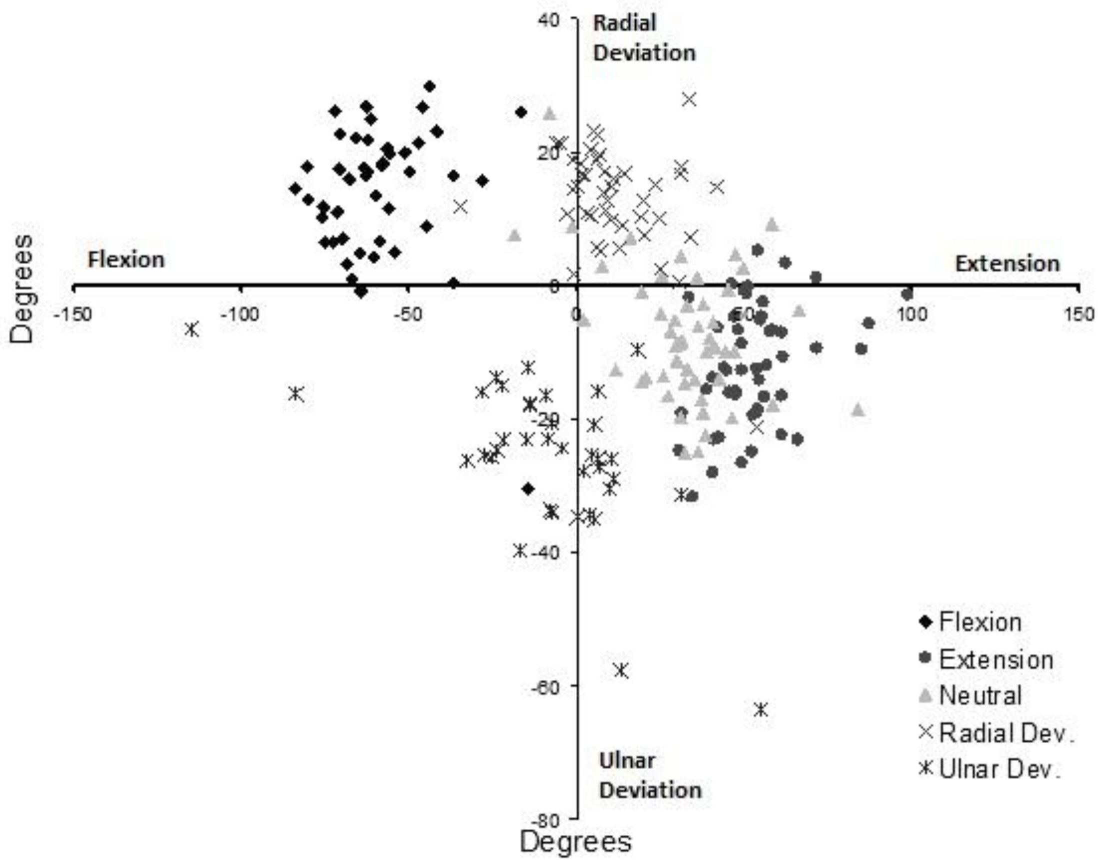


Figure 4.0.1: *The mean angles chosen by the subjects in the five wrist orientations shows coupling of motion in other planes.*

The Box-Plots of the kinematic results showed outliers and some extremes (Appendix G3). Thus, as before, the Mann-Whitney W test was used to define any differences between genders. The test (Appendix G5) showed no significant differences between genders in extension, flexion and ulnar deviation. However, there is a statistically significant difference between genders in the wrist position chosen by the subjects in the radial deviation trials (see table 4.5). There is also a statistically significant difference between genders in the ulnar deviation accompanies the neutral wrist position (Table 4.1). The mean values (excluding the extremes) and the medians (for the whole data set) for every wrist position were therefore calculated regardless of gender, except in the cases of neutral and radial deviation.

Table 4.1: *The mean and median of the neutral wrist position, with the combined radioulnar deviation, by gender.*

	Mean (degrees) (±SD)		**Median** (degrees)	
	Males	**Females**	**Males**	**Females**
Neutral (-)	-37.2 (±10.5)	-35.2 (±10.8)	-35.1	-32.2
Combined Radial (-)-Ulnar (+) deviation	5.5 (±9.0)	10.8 (±8.2)	5.7	11.3

Table 4.2: *The mean and median of the extension wrist position, with the combined radioulnar deviation.*

	Mean (degrees) (±SD)	**Median** (degrees)
Extension(-)	-50.8 (±9.5)	-52.4
Combined Radial (-)-Ulnar (+) deviation	11.9 (±9.0)	12.4

Table 4.3: *The mean and median of the flexion wrist position, with the combined radioulnar deviation.*

	Mean (degrees) (±SD)	**Median** (degrees)
Flexion (+)	60.7 (±12.6)	61.9
Combined Radial (-)-Ulnar (+) deviation	-14.9 (±8.0)	-16.4

Table 4.4: *The mean and median of the ulnar deviation, with the combined flexion-extension.*

	Mean (degrees) (±SD)	**Median** (degrees)
Ulnar deviation (+)	23.8 (±7.9)	25.4
Combined Flexion (+)-Extension (-)	5.5 (±15.3)	7.3

Table 4.5: *The mean and median radial deviation, with the combined flexion-extension by gender.*

	Mean (degrees) (±SD)		**Median** (degrees)	
	Males	**Females**	**Males**	**Females**
Radial deviation (-)	-15.2 (±5.0)	-11.7 (±6.9)	-16.4	-10.6
Combined Flexion (+)-Extension (-)	-11.4 (±13.7)	-12.1 (±11.4)	-6.3	-8.2

The mean values of the wrist positions given in tables 4.1-4.5, are represented graphically, as the mean position vectors defining the optimum position for every trial type (Figures 4.2a,b).

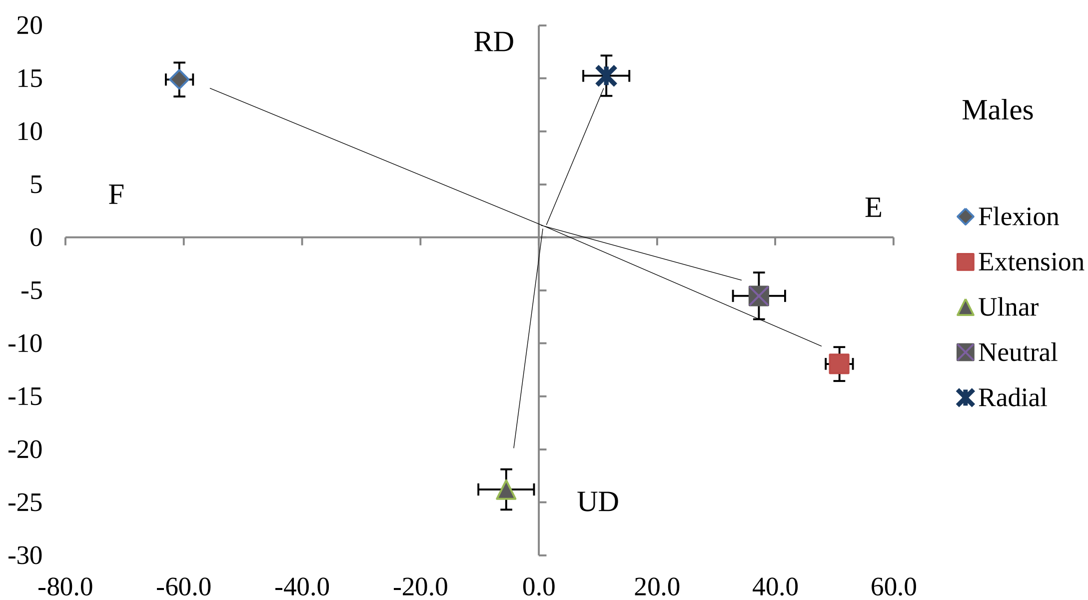


Figure 4.2a: *Position vectors (with standard errors) of the mean angles chosen by the male subjects in the five wrist positions (F,E,RD and UD the Flexion, Extension, Radial and Ulnar deviation respectively).*

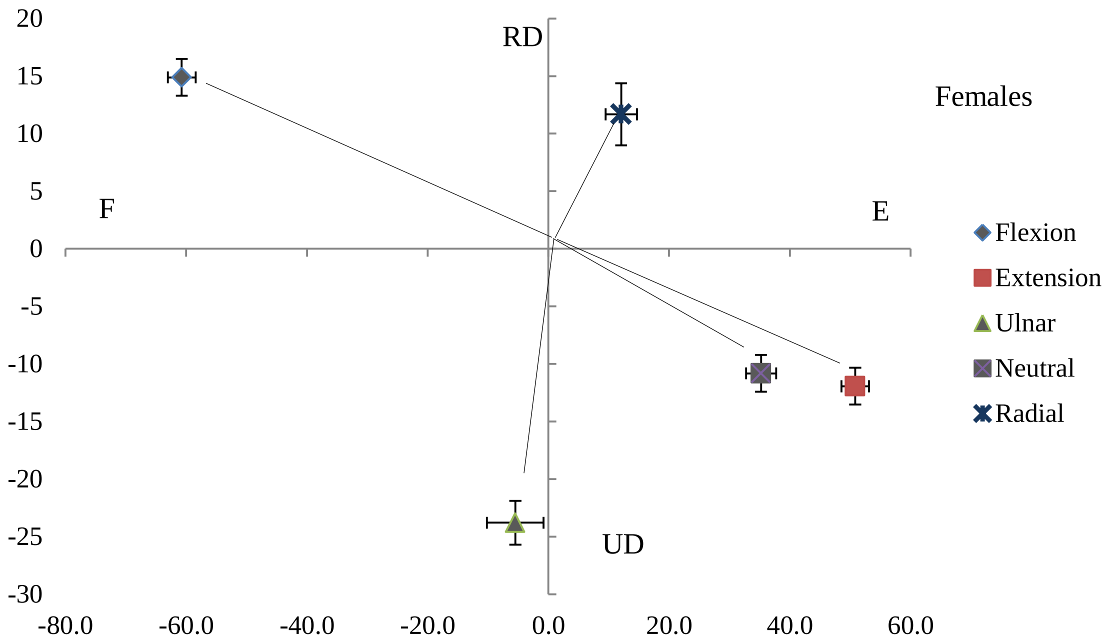


Figure 4.0.2b: *Position vectors (with standard errors) of the mean angles chosen by the female (bottom) subjects in the five wrist positions (F,E,RD and UD the Flexion, Extension, Radial and Ulnar deviation respectively).*

All the wrist positions were also examined for any correlation with the wrist joint laxity scores (Appendix G6), but no correlation was found between these variables. Additionally, the neutral, flexion and extension trial positions did not show any correlation with the maximum (passive) flexion and extension angles of the wrist, measured for the wrist joint laxity scores (Appendix G7).

Finally, the correlation between the optimum neutral position of the wrist and the position of wrist extension was also investigated (Figure 4.3) and showed that the neutral position of the wrist chosen by the subjects seems to be related to the extended position. The Regression analysis was used to statistically test this hypothesis (Figure 4.4).

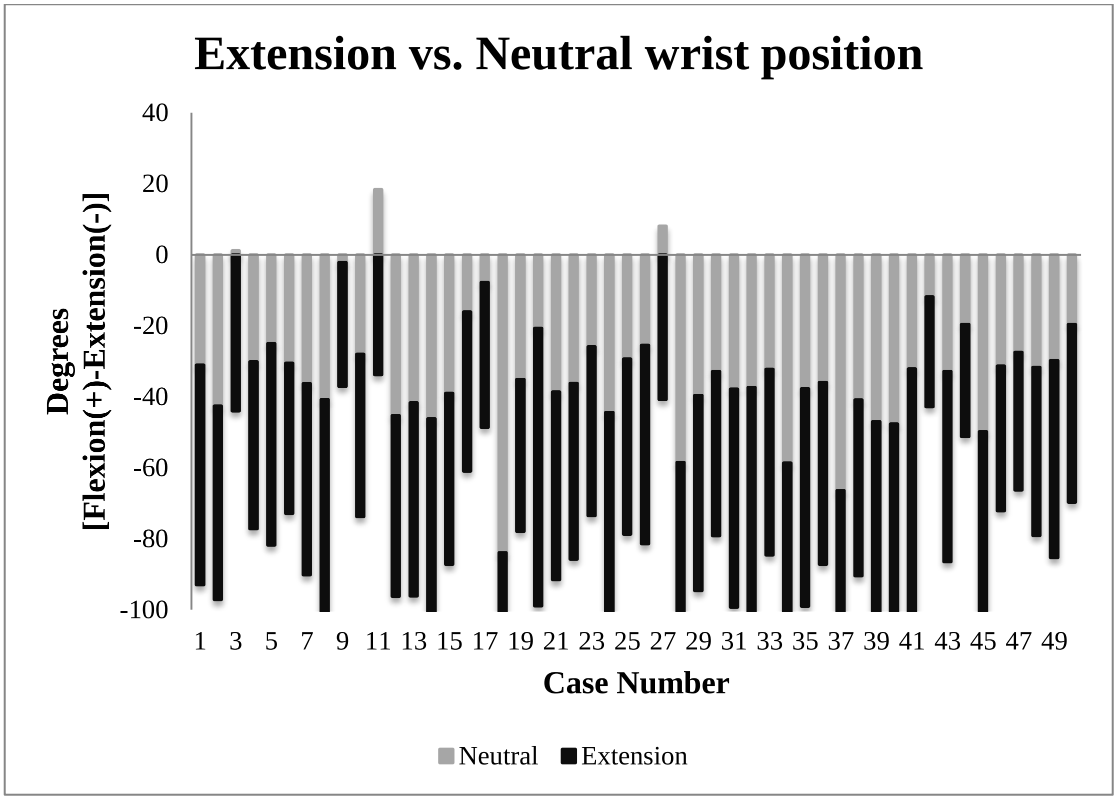


Figure 4.0.3: *The mean angles of neutral and extension chosen from every subject (cases).*

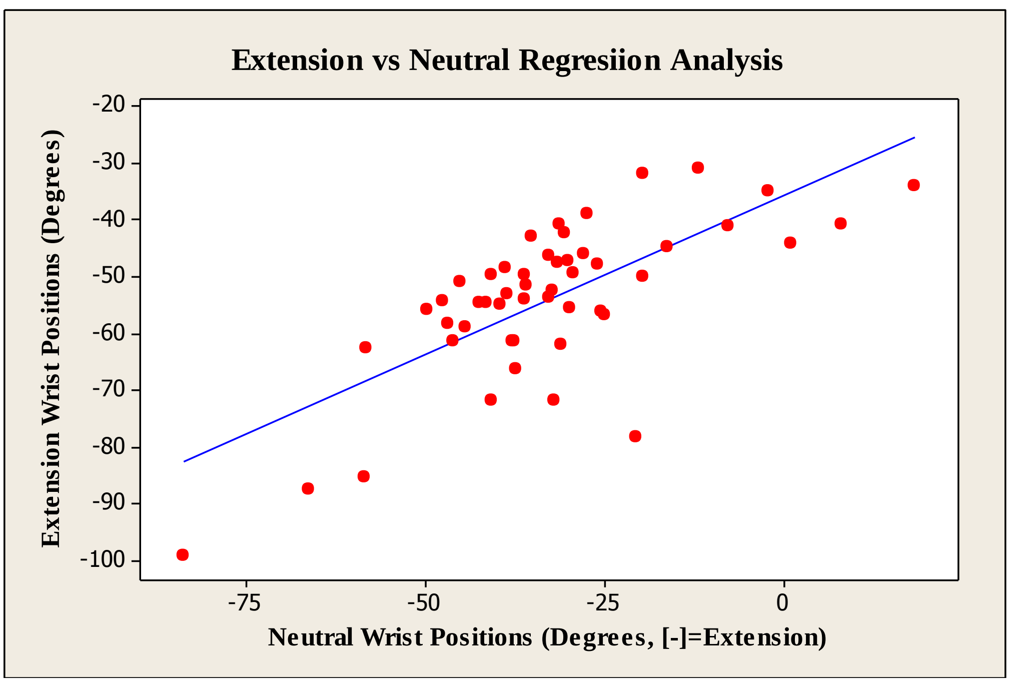


Figure 4.0.4: *The correlation graph of extension vs. neutral wrist position.*

There is evidence that the neutral position of the wrist is moderately correlated with the extended position (R-Sq (adj) =0.514, $p<0.05$). The subjects that produced a larger wrist extension also chose a more extended position for the neutral trials and vice versa.

4.3 Discussion

The study of Craigen and Stanley (1995) showed that wrist joints cover a kinematic spectrum (from row type to column type wrist), as far as the movement of the proximal row is concerned. They found that females have a greater tendency to scaphoid shortening (flexion) and less translation during the radial deviation and were of the column type wrist. Males, on the other hand, showed exactly the opposite characteristics and most of them were of row type wrist.

Based on the above described results, Garcia-Elias et al (1995) tried to correlate the type of the wrist with a clinical measurement, the WJLS. They claimed a statistical significant correlation ($p<0.001$) between the variables, but with only $R^2=33.2\%$ linear relation, which in statistics indicates a "medium correlation". They also found a significant difference in global laxity (WJLS) between the genders, with woman showing higher global laxity than men (Male: 48.5±15; Female: 56.7±15; $p=0.045$; N=60).

In this study no statistical significant difference was found between the genders in the WJLS, not only on their right, but also in their left hands. It is difficult to explain this discrepancy between the studies. Garcia-Elias et al (1995) used a non-parametric statistical test to compare male and female WJLS results and a parametric one (Pearson's test) to correlate WJLS with the type of the wrist. The present work showed that the distribution of the WJLS is normal (Appendix F2) and therefore there is no methodological error in their research, assuming that the distribution of their results is also normal. As the number of the subjects participated in these studies are similar

(N=50 in the present study, N=60 in Garcia-Elias' study), one possible explanation lies in the error of the measurements: the standard clinical goniometer and the calliper used do not provide as accurate results as needed in order to have consistency between the two studies.

Reviewing the literature, only a few papers have been found to use the Garcia-Elias' WJLS measurement in order to describe the laxity of the wrist, proving that the scientific community has low confidence in this method. Actually, the most recent one, conducted by van Andel et al (2008), showed that the WJLS is not suitable for quantification of laxity and seems to measure mobility rather than laxity. To quantify wrist laxity in a reliable and clinically relevant manner, it seems that a consensus needs to be established between clinicians as to what elements of (abnormal) wrist motion define the wrist as "lax". The authors proposed that the development and testing of a measurement device that quantifies wrist translation might be needed for determining an objective score for wrist laxity.

In conclusion, both the discrepancy of the results between this work and Garcia-Elias' one as well as the findings of van Andel et al (2008), indicate that the WJLS is not a suitable tool to assess the laxity of the wrist and therefore any correlation between this laxity and the type of the joint. It seems to measure the mobility and not the laxity of the wrist and as a clinical test with subjective factors to be involved in the measurements, its validity is low. In the present study many correlations between the WJLS and other variables follow and therefore the reader should keep in mind the above described limitations of the method.

In most of the subjects, flexion was combined with radial deviation of the wrist, extension with ulnar deviation, ulnar deviation with flexion of the wrist and radial deviation with extension. In the neutral trials a position of wrist extension combined with ulnar deviation was chosen. The analysis of these results, by gender, showed the symmetry presented in Figures 4.2a,b. In these graphs, the functional axes of the wrist are shifted clockwise with respect to the anatomical axes, providing a remarkable geometry. The flexion and extension positions lie almost on the same line, with an angle of 14º and 13.5º respectively in respect to the anatomical X axis, common for both genders. There are differences by gender though as regards the neutral position of the wrist. Specifically, the neutral wrist position chosen by the males and females, both have no statistically different extension but the combined ulnar deviation is less in male than in female subjects (8.5º and 17.6º respectively, with respect to the anatomical X axis). Note that the average of these two angles is 13º with respect to the anatomical X axis, namely very close to the flexion-extension line described above.

The ulnar deviated position has a common angle for both genders of 21.3º with respect to the anatomical Z axis, but there are statistically different positions by gender as regards the radial deviation position of the wrist. The male subjects provided more ulnar deviation in less extended position (13.7º with respect to the anatomical Z axis), while females exactly the opposite (34.5º with respect to the anatomical Z axis). The average of these two angles is 24.1º with respect to the anatomical Z axis, namely very close to the ulnar deviated angle described above. In general, the functional axes of the wrist (as regards the production of maximal gripping force) differ clearly from the anatomical ones, are shifted clockwise and keep an almost right angle between them.

There is no evidence in the literature referring to this phenomenon. The differences between the genders along the vertical axis (radioulnar deviation) may be explained by the type of the wrist. Craigen and Stanley (1995) claimed that females would be likely to have reduced range of motion in radial deviation as most of them are of column type wrist; male subjects, on the other hand, demonstrated increased range of motion in radial deviation as most of them are of row type wrist. The present study confirms that the type of the wrist is expressed in the kinematic results and fully verifies the Craigen and Stanley (1995) assumption. Specifically, female subjects presented –during the radial deviation trials- statistically significant less radial deviated positions of their wrists in comparison with the male subjects. The more extended position presented by the females with respect to the males in these trials, probably explains the need to overcome this reduction in mobility in radial deviation.

In neutral wrist position trials, both genders chose a non-statistical different extended position of the wrist, but females presented a statistically different combined ulnar deviation. The angle between the radial deviation position and the neutral (in Figures 4.2a,b) was shifted clockwise in female subjects, with respect to males, and it was smaller (84.5º for the male subjects and 73.1º for the females). This result may indicate that the scaphoid bone (and therefore the wrist type) governs the whole kinematic envelope between the radial deviation and the neutral wrist position, decreases its range for the column type wrists and it shifts it ulnarly, in less compressed for the scaphoid positions, in order for the hand to produce its maximal static gripping force.

The results of the present work show that, even if there is more than one kinematic pattern for the scaphoid as Moojen et al (2002) claimed, males and females have different wrist kinematic behaviour which may indicate that the "type of wrist" theory exists and needs further investigation.

The WJLS was not correlated with any of the functional wrist positions chosen by the subjects, and the maximal passive flexion and extension of the wrist with the functional flexion extension or neutral wrist positions. This is reasonable, as the WJLS likely describes the mobility of the wrist more than its laxity, and it is unclear if this mobility is strongly correlated with the type of the wrist. Thus, the range of motion characteristics around the anatomical axes does not seem to affect the wrist positions during the maximal stating gripping force tasks. A medium correlation was found between the functional neutral and extension position chosen by the subjects, regardless of the gender; however, there is no evidence in the literature about this. The importance and clinical relevance of the kinematic results conversed previously, are discussed in the next chapter.

CHAPTER 5: **Kinetics: Results and Discussion**

5.1 The Maximal Grip Force

The loads were calculated as the mean magnitudes of the resultants applied to the thumb with respect to the metacarpal axis system (Appendix E) in each wrist position and represented numerically and graphically in Table 5.1 and Figure 5.1 respectively.

Table 5.1: *Mean forces and moments (magnitudes) of the thumb in the five wrist positions.*

	Maximal Mean Force (N)(±SD)	Maximal Mean Moment (Nm)(±SD)
Neutral	70.8 (20.6)	3.16 (0.91)
Extension	60.7 (22.0)	2.82 (1.06)
Flexion	49.0 (16.8)	1.99 (0.74)
Radial Deviation	59.8 (15.4)	2.24 (0.75)
Ulnar Deviation	57.4 (16.2)	2.50 (0.90)

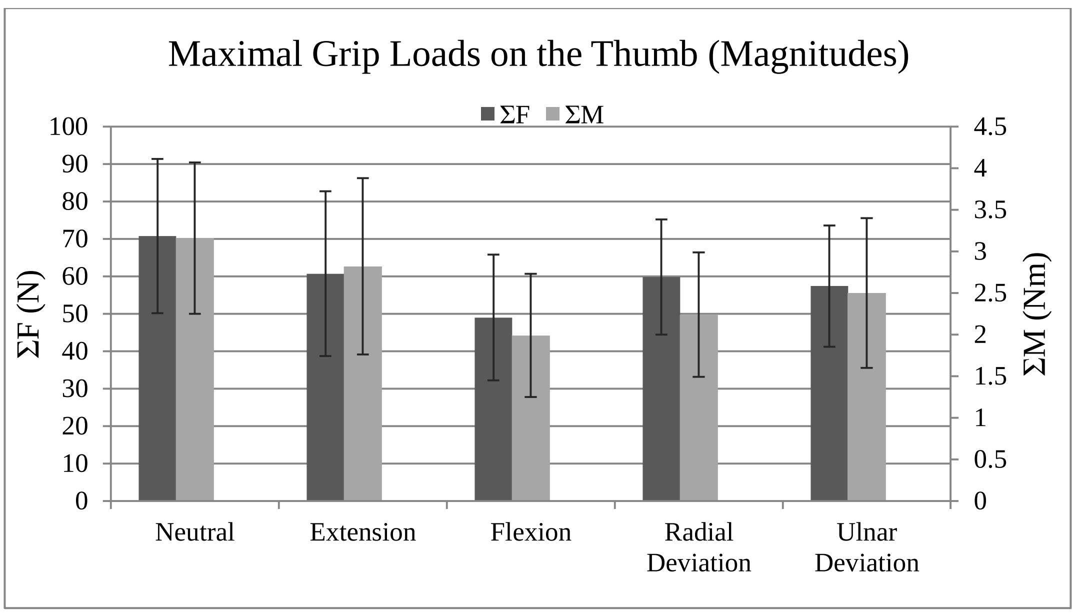


Figure 5.0.1: *Graphical representation of the mean magnitude loads (with SDs) of the thumb in the five wrist orientations.*

In the neutral wrist position (discussed in the previous chapter), the subjects were able to generate the maximum grip forces and moments whereas in the flexed position the minimum loads were achieved. The percentage differences of the mean magnitude of the resultant forces and moments in each wrist position with respect to the neutral position are shown in Figure 5.2.

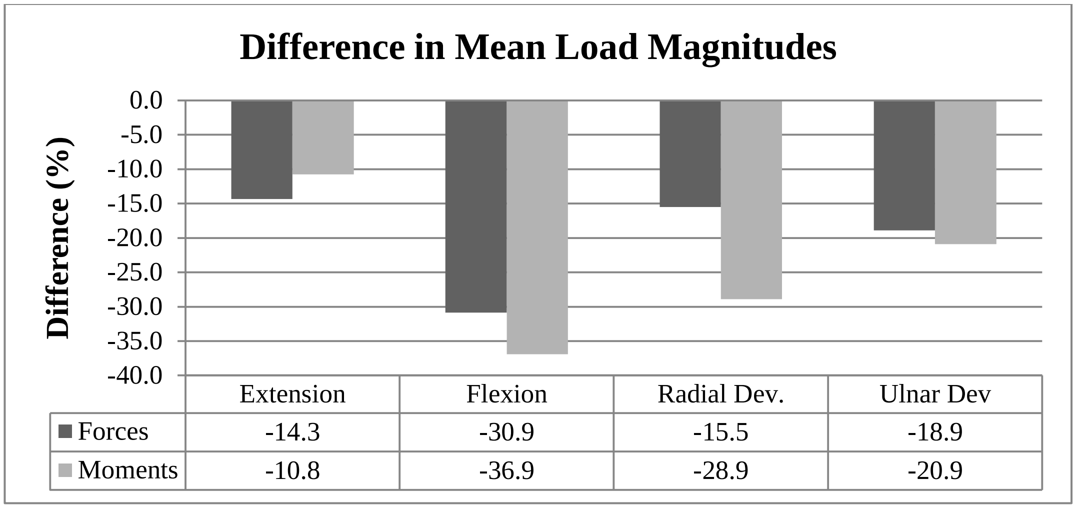


Figure 5.2: *The percentage difference of the mean magnitudes of the resultant forces and moments in each wrist position applied to the thumb with respect to the neutral position.*

Between genders, although neutral was the most effective wrist position for providing maximum forces and moments in both groups, and flexion the least effective, male subjects presented larger loads than females in all the wrist positions, as shown in Table 5.2.

Table 5.2: *Mean magnitudes of the resultant forces and moments applied to the thumb in the five wrist positions by gender.*

	Maximal Force Magnitude (N±SD)		Maximal Moment Magnitude (Nm±SD)	
Wrist orientation	Males	Females	Males	Females
Neutral	82.3 (22.1)	60.2 (12.0)	3.53 (0.81)	2.81 (0.87)
Flexion	58.4 (18.3)	40.3 (9.3)	2.25 (0.77)	1.76 (0.64)
Extension	72.7 (23.4)	49.1 (12.7)	3.29 (1.10)	2.36 (0.80)
Radial Deviation	67.4 (13.8)	51.9 (12.9)	2.43 (0.82)	2.05 (0.63)
Ulnar Deviation	67.5 (15.8)	49.9 (12.1)	2.75 (0.78)	2.31 (0.96)

These results are represented graphically in Figures 5.3 and 5.4.

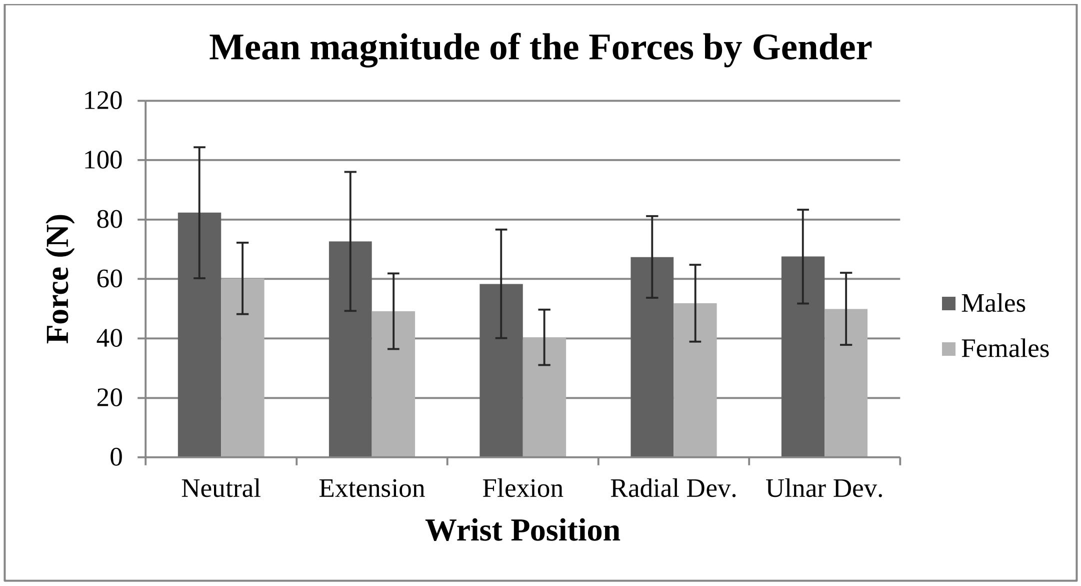


Figure 5.3: *The mean magnitude of the resultant forces (with SD) applied to the thumb by gender in the five wrist positions.*

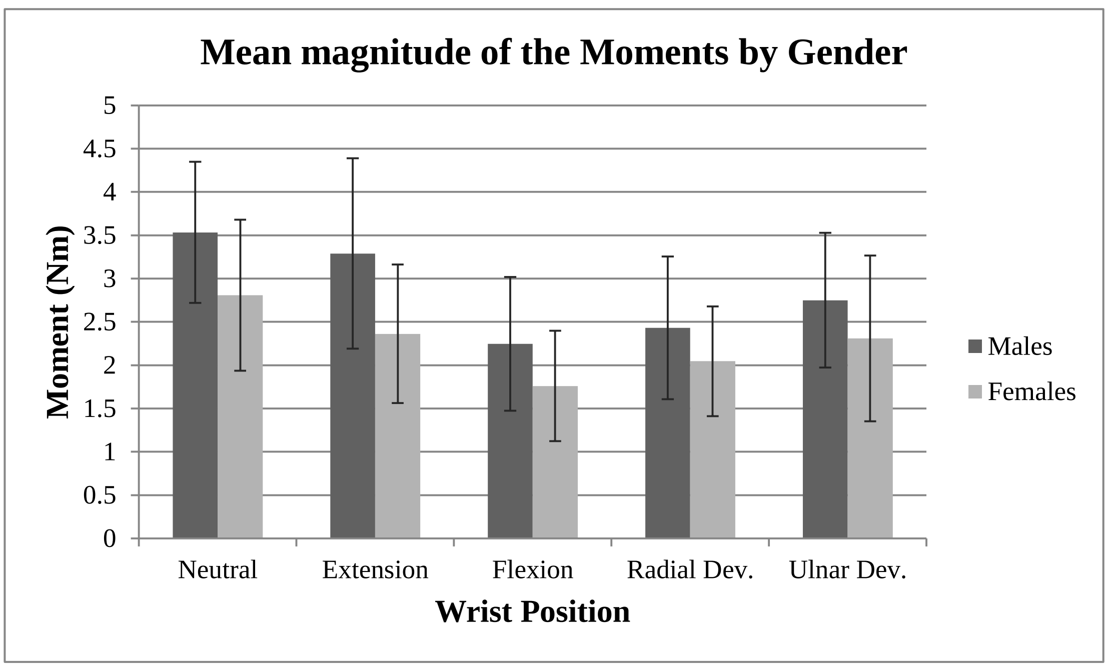
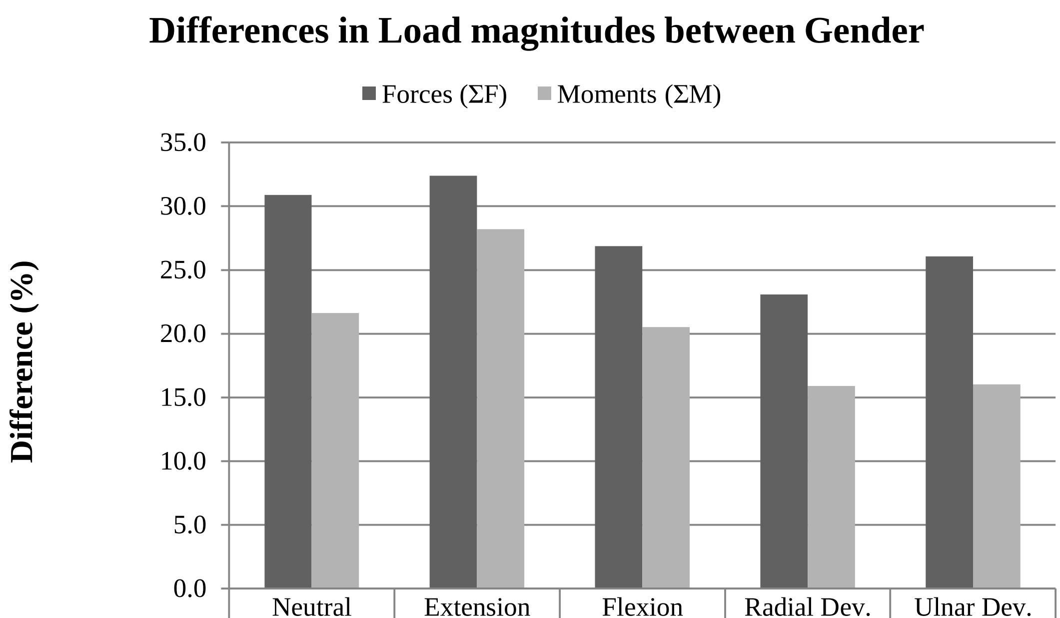


Figure 5.4: *The mean magnitude of the resultant moments (with SD) applied to the thumb by gender, in the five wrist positions.*

The percentage differences of the mean magnitude of the resultant forces and moments between genders in each wrist position are shown in Figure 5.5.



	Neutral	Extension	Flexion	Radial Dev.	Ulnar Dev.
Forces (ΣF)	30.9	32.4	26.9	23.1	26.1
Moments (ΣM)	21.6	28.2	20.5	15.9	16.0

Figure 5.5: *The percentage differences of the mean magnitude of the resultant forces and moments applied to the thumb between genders in each wrist position.*

5.2 The percentage distribution of the force across the fingers

The percentage distribution of the ΣF_zT force across the fingers was calculated with respect to the force transducer axis system. In this system, the F_zT axis is oriented normal to the transducer finger pads and a negative force produces compression on each transducer (Appendix E). ΣF_zT represents the summation of the measured F_zT force from each finger.

Statistical analysis (Appendix H3) showed no differences in this load distribution between the genders, thus the data for both male and female subjects were accumulated. The results for each wrist position are presented in Tables 5.3-5.7.

Table 5.3: *The percentage distribution of the $\Sigma F_z T$ across the fingers in the flexion position of the wrist.*

	Flexion	% of the $\Sigma F_z T$ (±SD)
Finger	Index	33.6% (11.8)
	Middle	30.2% (7.6)
	Ring	20.3% (4.9)
	Little	15.9% (6.3)

Table 5.4: *The percentage distribution of the $\Sigma F_z T$ across the fingers in the extension position of the wrist.*

	Extension	% of the $\Sigma F_z T$ (±SD)
Finger	Index	35.2% (8.9)
	Middle	26.7% (6.8)
	Ring	23.0% (5.3)
	Little	15.0% (5.1)

Table 5.5: *The percentage distribution of the $\Sigma F_z T$ across the fingers in the neutral position of the wrist.*

	Neutral	% of the $\Sigma F_z T$ (±SD)
Finger	Index	35.0% (7.6)
	Middle	29.9% (7.0)
	Ring	21.4% (5.5)
	Little	13.8% (6.0)

Table 5.6: *The percentage distribution of the $\Sigma F_z T$ across the fingers in the radial deviation of the wrist.*

	Radial Deviation	% of the $\Sigma F_z T$ (±SD)
Finger	Index	45.5% (13.0)
	Middle	25.8% (9.2)
	Ring	16.7% (5.3)
	Little	12.0% (5.7)

Table 5.7: *The percentage distribution of the ΣF_zT across the fingers in the ulnar deviation of the wrist.*

	Ulnar Deviation	% of the ΣF_zT (±SD)
Finger	Index	41.5% (11.2)
	Middle	23.9% (7.2)
	Ring	19.0% (6.2)
	Little	15.6% (5.0)

The graphical presentation of the percentage distribution of the ΣF_zT across the fingers in each wrist position in the force transducer axis system is shown (by wrist orientation) in Figure 5.6. and (by finger) in Figure 5.7.

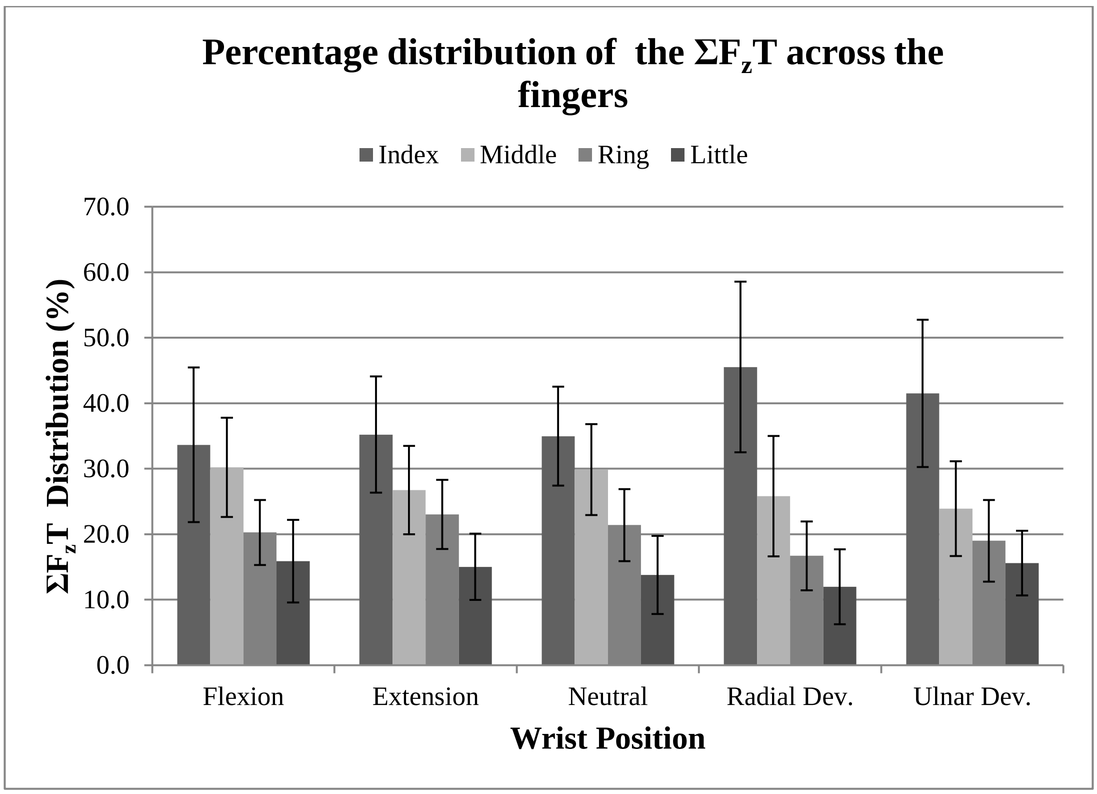


Figure 5.6: *The percentage distribution of the ΣF_zT (with SDs) across the fingers in each wrist position in the force transducer axis system (graph by wrist orientation).*

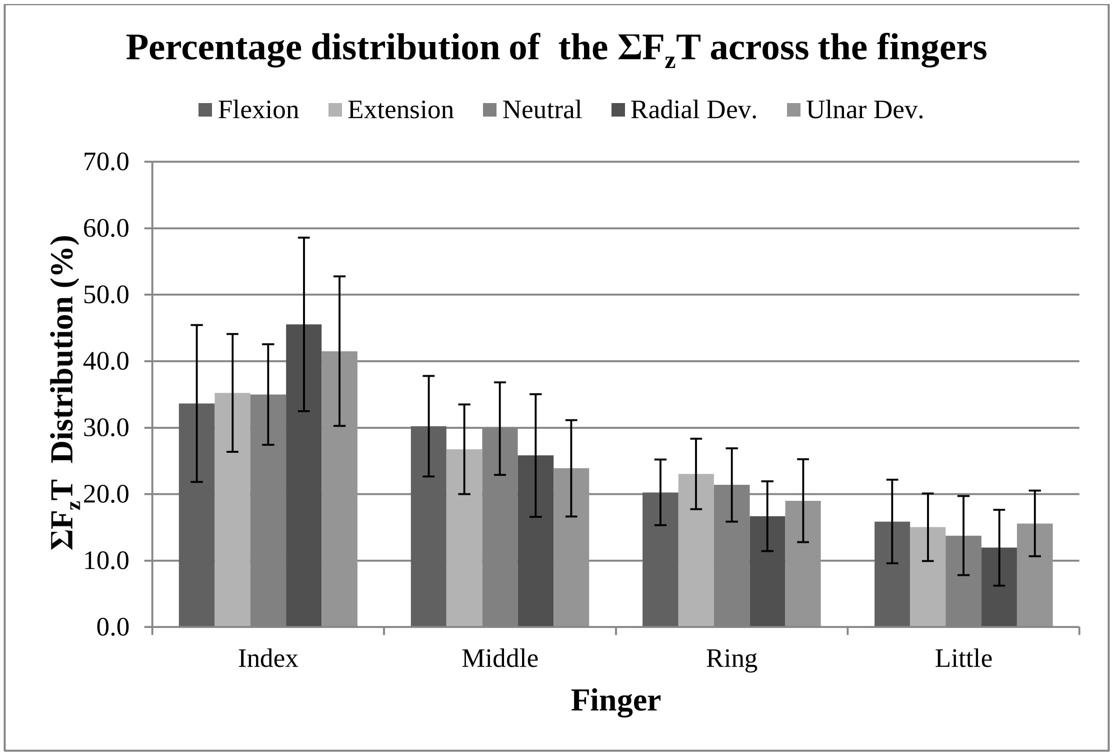


Figure 5.7: *The percentage distribution of the ΣF_zT (with SDs) across the fingers in each wrist position in the force transducer axis system (graph by finger).*

The differences in the percentage distribution of the ΣF_zT for each finger in the five wrist positions were investigated statistically (Appendices I2, I3). The results demonstrate a significant difference in the force distribution across the index, middle and ring finger, especially in the flexion-radial deviation and neutral-radial deviation of the wrist (Tables 5.8-5.11).

Table 5.8: *Differences in the percentage distribution of the ΣF_zT for the index finger in the five wrist positions.*

Index Finger				
	Flexion	Extension	Neutral	Radial Dev.
Extension	*p*= 0.566	---------------	---------------	---------------
Neutral	*p*= 0.779	*p*= 0.604	--------------	---------------
Radial Dev.	*P*= 0.008	*p*= 0.007	*p*= 0.001	---------------
Ulnar Dev.	*P*= 0.039	*p*= 0.073	*p*= 0.037	*p*= 0.012

Table 5.9: *Differences in the percentage distribution of the $\Sigma F_z T$ for the middle finger in the five wrist positions.*

Middle Finger				
	Flexion	Extension	Neutral	Radial Dev.
Extension	*p*= 0.234	---------------	---------------	---------------
Neutral	*p*= 0.795	*p*= 0.151	---------------	---------------
Radial Dev.	*p*= 0.035	*p*= 0.125	*p*= 0.012	---------------
Ulnar Dev.	*p*= 0.010	*p*= 0.105	*p*= 0.003	*p*= 0.863

Table 5.10: *Differences in the percentage distribution of the $\Sigma F_z T$ for the ring finger in the five wrist positions.*

Ring Finger				
	Flexion	Extension	Neutral	Radial Dev.
Extension	*p*= 0.010	---------------	---------------	---------------
Neutral	*p*= 0.304	*p*= 0.567	---------------	---------------
Radial Dev.	*p*= 0.230	*p*= 0.001	*p*= 0.015	---------------
Ulnar Dev.	*p*= 1.0	*p*= 0.073	*p*= 0.315	*p*= 0.206

Table 5.11: *Differences in the percentage distribution of the $\Sigma F_z T$ for the little finger in the five wrist positions.*

Little Finger				
	Flexion	Extension	Neutral	Radial Dev.
Extension	*p*= 0.341	---------------	---------------	---------------
Neutral	*p*= 0.604	*p*= 0.697	---------------	---------------
Radial Dev.	*P*= 0.056	*p*= 0.198	*p*= 0.353	---------------
Ulnar Dev.	*P*= 0.559	*p*= 0.559	*p*= 0.531	*p*= 0.027

For better understanding of the aforementioned differences in the percentage distribution of the $\Sigma F_z T$ across the fingers, a map-table for every finger follows (with colour are presented the statistical important differences) (Tables 5.12-5.15).

Table 5.12: *Map-table, with the statistical important differences (in colour), of the percentage distribution of the $\Sigma F_z T$ across the Index finger.*

		Index		
	Flexion	Extension	Neutral	Radial D.
Flexion				
Extension				
Neutral				
Radial D.				
Ulnar D.				

Table 5.13: *Map-table, with the statistical important differences (in colour), of the percentage distribution of the $\Sigma F_z T$ across the Middle finger.*

		Middle		
	Flexion	Extension	Neutral	Radial D.
Flexion				
Extension				
Neutral				
Radial D.				
Ulnar D.				

Table 5.14: *Map-table, with the statistical important differences (in colour), of the percentage distribution of the $\Sigma F_z T$ across the Ring finger.*

		Ring		
	Flexion	Extension	Neutral	Radial D.
Flexion				
Extension				
Neutral				
Radial D.				
Ulnar D.				

Table 5.15: *Map-table, with the statistical important differences (in colour), of the percentage distribution of the $\Sigma F_z T$ across the Little finger.*

		Little		
	Flexion	Extension	Neutral	Radial D.
Flexion				
Extension				
Neutral				
Radial D.				
Ulnar D.				

5.3 The loads on every finger in the metacarpal axis system

5.3.1 General

The loads on every finger (F_x, F_y, F_z, M_x, M_y, M_z) in every wrist position were calculated in terms of the metacarpal axis system (Appendix J) and the results are illustrated in Table 4.16 and given graphically in the following figures. In the metacarpal axis system $+F_x$ is palmarly directed, $+F_y$ is proximally directed and $+F_z$ radially directed according to ISB recommendations (Wu et al, 2005). The $+M_x$ tends to adduct the thumb, index and middle fingers and abduct the ring and little fingers, whereas $+M_y$ tends to internally rotate and $+M_z$ tends to flex all the fingers and the thumb (Appendix E).

Table 5.16: *Mean maximal external applied forces and moments with respect to the metacarpal axis system of each digit with varying wrist orientation (standard deviations given in parenthesis).*

	***Fx* (+ *palmar*)**					***Fy* (+ *proximal*)**					***Fz* (+ *radial*)**				
	Thumb	*Index*	*Middle*	*Ring*	*Little*	*Thumb*	*Index*	*Middle*	*Ring*	*Little*	*Thumb*	*Index*	*Middle*	*Ring*	*Little*
Neutral	-56.6 (20.1)	-2.9 (4.6)	-2.8 (4.5)	-3.7 (2.8)	-4.3 (3.5)	15.5 (14.6)	-18.7 (7.3)	-18.8 (8.0)	-13.5 (5.1)	-8.7 (4.7)	23.5 (25.4)	-13.3 (4.5)	-8.4 (4.6)	-6.0 (2.8)	1.9 (2.8)
Flexion	-32.4 (12.7)	-4.5 (3.5)	-2.4 (3.3)	-2.7 (1.9)	-1.6 (2.4)	20.0 (7.9)	-14.1 (5.0)	-15.7 (7.0)	-8.8 (3.8)	-6.4 (3.7)	21.5 (17.2)	-6.9 (2.9)	-3.1 (2.6)	-2.7 (2.0)	2.0 (2.0)
Extension	-43.5 (20.5)	-6.4 (4.5)	-3.9 (3.2)	-4.9 (3.4)	-4.4 (2.8)	8.7 (11.6)	-14.2 (5.4)	-12.1 (4.7)	-11.0 (4.8)	-6.5 (4.0)	27.5 (20.5)	-11.9 (6.4)	-5.3 (4.7)	-5.6 (4.4)	1.8 (3.4)
Radial Dev.	-47.5 (15.2)	0.8 (4.2)	-1.1 (3.6)	-1.8 (2.9)	-1.4 (2.1)	23.9 (9.9)	-17.6 (6.6)	-11.5 (6.2)	-7.7 (3.7)	-6.1 (3.7)	16.8 (16.8)	-14.7 (7.5)	-7.4 (4.2)	-4.9 (2.5)	1.8 (2.1)
Ulnar Dev.	-47.2 (15.0)	0.7 (5.2)	0.1 (3.2)	-2.3 (3.2)	-3.2 (2.8)	13.6 (11.9)	-12.2 (4.4)	-10.3 (4.7)	-7.6 (3.7)	-7.5 (3.3)	10.3 (16.8)	-19.3 (9.3)	-9.5 (4.5)	-6.4 (4.8)	0.8 (4.0)

	***Mx* (+ *tt. adduct*)**					***My* (+ *tt. pronate*)**					***Mz* (+ *tt. flex*)**				
	Thumb	*Index*	*Middle*	*Ring*	*Little*	*Thumb*	*Index*	*Middle*	*Ring*	*Little*	*Thumb*	*Index*	*Middle*	*Ring*	*Little*
Neutral	-1.21 (1.19)	0.97 (0.35)	0.42 (0.37)	0.21 (0.26)	-0.22 (0.20)	-0.70 (0.67)	0.55 (0.23)	0.53 (0.28)	0.36 (0.19)	0.01 (0.16)	-2.33 (0.93)	-0.99 (0.49)	-1.22 (0.58)	-0.93 (0.36)	-0.62 (0.40)
Flexion	-1.08 (0.77)	0.65 (0.25)	0.26 (0.27)	0.14 (0.18)	-0.29 (0.24)	-0.30 (0.48)	0.21 (0.17)	0.12 (0.17)	0.12 (0.10)	0.01 (0.11)	-1.22 (0.59)	-0.83 (0.44)	-088 (0.48)	-0.50 (0.23)	-0.22 (0.26)
Extension	-1.34 (1.14)	0.83 (0.32)	0.25 (0.32)	0.23 (0.28)	-0.18 (0.27)	-0.44 (0.69)	0.39 (0.31)	0.27 (0.29)	0.28 (0.28)	-0.01 (0.13)	-1.81 (0.98)	-0.90 (0.43)	-0.75 (0.32)	-0.71 (0.34)	-0.43 (0.28)
Radial Dev.	-0.84 (0.92)	0.99 (0.42)	0.36 (0.35)	0.21 (0.22)	-0.23 (0.17)	-0.38 (0.54)	0.60 (0.33)	0.42 (0.29)	0.26 (0.16)	-0.04 (0.09)	-1.75 (0.69)	-0.67 (0.45)	-0.69 (0.41)	-0.48 (0.25)	-0.31 (0.23)
Ulnar Dev.	-0.63 (0.84)	1.05 (0.34)	0.36 (0.32)	0.11 (0.23)	-0.27 (0.32)	-0.36 (0.53)	0.67 (0.42)	0.52 (0.27)	0.41 (0.29)	0.12 (0.19)	-1.94 (0.55)	-0.40 (0.28)	-0.54 (0.26)	-0.49 (0.23)	-0.30 (0.20)

5.3.2 Forces

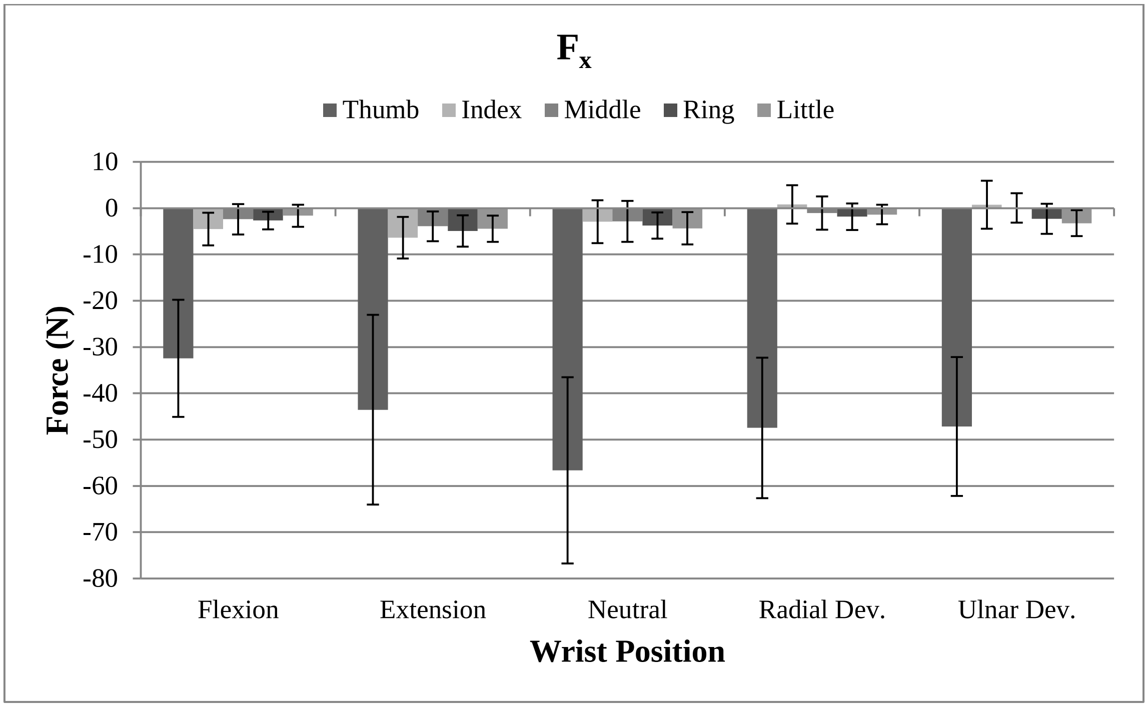


Figure 5.8: *The mean F_x force (with SD), in the metacarpal axis system, applied to each digit in every wrist orientation.*

The reaction force $\boldsymbol{F_x}$ (Figure 5.8) is dorsally oriented for all the fingers in all the positions, tending to extend the wrist joint. However, in radial deviation the index and in ulnar deviation the index and the middle finger see palmarly applied F_x forces which will tend to flex the wrist. That is probably because in these wrist positions these fingers were placed by most of the subjects in an internally rotated position for a comfortable grip, contacting the tool with the radial side of the digital pads.

The large magnitude of the negative F_x on the thumb is due to the required equilibrium of forces: the resultant reaction force exerted on the thumb, which is the summation of its F_x, F_y and F_z components, has to be in equilibrium with the summation of the fingers' resultant reaction forces.

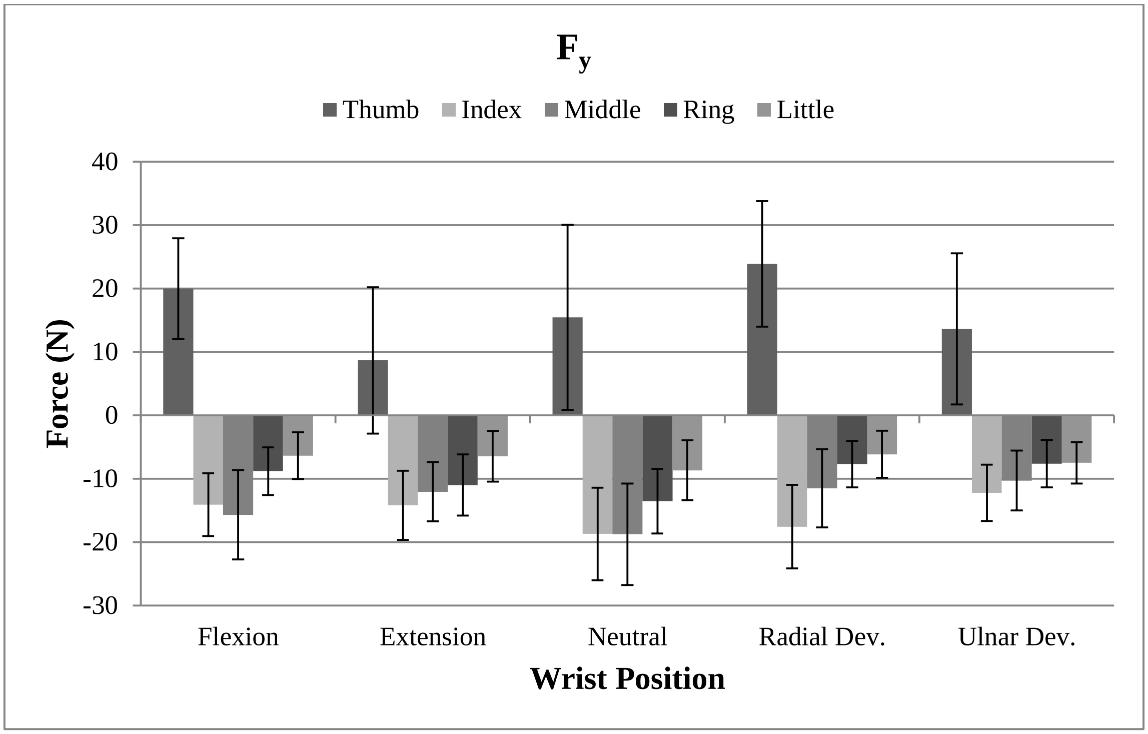


Figure 5.9: *The F_y force (with SD), in the metacarpal axis system applied to each digit in every wrist position.*

The reaction force $\boldsymbol{F_y}$ (Figure 5.9) is distally oriented for all the fingers in all the wrist positions. The distribution across the fingers is similar to that measured for F_z in the transducer axis system. However, the reaction force F_y is proximally oriented in the thumb, tending to compress the thumb metacarpal. The fingers comprise three bones and thus they are able to perform a “hook” type grip with the distal digits presenting almost in parallel to their respective metacarpals. Hence, the reaction forces on this axis are transferred from a force tending to compress the distal segments to a distally directed force at the metacarpal level (tension). On the other hand, the thumb consists of only two segments and thus it is unable to perform the same hook gripping as the fingers.

Additionally, in contrast with the fingers, the thenar muscles generally produce a large contribution of the thumb’s gripping force with less from the intrinsic flexor muscles. Therefore, the thumb segments are held in a less flexed position during gripping and the reaction force on this axis is transferred as force tending to compress the thumb metacarpal bone.

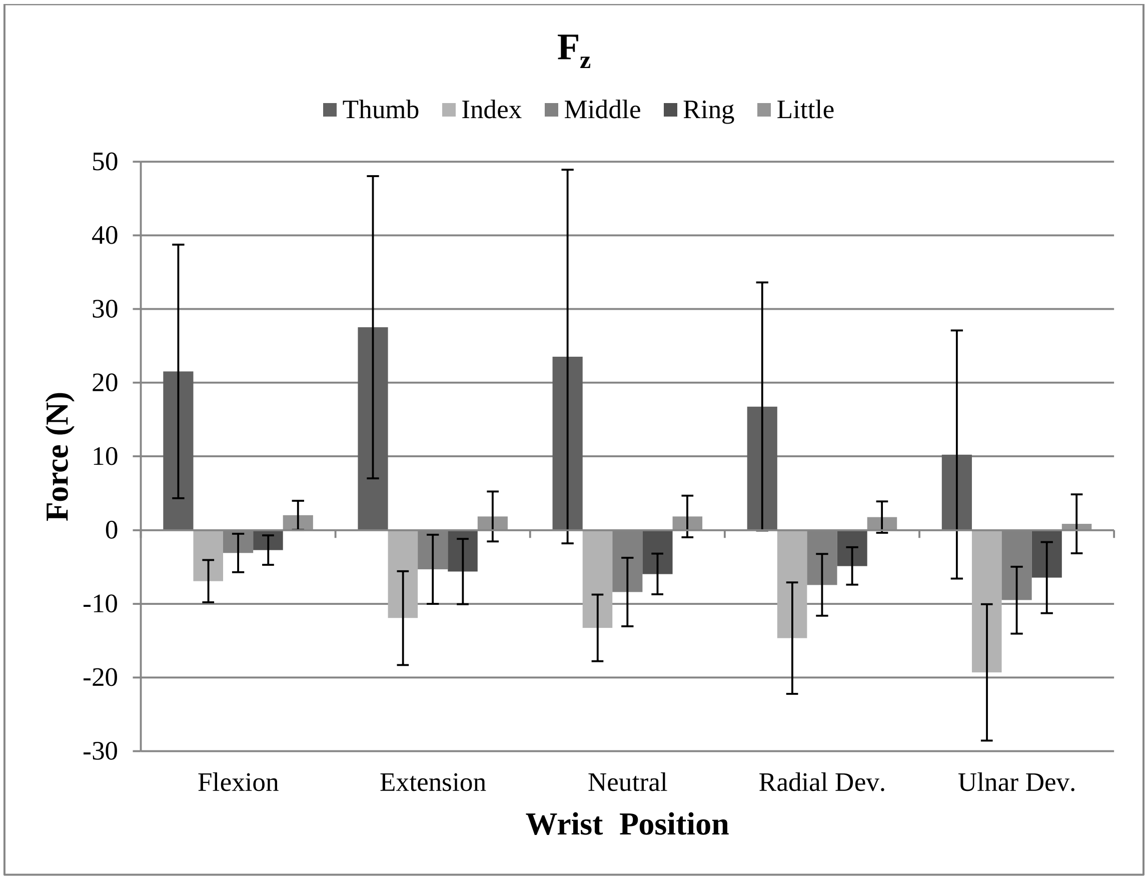


Figure 5.10: *The F_z force (with SD), in the metacarpal axis system applied to each digit in every wrist position.*

The F_z reaction force (Figure 5.10) is ulnarly oriented for the index, middle and ring fingers and radially for the little finger. This distribution of the F_z reaction force demonstrates the functional anatomy of the hand: the fingers tend to fold in to the centre of the palm. During the trials, the index, middle and ring finger were placed radially with respect to this centre and thus experienced a negative F_z whereas the little finger was placed ulnarly and a positive F_z was applied.

In radial and ulnar deviation the F_z force is larger in the index finger than in the other positions. That is probably because of the placement of the index finger in these two positions. As described above, the finger, in radial and ulnar deviation in particular, was internally rotated contacting the gripping tool with its radial side. Hence, the reaction force negative F_z is bigger than that in the other wrist positions. The thumb also tends to fold in to the centre of the palm like the fingers. However, as it acts in opposition to the fingers, the direction of the applied F_z is reversed.

5.3.3 Moments

According the metacarpophalangeal axis system (Appendix J), the MCP moment axis system is presented in figure 5.11 for better understanding of the results. In this axis system the origin (O) represents the joint centre (in the precented case the centre of the third metacarpalangeal joint), the $+M_y$ tends to internally rotate the MCP joints, the $+M_z$ tends to flex the MCP joints and the $+M_x$ to ulnary deviate the MCP joints.

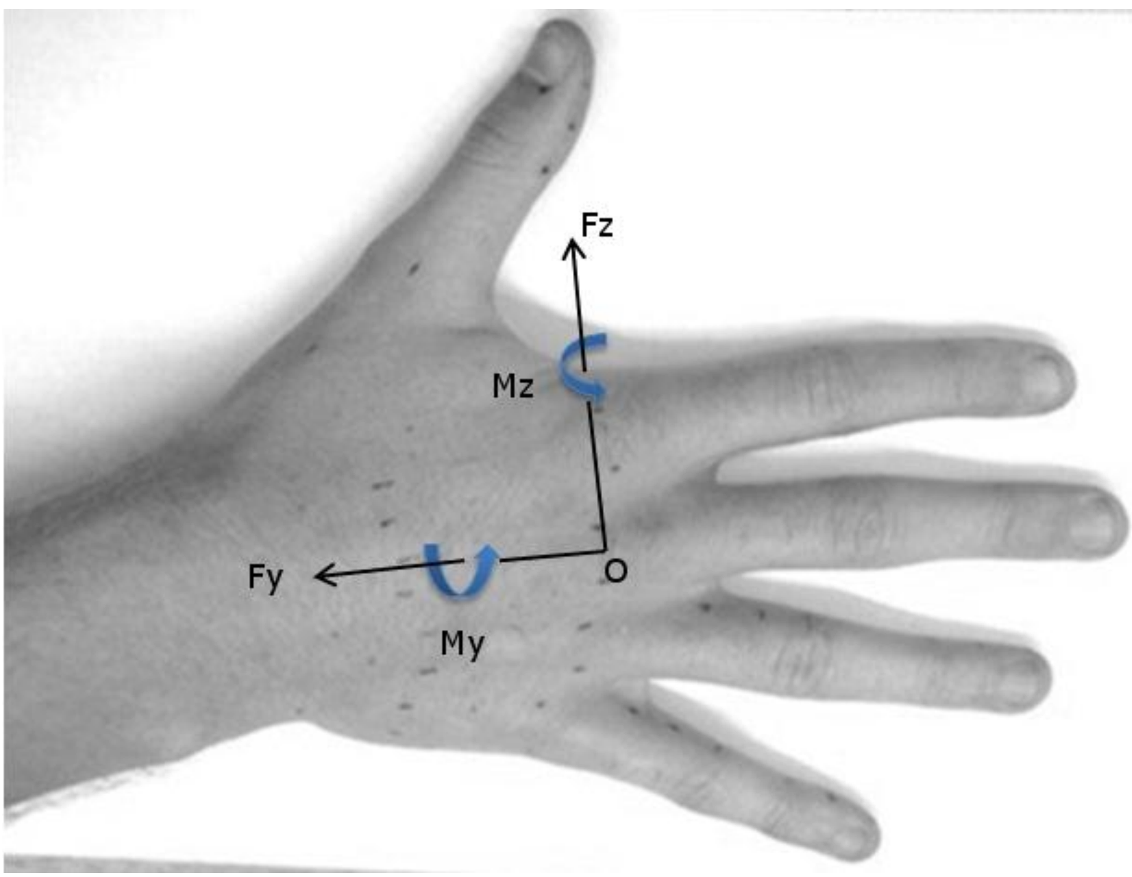


Figure 5.11 *The MCP joint moment axes.*

The applied $\boldsymbol{M_x}$ *moment* (Figure 5.12), like the F_z force tends to adduct the fingers toward the centre of the palm. As the index, middle and ring fingers were placed radial to the centre of the palm the M_x exerted on them is positive, while it is negative on the little finger which was positioned ulnarly to the palm centre.

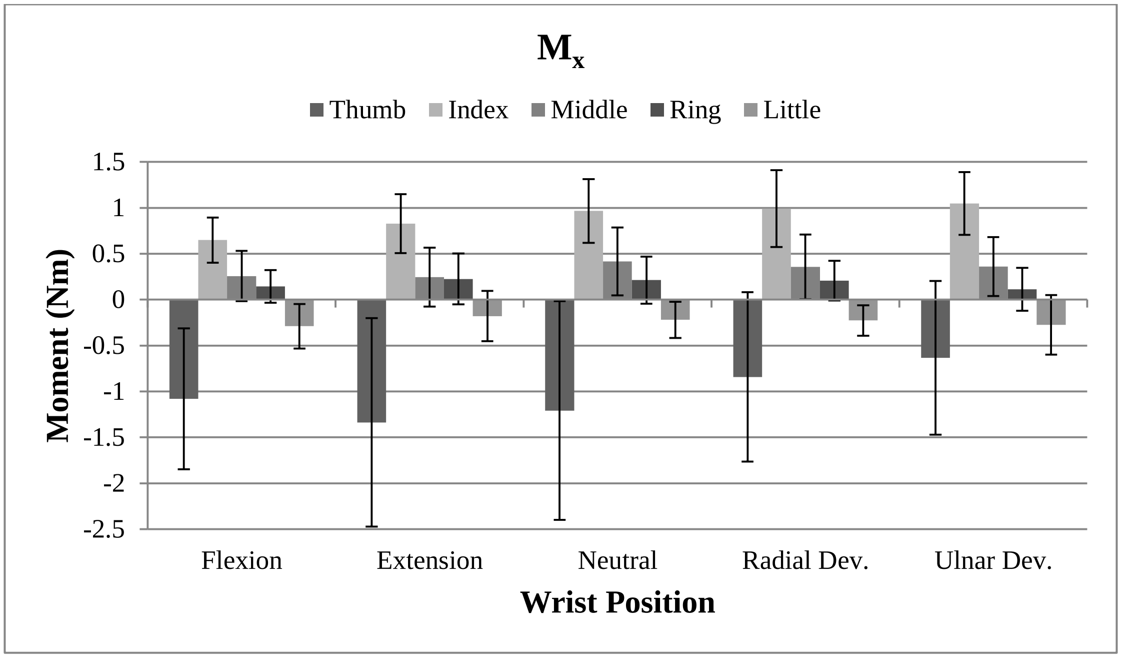


Figure 5.12: *The M_x moment (with SD), in the metacarpal axis system applied to each digit in every wrist position.*

The magnitude of the M_x that is applied to the index finger is much greater than applied to the other fingers, especially with the wrist in radial deviation. This is probably because of the orientation of the index finger as described above. The higher values for F_z (with their large moment arms at the metacarpals) which are produced as a factor of this twisted index finger position contribute to the increased values for applied M_x. The M_x moment also tends to pull the thumb toward the centre of the palm and as the thumb opposes the fingers, the orientation of the applied M_x moment is reversed.

The $\boldsymbol{M_y}$ *moment* (Figure 5.13) tends to internally rotate the index, middle and ring fingers towards the centre of the palm. As the little finger is ulnarly placed with respect to the centre of the palm, an external rotational moment (negative M_y) is exerted on it, with an exception in the ulnar deviation of the wrist, probably because of the orientation of the finger in this position. The thumb also tends to be rotated towards the palm centre but as it opposes the fingers on the gripping tool, the orientation of the M_y applied to it is reversed.

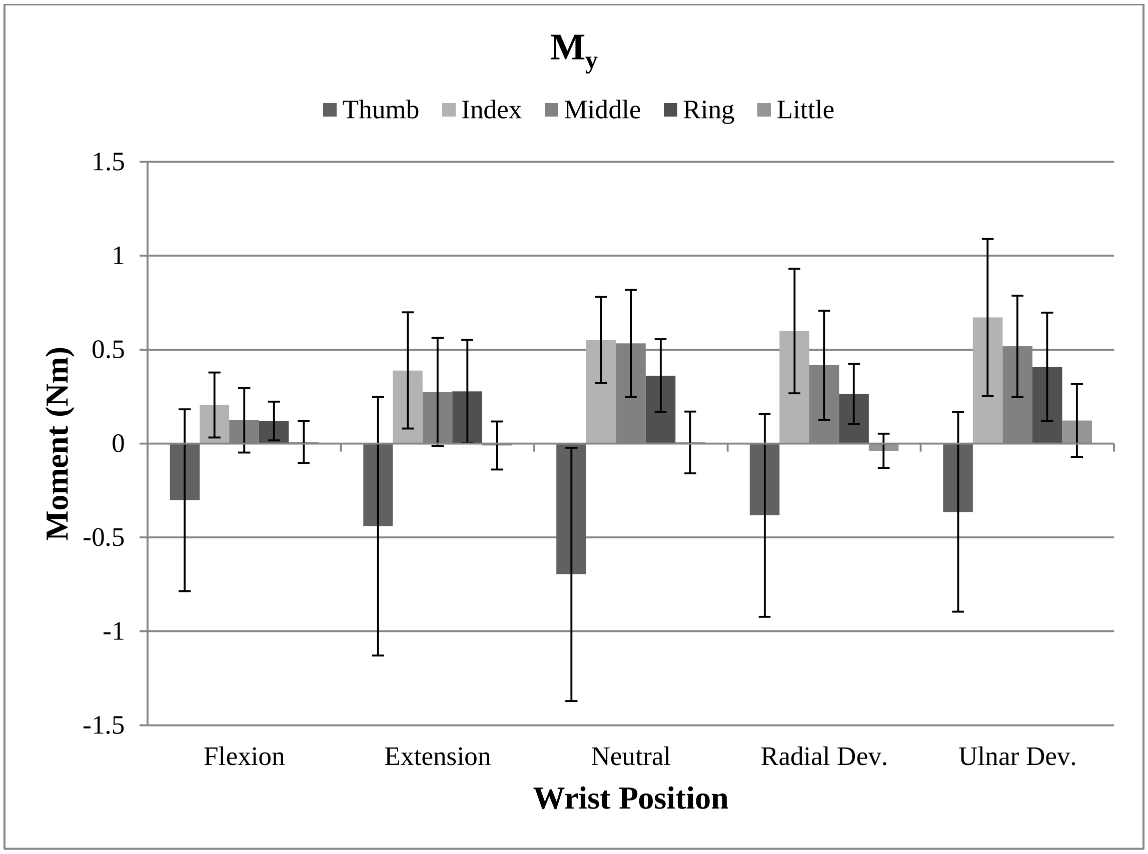


Figure 5.13: *The M_y moment (with SD), in the metacarpal axis system applied to each digit in every wrist position.*

*The applied **Mz** moment* (Figure 5.14) tends to extend the joints of all the fingers and the thumb, as a reaction to the flexion moment generated on the gripping tool. However, the finger ratios vary especially in the radial and ulnar deviation. In these wrist positions the Mz applied to the ring and the little finger has a similar magnitude as the other wrist positions, but the magnitude of the applied Mz on the index and middle fingers is significantly smaller. This is probably because the applied Fx forces in this position tend to flex the carpo-metacarpal joints (Figure 5.8) and they do not contribute to the production of the negative Mz. Thus, the magnitude of the negative Mz remains small because of the orientation of the index and middle fingers on the gripping tool.

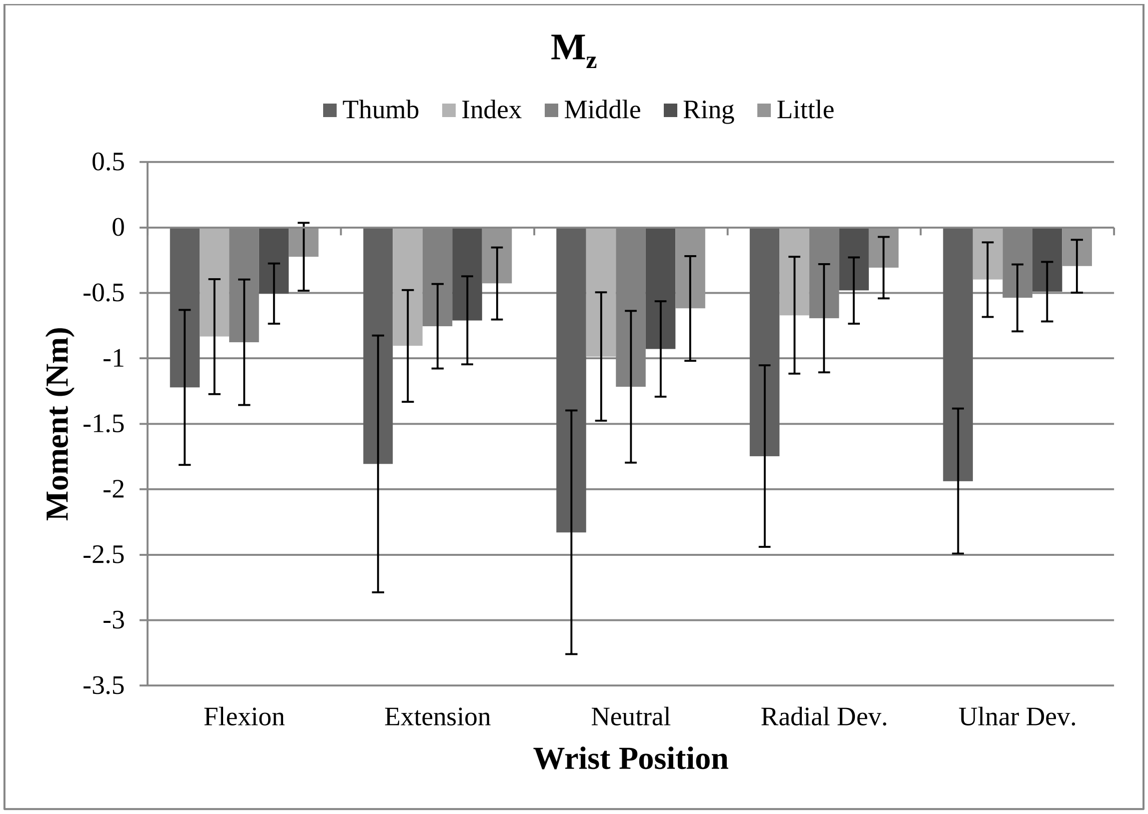


Figure 5.14: *The M_z moment (with SD), in the metacarpal axis system, applied to each digit in every wrist position.*

5.3.4 The shear forces

The resultant shear force (F_xT, F_yT are the shear forces on the transducers) was also calculated in the transducer axis system and presented in Table 5.16 and in Figure 5.15.

Table 5.16: *The resultant shear forces (N)(±SD)on the force transducers.*

	Thumb	*Index*	*Middle*	*Ring*	*Little*
Flexion	8.9 (4.1)	3.5 (2.8)	3.9 (2.1)	2.4 (1.1)	1.9 (1.3)
Extension	11.3 (4.6)	4.1 (2.9)	4.2 (2.1)	3.0 (1.1)	2.4 (1.8)
Neutral	10.9 (4.3)	4.3 (3.2)	4.9 (4.0)	3.5 (1.7)	2.9 (1.5)
Radial Dev.	7.7 (4.0)	3.3 (1.6)	4.2 (2.1)	3.2 (1.4)	2.7 (1.4)
Ulnar Dev.	6.2 (3.2)	3.2 (1.4)	4.1 (1.9)	2.3 (1.2)	3.3 (1.6)

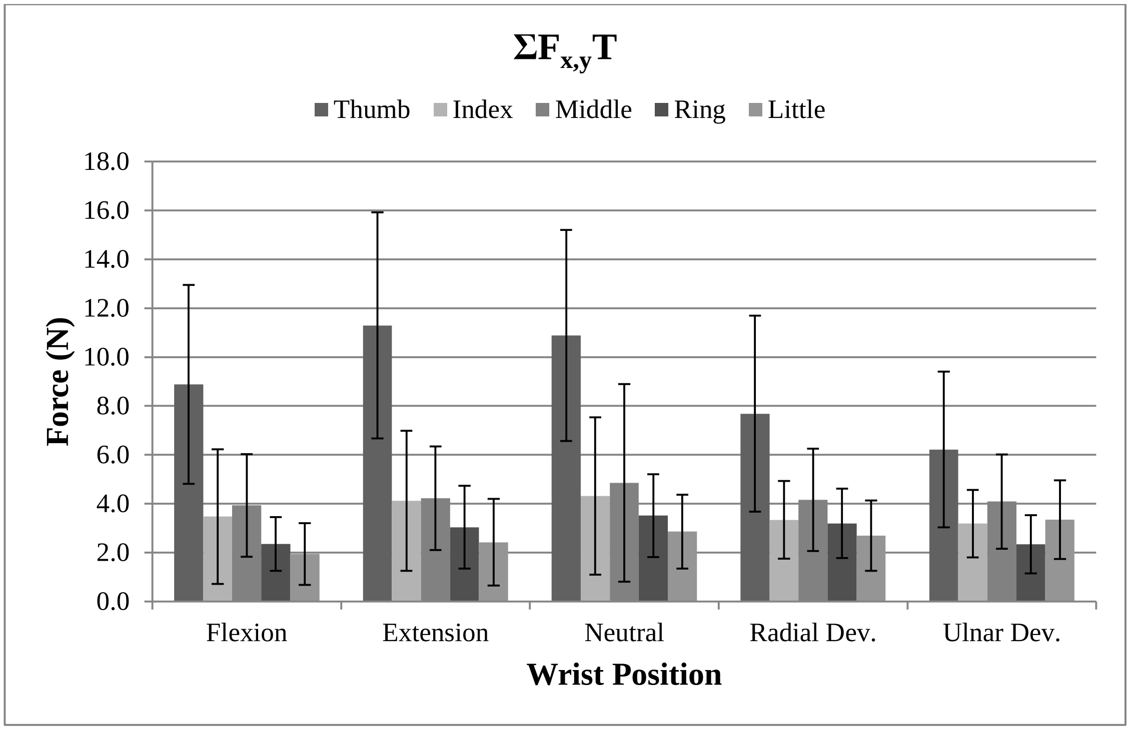


Figure 5.15: *The resultant shear forces ($\Sigma F_{x,y}T$)(with SDs) on the force transducers.*

The shear resultant forces as a percentage of the ΣFT are shown in Table 5.17 and Figure 5.16.

Table 5.17: *The shear resultant forces as a percentage of the ΣFT*

	Thumb	*Index*	*Middle*	*Ring*	*Little*
Flexion	18.9	20.7	23.6	23.8	25.5
Extension	19.7	19.8	28.8	21.6	27.1
Neutral	15.7	18.0	22.4	22.4	27.4
Radial Dev.	13.0	14.0	28.0	32.1	37.3
Ulnar Dev.	11.4	13.2	27.5	20.7	35.5

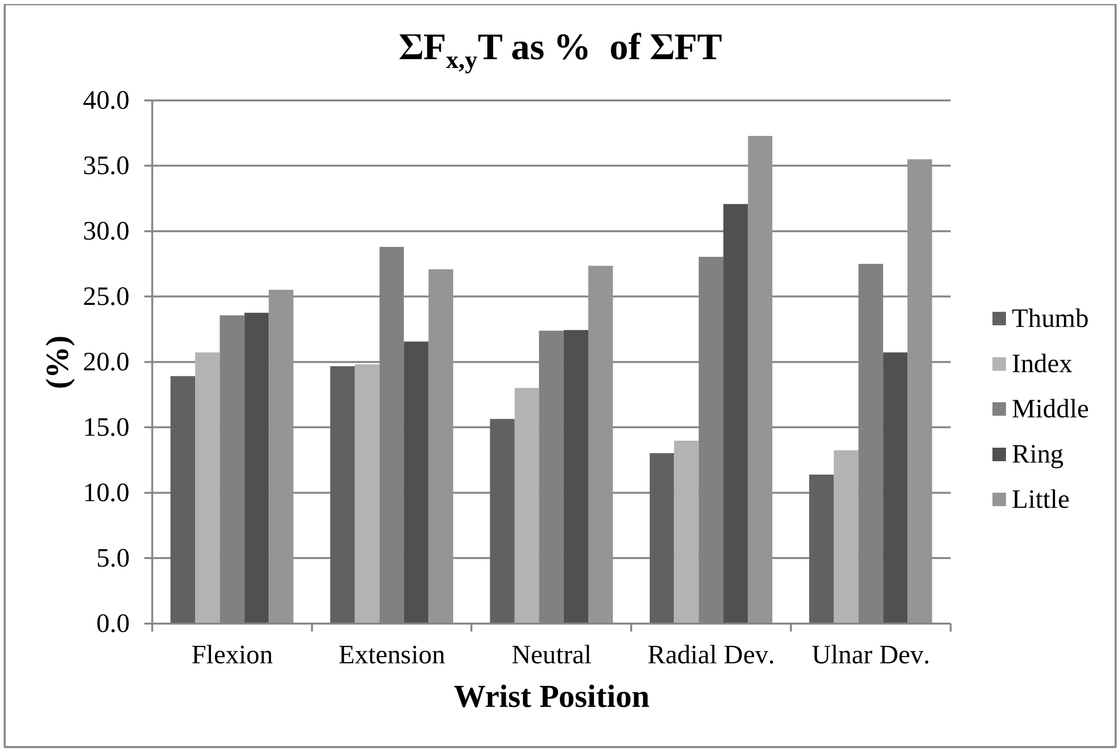


Figure 5.16: *The shear resultant forces as a percentage of the ΣFT.*

From the above results it is clear that shear forces are of very high values to be neglected. These shear forces contribute to the high level moments observed in the metacarpophalangeal joints. Therefore, a six degree of freedom transducer must be used in the studies of the hand grip, otherwise a lot of valuable load information is lost.

5.4 Discussion

5.4.1 The Maximal Grip Force

The resultant external forces and moments applied to the thumb in each wrist position were calculated (in the metacarpal axis system) as a measure of overall grip strength (since the thumb acts in opposition to the finger grip contributions). In the neutral wrist position, the subjects were able to generate the maximum resultant forces and moments whereas in the flexed position of the wrist the minimum loads were achieved.

Significant differences appeared in the resultant loads generated by gender. On average (including all wrist orientations), males exerted 27.8% greater mean resultant grip force than females. Males also provided an average of 20.4% greater resultant moments than females. In both cases, the greatest difference between genders was in wrist extension and the closest results were in radial and ulnar deviation.

Several studies have investigated the maximal grip force between the genders, with different methodological approaches though, mainly as regards the apparatus and the type of grip. In accordance with this study, they all have shown significant differences in the maximal grip force generated, regardless the aforementioned methodological differences. Specifically, females attained from 57% (Kamarul et al, 2006), 58% (Urska Puh, 2010), 59% (Mathiowetz et al, 1985; Crosby et al, 1994; Haward and Griffin, 2002), 65% (Kellor et al, 1971; Agnew and Maas, 1982; Harkonen et al, 1993a), to 66% (Leyk et al, 2007) of male strength values. All these studies used a Jamar type of dynamometer. Differences between genders were also a fact in pinch grips, varies for females between 71% (Urska Puh, 2010; Crosby et al, 1994) to more than 80% (Mathiowetz et al, 1985) of male strength values. However, the load measurements in all the aforementioned studies were in one dimension. Nonetheless, as it is shown in the present study, the shear forces on the force transducer are very high to be neglected, are affected by the wrist orientation, and contribute in the creation of high value moments across the metacarpals.

It is well known that manual lifting and carrying of loads are common types of exercise in everyday life. Despite the application of high technology, especially at work, there are still physically demanding occupations in many fields, like automotive industries, manual material handling jobs, emergency and military services. Additionally, in the last two decades there has been a large increase in the number of woman employed in the traditionally male-dominated occupations (Haward and Griffin, 2002), and the absolute loads to be handled on the job are similar for both men and women. Furthermore, hand-grip strength has been identified by many authors as a limiting factor for manual carrying (Bystrom and Fransson-Hall, 1994; von Restorff, 2000). Therefore, the knowledge of grip force and gender differences, as well as their assessment, interests in particular the fields of ergonomics and human resource management. The contribution of the present study in these fields has to do with the information given for a grip-type and an apparatus never used before, as well as the information about the 3D forces and the moments in the complete envelope of wrist orientations.

5.4.2 The Percentage Force Distribution

Radwin et al (1992) and Kinoshita et al (1995) used a similar gripping tool and found comparable results, though in a neutral wrist position only. The average contribution of the index, middle, ring and small fingers were 35%, 26%, 20% and 19% respectively in the first study and 42.0%, 27.4%, 17.6% and 12.9% respectively in the second study. Ohtsuki (1981) found 23-25% for the index, 33% for the middle, 27-28% for the ring and 15-16% for the little finger, by using maximum voluntary strength of flexion of individual fingers in neutral wrist position. Hazelton et al (1975) used a similar method in five different wrist positions: neutral, flexion, extension, radial and ulnar deviation, though not in maximal (energetic or functional) positions. Their results in neutral wrist position were 25.3%, 33.7%, 25.7% and 15.6% for the index, middle, ring and little finger, respectively, and similar in the other wrist positions.

Li (2002a) used four 6DoF transducers in a custom built gripping tool and found a percentage distribution of 32.2%, 32.6%, 23.5% and 11.7% among the index, middle, ring, and small finger, respectively, in the neutral wrist position. In contrast, all the authors who used power gripping tools have found a bigger average contribution of the middle finger rather than of the index finger (Amis, 1987; Lee and Rim, 1991; Radhakrishnan and Nagaravindra, 1993). Since none of these authors have provided standard deviations, their results are not statistically comparable with the results of this study.

Table 5.18*: Comparison of force distribution across the fingers in the neutral wrist (mean percentage values (with standard deviations where available)).*

	Index (%)	*Middle (%)*	*Ring (%)*	*Little (%)*
Current Study	35.0 (7.6)	29.8 (7.0)	21.4 (5.5)	13.8 (6.0)
Radwin et al (1992)	34.7 (9.3)	26.4 (7.5)	20.1 (5.8)	18.8 (5.1)
Kinoshita et al (1995)	42.0	27.5	17.6	12.9
Ohtsuki (1981)	24.7 (3.9)	32.8 (3.4)	27.0 (2.2)	15.5 (2.0)
Hazelton et al (1975)	25.3	33.7	25.7	15.6
Amis (1987)	30	30	22	18
Talsania and Kozin (1998)	25	35	26	15
Lee and Rim (1991)	29.5	32.5	22.6	15.4
Radhakrishnan and Nagaravindra (1993)	32	33	21	14
Li, (2002a)	32.2 (3.8)	32.6 (4.3)	23.5 (4.5)	11.5 (4.9)

The variables that may be responsible for the differences in these studies are the gripping tools used in these studies, the different finger positions on them and the reliability of the studies. Li et al (1998) found that the placement of the thumb opposed to the different fingers results in different load distribution across the digits. However, in most of the everyday gripping tasks, thumb is positioned opposite the area between the index and middle finger, something that was observed in the present experiment. Furthermore, Li et al (1998) reported that the maximal grip force could be generated in the position that was the most comfortable for the subjects, issue that was a fact in the present study, due to experimental design. Therefore, there are no issues regarding the results of the present study, as they are consistent with the type of grip and the apparatus used. But in any case, further investigation is needed in the field, and it is an interesting future task.

The percentage distribution of the external loads on the fingers is important knowledge for designers and manufacturers of sensitive tools and equipment but it is not very important in hand biomechanics though, and for that reason only the F_z was calculated for this task in the present study. On the other hand, the different distribution of the forces across the fingers results in a different distribution of the force across the metacarpals and the wrist. Thus, by comparing the results of the forces distribution across the fingers it would be possible to make assumptions about the force distribution across the metacarpals and the wrist. However, the important shear loads on the transducers presented in this study indicate that, in order to make inferences about the metacarpals and the wrist, all the 3D loads should be taken under consideration.

5.4.3 The Wrist Orientation in relation to maximal grip

The specific anatomy of each individual wrist is an important factor in describing the functional characteristics of the joint and the variation in the kinematic properties which arise between the subjects in the different wrist configurations. Every subject has their own specific functional kinematic envelope, inside which the maximal grip force is produced. In the investigation of these optimal functional positions therefore, it is preferable to allow the subject to self-define the test position, rather than use wrist immobilisation in a specific orientation. It is this variation in inter-subject wrist anatomy, grip force and optimal functional position which is evident in the high standard deviation figures obtained in the current study (see previous chapter).

Previous studies in the influence of the wrist position in the maximal grip force generation are characterized by different strategies, techniques, equipments and results. Hazelton (1975) used immobilized wrist position to measure the maximal grip in flexion, extension, radial and ulnar deviation and concluded that radial and ulnar deviations were not affected by handle position; a minimum of 25 degrees of wrist extension was required for optimum grip strength. In the study of O'Driscoll et al, (1992), the authors found also that radial and ulnar deviations were not affected by handle position, while a minimum of 25 degrees of wrist extension was required for optimum grip strength. These studies agree with what is defined as neutral in the present study (35-37 degrees of extension, see previous chapter), although there is a discrepancy as regards the radio-ulnar deviation results. The different results are probably the result of the immobilization of the wrist, as well as the low accurate equipment they used in these studies.

The effect of wrist deviation on grip strength was investigated by Lamoreaux and Hoffer (1995). In contrast with the previous studies, they found statistically important decreases of the maximal grip force in radial and ulnar deviation in comparison with the (anatomical) neutral wrist position.

Brumfield and Champoux (1984) used a uniaxial electrogoniometer to determine the range of wrist motion required to accomplish 15 activities of daily living, and found that the optimum functional motion for the wrist is from 10 degrees of flexion to 35 degrees of extension; there were no conclusions about an optimal wrist position as regards the maximal gripping force generation, or other wrist positions which were investigated, although the 35 degrees of extension agrees with the optimal neutral wrist position presented in this study.

In the same spirit, the functional ranges of motion of the wrist joint were investigated by Ryu et al (1991), to determine the functional range of motion required to perform activities of daily living. The amount of wrist flexion and extension, as well as radial and ulnar deviation, was measured in this study simultaneously by means of a biaxial wrist electrogoniometer. The authors found that the entire battery of evaluated tasks could be achieved with 60 degrees of extension, 54 degrees of flexion, 40 degrees of ulnar deviation, and 17 degrees of radial deviation, which reflects the maximum wrist motion required for daily activities. They also concluded that the majority of the hand placement and range of motion tasks that were studied in this project could be accomplished with 70 percent of the maximal range of wrist motion. This converts to 40 degrees each of wrist flexion and extension, and 40 degrees of combined radial-ulnar deviation. Inside that kinematic envelope are most of the wrist positions of the present study, and the neutral wrist orientation in particular.

In all the previous studies there is no evidence of the coupling of motion with other planes in the wrist kinematics, as shown in the chapter four of the present study, nor differences between the genders. Li et al (2005) observed similar results in a series of experiments examining the kinematic patterns in the unloaded (free) wrist. In common with the current study, the results of Li et al (2005) showed that wrist extension was coupled with ulnar deviation, radial deviation with extension and ulnar deviation with some degree of flexion. Conversely, Li et al found wrist flexion was coupled with ulnar deviation rather than the radial deviation found in the current study. This discrepancy may be due to differences in kinematic behaviour in the loaded and unloaded joint.

Additionally, Li (2002a) investigated the influence of wrist orientation on individual finger forces during forceful grip. They found that peak finger forces were produced at 20 degrees of extension and 5 degree of ulnar deviation. Although the results of these two studies are comparable with the results of this work, they have many differences in the procedures (they are dynamic studies) as well as in the equipment used. It is published that dynamic grip strength may underestimate the dynamic one by as high as 30% in some wrist positions (LaStayo and Hartzel, 1999).

The Functional Neutral Wrist Position

When a person is asked to perform a grip task without specifying the wrist joint angle, a reproducible wrist joint angle is selected in a way of optimal performance, such as comfort or maximal force generation. In the current study, that was found as a combination of 37.2 degrees of extension with 5.5 degrees of ulnar deviation for male subjects, and 35.2 degrees of extension with 5.7 degrees of ulnar deviation for female subjects. The ulnar deviation is consistent with the dynamic grip experiments aforementioned, but not the amount of extension. This discrepancy may be attributable to the size of the apparatus. O'Driscoll et al (1992) stated that the degree of self-selected optimum wrist extension is linearly and inversely related to the size of the Jamar dynamometer. He found that a difference of about 10 degrees in extension was evident between the smallest and largest sizes of the dynamometer, with the largest extension position related with the smallest dynamometer setting. Therefore, it may be the medium size of the apparatus (5cm), which is the reason for the 10 degrees of difference with the previous dynamic studies.

The relationship between the object size and the amount of extension is reasonable, considering the optimum functioning of the musculotendinous units under length-tension relationship (Loren et al, 1996). When smaller objects are being grasped, fingers are more curved with increased flexion angles at the interphalangeal and metacarpophalangeal joints, and a more extended wrist position is required to preserve the optimum musculotendinous length of the extrinsic flexors, and vice versa.

This length-tension relationship could also explain why the maximal grip force is dramatically reduced in flexion wrist position, but not so much in extension. As the wrist joint moves from the optimum (neutral) position, the associated muscular compartment for each finger becomes less optimum, resulting to an impairment of flexion force production. Additionally, a large muscle length change is more likely to happen with musculotendinous units that cross more than one joint, such us extrinsic finger flexors (flexor digitorum profundus and digitorum superficialis), which are primarily responsible for the powerful finger force generation. Durring gripping, when an external force is applied at the distal phalanx, the only flexor that balances the external extension moment at the distal interphalangeal joint is the profundus (Li et al, 2000). The moment balance at the metacarpophalangeal and proximal interphalangeal joints is progressively aided by the intrinsic muscles and flexor digitorum superficialis. Thus, decreased grip force at a deviated from the optimum wrist position, could be mainly caused by the weakened force production capability of the flexor digitorum profundus (Li et al, 2000).

Additionally, finger flexion force generation, in wrist flexion in particular, is an outcome of interaction between flexor and extensor muscles. Therefore, the decreased finger force generation may be related to tension development in the antagonists, in particular the passive stretching of extensors at wrist flexion (Li et al, 2000). With the wrist in flexed position, the extensor digitorum communis (the primarily finger extensor) may be passively stretched and produce tension in the direction of finger extension, causing a reduction in finger flexion force (Savage, 1988). This opposing (i.e. extension) force can be considerably large at an extensive flexed wrist position. The decrease in active contraction of flexors and the passive stretching of extensors could explain the weakened grip force detected at positions of large wrist flexion (Li et al, 2000). On the other hand, when there is extension of the wrist, passive stretching of the flexors facilitates flexion force, compensating for the attenuating effect of sarcomere lengthening of flexors. This may be why a less severe decrease in total flexion force was detected in this study at wrist extension.

Finally, the effect of radio-ulnar deviation on the magnitude of finger force generation is less remarkable with wrist flexion, and comparable with wrist extension. This may occur due to smaller changes in musculotendinous excursion of both flexors and extensors associated with radio-ulnar deviation. It has been reported that there is less variation in the moment arm of wrist flexors with radio-ulnar deviation as compared with the flexion of the wrist (Li et al, 2000).

Implications

Extreme wrist position is not only a determinant to finger force generation, but also linked with high risk for cumulative trauma disorders of the wrist during repetitive manual exertion (Armstrong and Chaffin, 1979). Additionally, in athletic activities extreme wrist deviations have been reported to be related with an increased incidence of injury for golfers (Friedman et al, 1993) and gymnasts (An and Bejjani, 1990; Markolf et al, 1990). It is important in equipment design and orientation to accommodate wrist positions that afford strong grips forces, especially for tasks that demand a strenuous exertion or repetitive operation (Li et al, 2000). Clinically, wrist fusion is a common surgery to relieve pain caused by rheumatoid arthritis, after traumatic injury (Brand, 1993), spasticity (Chazi et al, 1999), etc. Since nowadays, orthopaedic surgeons have not concluded about the optimal wrist position for fusion; there are suggested several wrist orientations and techniques with contradicted results (Chazi et al, 1999; Papaioannou and Dickson, 1982; Barbier et al, 1999; Field et al, 1996; Papp et al, 2006). This study indicates that wrist fusion at an extended wrist position (of about 30 degrees) and slight ulnar deviation (slightly bigger for females) may be advantageous for a wrist fusion in terms of strength generation.

Lastly, the effect of wrist deviation in grip strength presented in this study has been observed in several clinical situations (Urban et al, 1990). In these cases the surgeons proceed in centralisation of the wrist in most of the cases (Urban et al, 1990; Watson et al, 1984; Lamoreaux and Hoffer, 1995). Also in this case, instead of centralisation of the wrist, the functional wrist position presented in this study may be advantageous.

5.4.4 The Metacarpal Loads

The load distribution across the metacarpals presented in this study is an important biomechanical factor of the hand and they have been used in the calculation of the distribution of the loads across the wrist (Gislason et al, 2009). There is no evidence in the literature about these loads, and therefore the results are not comparable. As the results follow the functional anatomy of the hand they could be considered reliable and they could be used by orthopaedic surgeons, joint implant designers as well as for metacarpophalangeal joint modelling. However, the reader should keep in mind that there is an error in the calculation procedure of these loads: the joint centres were assumed static and their positions were estimated with the pointing trials procedure. This error from the joint centre calculation is known in the literature (see *Accuracy of the Photogrammetric Systems* in literature review, p. 17) and it is present in all the stereophotogrammetric measurements.

An interesting clinical implication of the load distribution across the metacarpophalangeal joints has to do with the rheumatoid hand deformities. These deformities are well studied in the literature (Apfelberg et al, 1978; Stirrat, 1996;

Kimball et al, 2003; Bielefeld and Neumann, 2005; Trieb, 2008), they follow specific pattern and have the appearance shown in Figure 5.16. In these deformities, the fingers are ulnarly deviated in the metacarpophalangeal joints, and internally rotated except the little finger which is rotated externally (Bielefeld and Neumann, 2005; De Santolo et al, 2008). Despite the fact that the biological ground of these deformities are well established in the literature (Apfelberg et al, 1978; Bielefeld and Neumann, 2005; Trieb, 2008) the mechanics of them remain unclear (Abboud et al, 2003).

However, in the present study results, the F_z (Figure 5.10) together with the M_x (Figure 5.12) tends to ulnary deviate the metacarpophalangeal joints of the Index, Middle and Ring fingers, and the M_y (Figure 5.13) tends to internally rotate the Index, Middle and Ring fingers and externally rotate the little finger, as in Figure 5.17.

Figure 5.17: *The rheumatoid hand deformities.*

There is only a discrepancy for ulnar deviation of the little finger, and this is probably because of its position on the apparatus. Therefore, there is probably a relation between the loads in the metacarpophalangeal joints during the everyday activities and the rheumatoid hand deformation; these loads, under the biological ground of the disease, may produce these severe damages on the joints. Further investigations of these loads could explain the contribution of the external loads in the appearance of these deformities. Additionally, comparison of the distribution of the loads across the metacarpals in different handgrips is an interesting future task, which could demonstrate the importance of the gripping tools in the distribution of the loads across the metacarpals and the wrist.

CHAPTER 6: **Principal Components Analysis of the Hand**

6.1 Introduction

6.1.1 The Task

The study of the wrist-hand complex as a whole is a demanding task, mainly due to the number of the joints involved, the multivariate positions the fingers may take and the numerous tasks the hand is called upon to perform. There is no evidence in the literature about the way that all the hand-wrist variables measured in the present study serve the total variance of the hand as a tool in a precision grip. The purpose of this analysis targets to fill this gap, and specifically: a) to pool all the variables measured and define any correlations between them, b) to uncover and reduce them to the most important ones, describing at least 80% of the total variance, and c) to understand how they work together, by grouping and arranging them by priority in a few uncorrelated factors, which can substitute the entire variables in the case of any further analysis. In order to do so, the appropriate multivariate statistical tool must be chosen.

6.1.2 Multivariate Analysis

Multivariate statistical techniques are used whenever there is a need of studying a large amount of variables, and are divided in Dependent and Independent methods. In Dependent techniques, an equation is built with the dependent variables on the left side and the independents (those which are measured) on the right, as in the following forms:

$Y = X_1+X_2+...+X_n$, or

$Y_1+Y_2+...+Y_n = X_1+X_2+...+X_n$

The type of the equation, as well as the type of the data (qualitative, quantitative or both) decides the appropriate Multivariate technique, such as correlation, regression analysis, discriminant analysis, MANOVA, etc. In Independent techniques, all the variables are pooled and there is no equation, in a statistical procedure generally named Data Mining.

Data mining is a procedure of selecting, exploring, and modelling great amounts of data to discover new trends and patterns in massive databases. These techniques can be generally categorized into unsupervised and supervised methods. The core difference between unsupervised and supervised methods is the underlying model structure. In supervised methods, relationships between the input and the target variables are established, while no variable is defined as target variable in unsupervised methods. That means, for most types of unsupervised methods, the inputs are same as the targets, and all the variables are expected to be influenced by a few components (factors).

In general, if there are *n* variables in a database, each variable could be regarded as constituting a different dimension, in a *n*-dimensional hyperspace. This multi-dimensional hyperspace is often hard to understand or visualise, so the main objectives of the unsupervised methods are to reduce the dimensions and to summarise multivariate features by two or three that could be presented graphically with minimum loss of information. The most common unsupervised methods are the principal component and factor analyses.

Principal Components Analysis (PCA) is sometimes confused with Factor Analysis (FA), because there are many significant similarities between them: both are data mining, multivariate and unsupervised variable reduction methods, which can be used to indentify groups of variables that tend to hang together. Nevertheless, there are some important differences between FA and PCA. The most important has to do with the assumption of an underlying causal structure: FA assumes that the covariation in the observed variables is because of the presence of one or more latent variables that influence these observed variables. Researchers use FA when they consider that these certain latent factors exist, and Exploratory Factor Analysis (EFA) helps them to identify the nature and the number of them.

In contrast, PCA makes no assumption about an underlying causal model; it is just a variable reduction process that has as a result a somewhat small number of components that account for most of the variance in a set of observed variables. Because there is no evidence of any underlying causal factor in the wrist-hand model, the PCA is the appropriate statistical tool for this study (Jackson, 2003; Jolliffe, 2002).

6.2 Principal Component Analysis

6.2.1 Objectives

In this work, principal component analysis can meet the following three objectives:

i. Identify the structure or relationships among variables
ii. Identify representative variables from a much larger set of variables for use in subsequent multivariate analysis.
iii. Create an entirely new set of variables, much smaller in number, to partially or completely replace the original set of variables for inclusion in subsequent techniques, ranging from the dependence methods of regression, correlation, or discriminant analysis to cluster analysis, another independent technique.

The first objective makes the identification of the underlying dimensions of factors (components); the estimates of the factors and the contributions of each variable to the factors (termed "Loadings") are all that are required for the analysis. The second objective relies on the factor loadings as well but uses them as the basis for identifying variables for subsequent analysis with other techniques. The third objective requires that estimates of the factors themselves (factor scores) be obtained. Then the factor scores replace the original variables in uses such as independent variables in other techniques.

6.2.2 Assumptions

Every statistical tool has its own assumptions and can be used only if these assumptions are satisfied. The PCA assumptions are the following:

i. Type of data: variables for PCA are generally assumed to be of metric measurement (quantitative); other types of variables can be accepted as long as they are not too many.
ii. Sample size: PCA is a large sample procedure. To obtain reliable results, the minimal number of subjects providing usable data for the analysis should be about five times the number of variables being analyzed.
iii. Linearity: Any correlation between the variables is assumed to be linear (Jackson, 2003; Jolliffe, 2002).

6.2.3 Variables

In this study, the following variables have been measured:

1. The age of the subjects (in years)
2. The gender (used: males=1, females=2)
3. The length of the third metacarpal bone (in cm)
4. The circumference of the forearm, at a position 3cm distal to the elbow joint (in cm)
5. The ulna length (in cm)
6. The wrist joint laxity scores (dimensionless)
7. The positions of the wrist (in degrees)
8. The resultant force on the transducer axis system, in every wrist orientation, for every finger (in N)(25 variables)
9. The resultant moment on the transducer axis system, in every wrist orientation, for every finger (in Nm)(25 variables)
10. The 3D forces on the transducer axis system, in every wrist orientation, for every finger (in N)(75 variables)
11. The 3D moments on the transducer axis system, in every wrist orientation, for every finger (in Nm)(75 variables)

12. The 3D forces on the metacarpal axis system, in every wrist orientation, for every finger (in N)(75 variables)
13. The 3D moments on the metacarpal axis system, in every wrist orientation, for every finger (in Nm)(75 variables)

Thus, the total number of variables is 357. As there are 50 subjects measured in this work, data must be reduced to about 10 variables, in order to meet the sample size assumptions.

6.2.4 Data Reduction

Data reduction in PCA and in FA in general, is a combination of logical and statistical procedure (Jackson, 2003; Jolliffe, 2002), and in the present study both are used. Specifically, from the five wrist orientations only the neutral position is selected, because in this position the hand can generate the maximal gripping force and therefore these variables carry more information than those in the other wrist orientations. Additionally, only the thumb is selected, because it opposes the resultant force of the four fingers on the tool, and thus can be considered as representative of them all. Finally, the vertical force on the transducer surface axis is chosen (Z) as it carries more meaningful information in respect to the others. Hence the variables are:

1. The age of the subjects (in years)
2. The gender (used: males=1, females=2)
3. The length of the third metacarpal bone (3^{rd}_L) (in cm)
4. The circumference of the forearm, at a position 3cm distally the elbow joint (Circumf)(in cm)
5. The ulna length (Ulna_L)(in cm)
6. The wrist joint laxity scores (WJLS)(dimensionless)
7. The position of the wrist in neutral (N_Degrees)(in degrees)
8. The thumb resultant force on the transducer axis system, in neutral wrist orientation (ΣFT)(in N)

9. The thumb resultant moment on the transducer axis system, in neutral wrist orientation(ΣMT) (in Nm)
10. The thumb F_z force on the transducer axis system, in neutral wrist orientation, (F_zT)(in N)
11. The 3D forces ($F_{x,y,z}$) on the metacarpal axis system, in neutral wrist orientation, (in N)(3 variables)
12. The 3D moments ($M_{x,y,z}$) on the metacarpal axis system, in neutral wrist orientation (in Nm)(3 variables)

Only sixteen variables now exist in the PCA design, without losing much of the information of the total hand variance. The correlation matrix (see Table 6.1) of these variables shows that the wrist joint laxity scores (WJLS) are not correlated with any of the other variables of the model (see Appendix K1 for *p*-values and coefficients of determination), and can be omitted from the PCA model. The absence of any correlation of this variable, even with the anthropometric data, confirms the study of van Andel et al (2008), saying that this variable hardly measures the laxity of the wrist and probably describes the general mobility of the joint. Thus, in a healthy hand with normal range of motion, mobility does not seem to statistically affect the generation of maximal strength in the neutral wrist position for the specific grip.

Additionally, the resultant force applied on the transducer by the thumb (ΣFT) has the highest correlation (r=1) with the normal force on the transducer surface (F_zT) (see Table 6.1). Hence, both these variables have exactly the same correlation with all the others and therefore one of them can be excluded. It is preferable to exclude the ΣFT as the F_zT variable carries more information (apart from the magnitude it also carries the direction of the force vector).

Table 6.1: *Correlation matrix (Pearson) (Continues)*

Variables	Age	Gender	3^{rd}_L	Circumf	Ulnar_L	WJLS	N_Degrees
Age	**1**	0.060	0.066	**0.324**	0.161	-0.257	0.082
Gender	0.060	**1**	**0.414**	**0.665**	**0.695**	-0.109	0.030
3^{rd}_L	0.066	**0.414**	**1**	**0.483**	**0.549**	0.028	-0.161
Circumf	**0.324**	**0.665**	**0.483**	**1**	**0.671**	-0.196	0.151
Ulnar_L	0.161	**0.695**	**0.549**	**0.671**	**1**	-0.146	-0.037
WJLS	-0.257	-0.109	0.028	-0.196	-0.146	**1**	-0.093
N_Degrees	0.082	0.030	-0.161	0.151	-0.037	-0.093	**1**
ΣFT	0.222	**0.557**	**0.326**	**0.615**	**0.461**	-0.104	0.055
ΣMT	0.207	0.065	-0.099	0.079	-0.031	0.100	-0.038
FzT	0.221	**0.558**	**0.319**	**0.608**	**0.455**	-0.107	0.053
Fx	-0.077	**-0.505**	-0.229	**-0.445**	**-0.379**	0.030	0.048
Fy	0.199	**0.281**	0.072	**0.330**	**0.316**	-0.089	**0.385**
Fz	**0.301**	**0.291**	0.002	0.214	0.146	-0.213	0.038
Mx	**-0.325**	-0.031	0.120	-0.076	-0.039	0.153	**-0.333**
My	-0.183	0.053	0.165	-0.007	-0.015	0.137	**-0.357**
Mz	-0.100	-0.097	0.039	-0.244	-0.176	0.045	**-0.303**

Values in bold are different from 0 with a significance level alpha=0.05

Table 6.1: *Correlation matrix (Pearson)*

Variables	ΣFT	ΣMT	FzT	Fx	Fy	Fz	Mx	My	Mz
Age	0.222	0.207	0.221	-0.077	0.199	**0.301**	**-0.325**	-0.183	-0.100
Gender	**0.557**	0.065	**0.558**	**-0.505**	**0.281**	**0.291**	-0.031	0.053	-0.097
3rd_L	**0.326**	-0.099	**0.319**	-0.229	0.072	0.002	0.120	0.165	0.039
Circumf	**0.615**	0.079	**0.608**	**-0.445**	**0.330**	0.214	-0.076	-0.007	-0.244
Ulnar_L	**0.461**	-0.031	**0.455**	**-0.379**	**0.316**	0.146	-0.039	-0.015	-0.176
WJLS	-0.104	0.100	-0.107	0.030	-0.089	-0.213	0.153	0.137	0.045
N_Degrees	0.055	-0.038	0.053	0.048	**0.385**	0.038	**-0.333**	**-0.357**	**-0.303**
ΣFT	**1**	**0.409**	**1.000**	**-0.686**	**0.422**	**0.309**	-0.059	-0.072	-0.165
ΣMT	**0.409**	**1**	**0.414**	-0.243	0.129	**0.293**	**-0.331**	-0.254	-0.082
FzT	**1.000**	**0.414**	**1**	**-0.691**	**0.417**	**0.312**	-0.060	-0.074	-0.163
Fx	**-0.686**	-0.243	**-0.691**	**1**	**-0.429**	-0.228	0.024	0.143	**0.350**
Fy	**0.422**	0.129	**0.417**	**-0.429**	**1**	**0.367**	-0.231	-0.231	**-0.348**
Fz	**0.309**	**0.293**	**0.312**	-0.228	**0.367**	**1**	**-0.461**	-0.018	0.092
Mx	-0.059	**-0.331**	-0.060	0.024	-0.231	**-0.461**	**1**	**0.610**	**0.629**
My	-0.072	-0.254	-0.074	0.143	-0.231	-0.018	**0.610**	**1**	**0.740**
Mz	-0.165	-0.082	-0.163	**0.350**	**-0.348**	0.092	**0.629**	**0.740**	**1**

Values in bold are different from 0 with a significance level alpha=0.05

The following 14 variables remain in the PCA model:

1. The age of the subjects (in years)
2. The gender (used: males=1, females=2)
3. The length of the third metacarpal bone (3^{rd}_L) (in cm)
4. The circumference of the forearm, at a position 3cm distally the elbow joint (Circumf)(in cm)
5. The ulna length (Ulna_L)(in cm)
6. The position of the wrist in neutral (N_Degrees)(in degrees)
7. The thumb resultant moment on the transducer axis system, in neutral wrist orientation(ΣMT) (in Nm)
8. The thumb F_z force on the transducer axis system, in neutral wrist orientation, (F_zT)(in N)
9. The 3D forces ($F_{x,y,z}$) on the metacarpal axis system, in neutral wrist orientation, (in N)(3 variables)
10. The 3D moments ($M_{x,y,z}$) on the metacarpal axis system, in neutral wrist orientation (in Nm)(3 variables)

The correlation matrix of these variables is shown in Table 6.2 (see Appendix K2 for *p*-values and coefficients of determination). Inspection of this correlation matrix reveals that 38 of the 91 correlations are statistically significant at 95% Confidence Intervals; in PCA, about half of them (or more) should be significant in order to increase the statistical power. To do that, further data reduction is needed.

Age is the preferable variable to be omitted for two main reasons: it has the weaker correlations with the other variables, and, although muscle strength decrease with age, this variable seems to contributes less in the gripping force of the subjects than other, hidden variables, like the level of activity of the subjects, their job etc.

Table 6.2: *Correlation matrix (Pearson) (Continues)*

Variables	Age	Gender	3rd_L	Circumf	Ulnar_L	N_Degrees
Age	**1**	0.060	0.066	**0.324**	0.161	0.082
Gender	0.060	**1**	**0.414**	**0.665**	**0.695**	0.030
3rd_L	0.066	**0.414**	**1**	**0.483**	**0.549**	-0.161
Circumf	**0.324**	**0.665**	**0.483**	**1**	**0.671**	0.151
Ulnar_L	0.161	**0.695**	**0.549**	**0.671**	**1**	-0.037
N_Degrees	0.082	0.030	-0.161	0.151	-0.037	**1**
ΣMT	0.207	0.065	-0.099	0.079	-0.031	-0.038
FzT	0.221	**0.558**	**0.319**	**0.608**	**0.455**	0.053
Fx	-0.077	**-0.505**	-0.229	**-0.445**	**-0.379**	0.048
Fy	0.199	**0.281**	0.072	**0.330**	**0.316**	**0.385**
Fz	**0.301**	**0.291**	0.002	0.214	0.146	0.038
Mx	**-0.325**	-0.031	0.120	-0.076	-0.039	**-0.333**
My	-0.183	0.053	0.165	-0.007	-0.015	**-0.357**
Mz	-0.100	-0.097	0.039	-0.244	-0.176	**-0.303**

Values in bold are different from 0 with a significance level alpha=0.05

Table 6.2: *Correlation matrix (Pearson):*

Variables	ΣMT	FzT	Fx	Fy	Fz	Mx	My	Mz
Age	0.207	0.221	-0.077	0.199	**0.301**	**-0.325**	-0.183	-0.100
Gender	0.065	**0.558**	**-0.505**	**0.281**	**0.291**	-0.031	0.053	-0.097
3rd_L	-0.099	**0.319**	-0.229	0.072	0.002	0.120	0.165	0.039
Circumf	0.079	**0.608**	**-0.445**	**0.330**	0.214	-0.076	-0.007	-0.244
Ulnar_L	-0.031	**0.455**	**-0.379**	**0.316**	0.146	-0.039	-0.015	-0.176
N_Degrees	-0.038	0.053	0.048	**0.385**	0.038	**-0.333**	**-0.357**	**-0.303**
ΣMT	**1**	**0.414**	-0.243	0.129	**0.293**	**-0.331**	-0.254	-0.082
FzT	**0.414**	**1**	**-0.691**	**0.417**	**0.312**	-0.060	-0.074	-0.163
Fx	-0.243	**-0.691**	**1**	**-0.429**	-0.228	0.024	0.143	**0.350**
Fy	0.129	**0.417**	**-0.429**	**1**	**0.367**	-0.231	-0.231	**-0.348**
Fz	**0.293**	**0.312**	-0.228	**0.367**	**1**	**-0.461**	-0.018	0.092
Mx	**-0.331**	-0.060	0.024	-0.231	**-0.461**	**1**	**0.610**	**0.629**
My	-0.254	-0.074	0.143	-0.231	-0.018	**0.610**	**1**	**0.740**
Mz	-0.082	-0.163	**0.350**	**-0.348**	0.092	**0.629**	**0.740**	**1**

Values in bold are different from 0 with a significance level alpha=0.05

The new set of variables for the PCA design is as follows:

1. The gender (used: males=1, females=2)
2. The length of the third metacarpal bone (3^{rd}_L) (in cm)
3. The circumference of the forearm, at a position 3cm distally the elbow joint (Circumf)(in cm)
4. The ulna length (Ulna_L)(in cm)
5. The position of the wrist in neutral (N_Degrees)(in degrees)
6. The thumb resultant moment on the transducer axis system, in neutral wrist orientation(ΣMT) (in Nm)
7. The thumb F_z force on the transducer axis system, in neutral wrist orientation, (F_zT)(in N)
8. The 3D forces ($F_{x,y,z}$) on the metacarpal axis system, in neutral wrist orientation, (in N)(3 variables)
9. The 3D moments ($M_{x,y,z}$) on the metacarpal axis system, in neutral wrist orientation (in Nm)(3 variables)

The correlation matrix of these variables is shown in Table 6.3 (see Appendix K3 for *p*-values and coefficients of determination). In this correlation matrix, 35 of the 78 correlations are significant at 95% Confidence Intervals. Inspecting the correlation matrix it is clear that there is no statistical way to further reduce the variables, and the only way to do that is by logical procedures.

The length of the third metacarpal (3^{rd}_L) and the length of the Ulna (Ulnar_L) are supposed to express the same thing: the size of the arm, directly related with its strength generation. The "3^{rd}_L" variable is correlated with the other anthropometric data, the gender and the F_zT; the "Ulnar_L" variable, on the other hand, is related with stronger correlations with all the aforementioned variables, as well as with the two of the three forces on the metacarpals. Thus, the length of the third metacarpal variable can be excluded from the model.

Table 6.3: *Correlation matrix (Pearson) (Continues):*

Variables	Gender	3rd_L	Circumf	Ulnar_L	N_Degrees	ΣMT
Gender	**1**	**0.414**	**0.665**	**0.695**	0.030	0.065
3rd_L	**0.414**	**1**	**0.483**	**0.549**	-0.161	-0.099
Circumf	**0.665**	**0.483**	**1**	**0.671**	0.151	0.079
Ulnar_L	**0.695**	**0.549**	**0.671**	**1**	-0.037	-0.031
N_Degrees	0.030	-0.161	0.151	-0.037	**1**	-0.038
ΣMT	0.065	-0.099	0.079	-0.031	-0.038	**1**
F_zT	**0.558**	**0.319**	**0.608**	**0.455**	0.053	**0.414**
F_x	**-0.505**	-0.229	**-0.445**	**-0.379**	0.048	-0.243
F_y	**0.281**	0.072	**0.330**	**0.316**	**0.385**	0.129
F_z	**0.291**	0.002	0.214	0.146	0.038	**0.293**
M_x	-0.031	0.120	-0.076	-0.039	**-0.333**	**-0.331**
M_y	0.053	0.165	-0.007	-0.015	**-0.357**	-0.254
M_z	-0.097	0.039	-0.244	-0.176	**-0.303**	-0.082

Values in bold are different from 0 with a significance level alpha=0.05

Table 6.3: *Correlation matrix (Pearson):*

Variables	F_zT	F_x	F_y	F_z	M_x	M_y	M_z
Gender	**0.558**	**-0.505**	**0.281**	**0.291**	-0.031	0.053	-0.097
3rd_L	**0.319**	-0.229	0.072	0.002	0.120	0.165	0.039
Circumf	**0.608**	**-0.445**	**0.330**	0.214	-0.076	-0.007	-0.244
Ulnar_L	**0.455**	**-0.379**	**0.316**	0.146	-0.039	-0.015	-0.176
N_Degrees	0.053	0.048	**0.385**	0.038	**-0.333**	**-0.357**	**-0.303**
ΣMT	**0.414**	-0.243	0.129	**0.293**	**-0.331**	-0.254	-0.082
F_zT	**1**	**-0.691**	**0.417**	**0.312**	-0.060	-0.074	-0.163
F_x	**-0.691**	**1**	**-0.429**	-0.228	0.024	0.143	**0.350**
F_y	**0.417**	**-0.429**	**1**	**0.367**	-0.231	-0.231	**-0.348**
F_z	**0.312**	-0.228	**0.367**	**1**	**-0.461**	-0.018	0.092
M_x	-0.060	0.024	-0.231	**-0.461**	**1**	**0.610**	**0.629**
M_y	-0.074	0.143	-0.231	-0.018	**0.610**	**1**	**0.740**
M_z	-0.163	**0.350**	**-0.348**	0.092	**0.629**	**0.740**	**1**

Values in bold are different from 0 with a significance level alpha=0.05

The following 12 variables now remain in the PCA model:

1. The gender (used: males=1, females=2)
2. The circumference of the forearm, at a position 3cm distally the elbow joint (Circumf)(in cm)
3. The ulna length (Ulna_L)(in cm)
4. The position of the wrist in neutral (N_Degrees)(in degrees)
5. The thumb resultant moment on the transducer axis system, in neutral wrist orientation(ΣMT) (in Nm)
6. The thumb F_z force on the transducer axis system, in neutral wrist orientation, (F_zT)(in N)
7. The 3D forces ($F_{x,y,z}$) on the metacarpal axis system, in neutral wrist orientation, (in N)(3 variables)
8. The 3D moments ($M_{x,y,z}$) on the metacarpal axis system, in neutral wrist orientation (in Nm)(3 variables)

Table 6.4: *Correlation matrix (Pearson) (Continues):*

Variables	Gender	Circumf	Ulnar_L	N_Degrees	ΣMT
Gender	**1**	**0.665**	**0.695**	0.030	0.065
Circumf	**0.665**	**1**	**0.671**	0.151	0.079
Ulnar_L	**0.695**	**0.671**	**1**	-0.037	-0.031
N_Degrees	0.030	0.151	-0.037	**1**	-0.038
ΣMT	0.065	0.079	-0.031	-0.038	**1**
F_zT	**0.558**	**0.608**	**0.455**	0.053	**0.414**
F_x	**-0.505**	**-0.445**	**-0.379**	0.048	-0.243
F_y	**0.281**	**0.330**	**0.316**	**0.385**	0.129
F_z	**0.291**	0.214	0.146	0.038	**0.293**
M_x	-0.031	-0.076	-0.039	**-0.333**	**-0.331**
M_y	0.053	-0.007	-0.015	**-0.357**	-0.254
M_z	-0.097	-0.244	-0.176	**-0.303**	-0.082

Values in bold are different from 0 with a significance level alpha=0.05

Table 6.4: *Correlation matrix (Pearson):*

Variables	F_zT	F_x	F_y	F_z	M_x	M_y	M_z
Gender	**0.558**	**-0.505**	**0.281**	**0.291**	-0.031	0.053	-0.097
Circumf	**0.608**	**-0.445**	**0.330**	0.214	-0.076	-0.007	-0.244
Ulnar_L	**0.455**	**-0.379**	**0.316**	0.146	-0.039	-0.015	-0.176
N_Degrees	0.053	0.048	**0.385**	0.038	**-0.333**	**-0.357**	**-0.303**
ΣMT	**0.414**	-0.243	0.129	**0.293**	**-0.331**	-0.254	-0.082
F_zT	**1**	**-0.691**	**0.417**	**0.312**	-0.060	-0.074	-0.163
F_x	**-0.691**	**1**	**-0.429**	-0.228	0.024	0.143	**0.350**
F_y	**0.417**	**-0.429**	**1**	**0.367**	-0.231	-0.231	**-0.348**
F_z	**0.312**	-0.228	**0.367**	**1**	**-0.461**	-0.018	0.092
M_x	-0.060	0.024	-0.231	**-0.461**	**1**	**0.610**	**0.629**
M_y	-0.074	0.143	-0.231	-0.018	**0.610**	**1**	**0.740**
M_z	-0.163	**0.350**	**-0.348**	0.092	**0.629**	**0.740**	**1**

Values in bold are different from 0 with a significance level alpha=0.05

The correlation matrix of these variables is shown in Table 6.4 (see Appendix K4 for *p*-values and coefficients of determination). In this correlation matrix, 31 of the 66 correlations are significant at 95% Confidence Intervals. As it is difficult to apply further statistical and/or logical, data reduction, these are the final variables for the PCA design. This final set of variables is close to, but do not meet the PCA criterion of five subjects per variable. However, as the number of variables are close to the targeted one, the PCA can be proceed and further data reduction can be performed latter.

6.2.5 Deriving the factors

As a beginning, it is assumed that there are as many factors as variables. The Eigenvalues (expressing the gravity of each factor) are shown in Table 6.5. It is clear that the first 4 factors explain almost 75% of the underlying structure and the first 5 factors more than 80% of the total variance.

In the literature, there are four criteria to decide how many factors to keep. Among them, the Latent Root Criterion and the Scree Test Criterion are the most common. The first one rejects all the factors with Eigenvalues less than 1.0, while the second accepts as a final factor the one which is below, but close to 1.0 (Jackson, 2003; Jolliffe, 2002). In this study, the Scree Test Criterion is selected, as it is considered the most accurate. The Scree Plot of the Eigenvalues of the factors is represented in Figure 6.1.

Table 6.5: *The Eigenvalues of the Factors.*

	Eigenvalues (Principal Components Analysis)		
Factors	**Eigenvalue**	**Proportion(%)**	**Cumulative(%)**
1	4.0235	33.5	33.5
2	2.4517	20.4	54
3	1.3942	11.6	65.6
4	1.0842	9	74.6
5	0.8837	7.4	82
6	0.6714	5.6	87.6
7	0.4398	3.7	91.2
8	0.3505	2.9	94.2
9	0.2617	2.2	96.3
10	0.2107	1.8	98.1
11	0.1893	1.6	99.7
12	0.0392	0.3	100

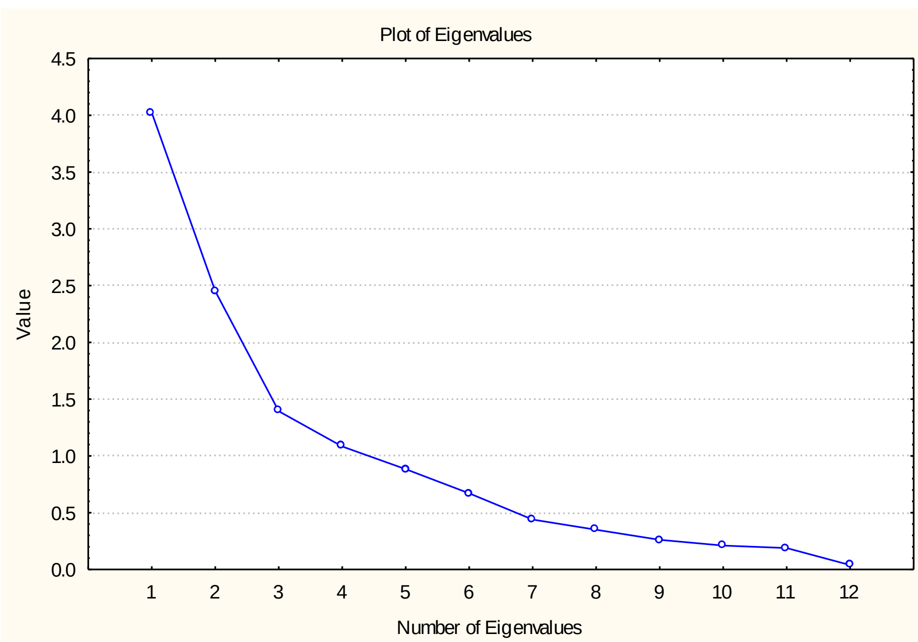


Figure 6.1: *The Scree Plot of the Eigenvalues.*

Five factors explain more than 80% of the common variance and are chosen to feed the Principal Component model (Table 6.6)

Table 6.6: *Principal Components: the factors' loadings.*

	Unrotated Factor Loadings Extraction: Principal Components (Marked loadings are > .70)				
Variable	**Factor1**	**Factor2**	**Factor3**	**Factor4**	**Factor5**
Gender	**0.707**	-0.459	0.128	-0.079	0.23
Circumf	**0.743**	-0.342	0.237	-0.07	0.14
L_Ulna	0.655	-0.405	0.314	-0.027	0.345
N_Degrees	0.266	0.485	0.312	-0.512	-0.348
ΣMT	0.353	0.19	**-0.701**	0.322	-0.082
F_zT	**0.778**	-0.292	-0.199	0.184	-0.253
F_x	**-0.72**	0.21	0.054	-0.355	0.303
F_y	0.65	0.139	0.036	-0.342	-0.444
F_z	0.454	0.007	-0.63	-0.499	0.202
M_x	-0.426	**-0.727**	0.209	0.139	-0.398
M_y	-0.373	**-0.779**	-0.127	-0.257	-0.075
M_z	-0.523	-0.636	-0.365	-0.308	-0.082
Variance	4.0235	2.4517	1.3942	1.0842	0.8837
% Var	0.335	0.204	0.116	0.09	0.074

In the above Table, "Variance" is the Eigenvalue and "% Var." is the proportion of each factor in the total variance. There are 5 factors in five columns. Every factor column is composed from the loadings from each variable on it (important loadings are bold). Calculating the power of analysis, in order to have about 80% with 50 measurements, factor loadings must be more than 0.70.

The unrotated (this term is explained later) factor solution has extracted the factors in the order of their importance, with factor 1 accounting for the most variance, factor 2 less etc. The first factor is composed mainly from the Gender, the forearm circumference, as well as from the F_zT and F_x variables. The second is composed mainly from M_x and M_y, and so on.

Although the previous unrotated factor loading matrix provides some information about the variance, interpretation would be extremely difficult and theoretically less meaningful. Thus, the factor matrix should be rotated, to redistribute the variance from the earlier factors to the later factors. According to the literature, this rotation should result in a simpler and theoretically more meaningful factor pattern (Jackson, 2003; Jolliffe, 2002).

There are two kinds of rotations: the orthogonal and the oblique (Jackson, 2003; Jolliffe, 2002). In the orthogonal one it is considered that, as mathematically the factors remain normalized, there is no correlation between them. In the oblique one, there are correlations between the factors, and therefore these have to be examined. After the oblique rotation process, the following correlation matrix between the factors emerges (Table 6.7):

Table 6.7: *The correlations between the oblique factors.*

Factor	1	2	3	4
1	1	0.174	0.285	0.286
2	0.174	1	0.042	0.323
3	0.285	0.042	1	0.291
4	0.286	0.323	0.291	1

It is clear that there is no significant correlation between the factors and each one can be considered as an independent factor, in orthogonal position with all the others; thus, the orthogonal rotation is the appropriate technique. Among the many methods to orthogonally rotate the factors, the Varimax method is the most accepted in the literature (Jackson, 2003; Jolliffe, 2002).

In the Table below (Table 6.8), the first and most important factor is composed of the gender, the forearm circumference and ulnar length, namely all the "anthropometric" characteristics of the subjects, and explains more than 23% of the total variance. The 2nd factor is composed of the moments on the metacarpals, explaining almost 20% of the total variance, and so on.

Table 6.8: *Principal Components: the factor loadings.*

	Rotated Factor Loadings (Varimax Rotation) Extraction: Principal Components (Marked loadings are > .70)				
Variable	**Factor1**	**Factor2**	**Factor3**	**Factor4**	**Factor5**
Gender	**0.851**	-0.05	-0.199	-0.138	-0.038
Circumf	**0.823**	0.056	-0.205	-0.047	-0.159
L_Ulna	**0.897**	0.062	-0.049	-0.009	0.013
N_Degrees	-0.033	0.279	0.144	-0.034	**-0.828**
ΣMT	-0.174	0.219	-0.668	-0.451	0.187
F_zT	0.488	-0.008	**-0.745**	-0.123	-0.143
F_x	-0.428	-0.108	**0.754**	-0.088	0.111
F_y	0.247	0.112	-0.354	-0.169	**-0.728**
F_z	0.19	-0.064	-0.145	**-0.899**	-0.154
M_x	-0.013	**-0.762**	-0.071	0.578	0.11
M_y	0.08	**-0.889**	0.119	0.015	0.151
M_z	-0.18	**-0.895**	0.131	-0.167	0.188
Variance	2.795	2.3346	1.8552	1.4485	1.4042
% Var	0.233	0.195	0.155	0.121	0.117

A strategy for reducing the variables one by one will strengthen the model with less, more important and stronger variables. In Table 6.8, the load of ΣMT on the factors is very weak and the variable can be omitted. As a result, the Eigenvalues are:

Table 6.9: *The Eigenvalues of the Factors.*

	Eigenvalues	(Principal Components Analysis)	
	Eigenvalue	**Proportion(%)**	**Cumulative(%)**
1	3.9295	35.7	35.7
2	2.4293	22.1	57.8
3	1.1863	10.8	68.6
4	0.9376	8.5	77.1
5	0.869	7.9	85
6	0.5188	4.7	89.7
7	0.3542	3.2	93
8	0.3117	2.8	95.8
9	0.2157	2	97.7
10	0.1986	1.8	99.6
11	0.0493	0.4	100

The Scree Plot of the Eigenvalues of the factors is represented in Figure 6.2.

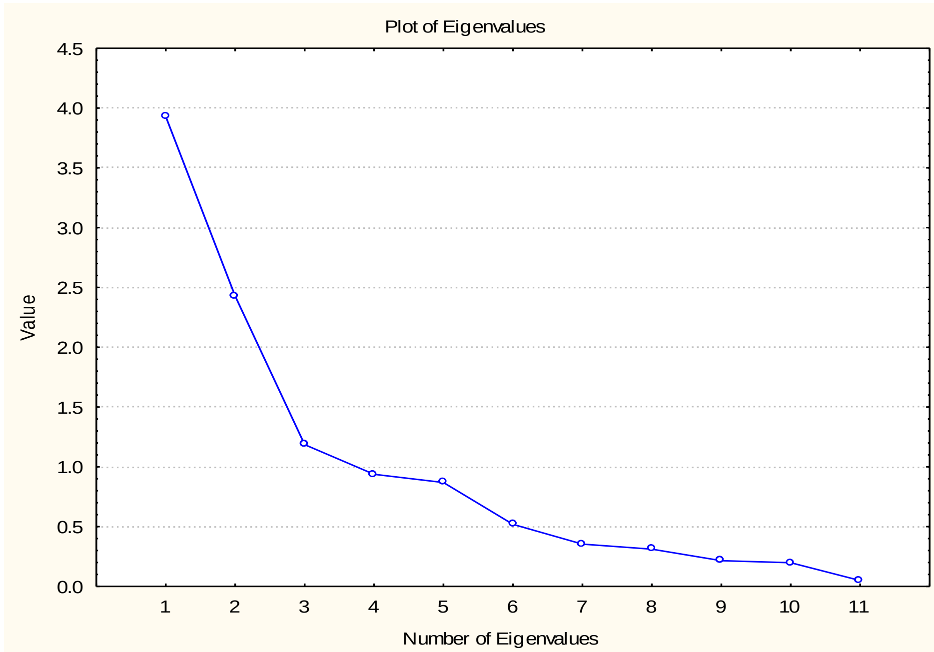


Figure 6.2: *The Scree Plot of the Eigenvalues.*

According to the prescribed criteria, 5 factors are chosen, with the following loads:

Table 6.10: *Principal Components: the factors' loadings.*

	Unrotated Factor Loadings Extraction: Principal Components (Marked loadings are > .70)				
Variable	**Factor1**	**Factor2**	**Factor3**	**Factor4**	**Factor5**
Gender	**0.73**	-0.427	0.035	-0.032	0.271
Circumf	**0.765**	-0.305	0.142	-0.172	0.258
L_Ulna	0.687	-0.362	0.204	-0.041	0.404
N_Degrees	0.273	0.517	-0.066	**-0.743**	-0.021
F_zT	**0.764**	-0.293	-0.011	0.082	-0.296
F_x	**-0.719**	0.196	-0.146	-0.281	0.483
F_y	0.655	0.167	-0.223	-0.326	-0.382
F_z	0.433	-0.008	**-0.86**	0.192	0.067
M_x	-0.393	**-0.726**	0.31	-0.242	-0.306
M_y	-0.348	**-0.789**	-0.223	-0.18	-0.012
M_z	-0.522	-0.672	-0.403	-0.18	-0.004
Variance	3.9295	2.4293	1.1863	0.9376	0.869
% Var	0.357	0.221	0.108	0.085	0.079

and after Varimax orthogonal rotation:

Table 6.11: *Principal Components: the factors' loadings.*

	Rotated Factor Loadings (Varimax Rotation) Extraction: Principal Components (Marked loadings are > .70)				
Variable	**Factor1**	**Factor2**	**Factor3**	**Factor4**	**Factor5**
Gender	**0.833**	-0.045	-0.267	-0.152	-0.005
Circumf	**0.838**	0.048	-0.249	-0.037	-0.164
L_Ulna	**0.888**	0.058	-0.135	-0.009	0.024
N_Degrees	0.033	0.247	0.099	0.003	**-0.91**
F_zT	0.459	0.012	**-0.725**	-0.153	-0.062
F_x	-0.291	-0.156	**0.879**	0.023	-0.083
F_y	0.151	0.136	-0.543	-0.251	-0.6
F_z	0.128	-0.023	-0.18	**-0.957**	-0.053
M_x	-0.033	**-0.769**	-0.132	0.552	0.126
M_y	0.07	**-0.889**	0.077	-0.005	0.159
M_z	-0.13	**-0.906**	0.212	-0.138	0.135
Variance	2.5432	2.3143	1.8539	1.3524	1.2881
% Var	0.231	0.21	0.169	0.123	0.117

It is obvious that, since the number of the variables is reduced, the important variables are of higher value and the value of the less important is also increased. As before, F_y seems to have a reduced effect on the factors and can be excluded from the model. Thus, the Eigenvalues are:

Table 6.12: *The Eigenvalues of the Factors.*

	Eigenvalues	(Principal Components Analysis)	
	Eigenvalue	**Proportion(%)**	**Cumulative(%)**
1	3.5771	35.8	35.8
2	2.4028	24	59.8
3	1.1633	11.6	71.4
4	0.9139	9.1	80.6
5	0.7457	7.5	88
6	0.3599	3.6	91.6
7	0.3119	3.1	94.7
8	0.2448	2.4	97.2
9	0.2156	2.2	99.3
10	0.065	0.7	100

The Scree Plot of the Eigenvalues of the factors is represented in Figure 6.3.

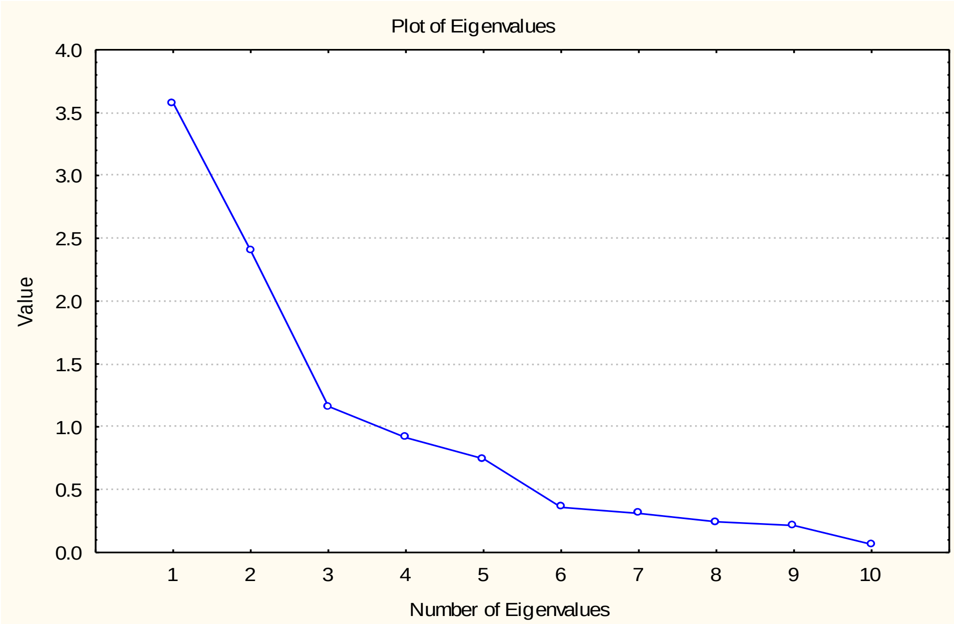


Figure 6.3: *The Scree Plot of the Eigenvalues.*

According to the rules followed previously, four factors are extracted with the following unrotated loadings:

Table 6.13: *Principal Components: the factors' loadings.*

	Unrotated Factor Loadings Extraction: Principal Components (Marked loadings are > .70)			
Variable	**Factor1**	**Factor2**	**Factor3**	**Factor4**
Gender	**0.778**	-0.363	-0.013	-0.179
Circumf	**0.802**	-0.239	0.108	-0.29
L_Ulna	**0.724**	-0.304	0.16	-0.223
N_Degrees	0.201	0.516	0.012	-0.65
F_zT	**0.781**	-0.238	-0.019	0.195
F_x	**-0.726**	0.146	-0.141	-0.482
F_z	0.406	0.008	**-0.89**	0.077
M_x	-0.36	**-0.763**	0.401	-0.015
M_y	-0.309	**-0.824**	-0.169	-0.145
M_z	-0.488	**-0.718**	-0.353	-0.165
Variance	3.5771	2.4028	1.1633	0.9139
% Var	0.358	0.24	0.116	0.091

and after Varimax orthogonal rotation:

Table 6.14: *Principal Components: the factors' loadings.*

	Rotated Factor Loadings (Varimax Rotation) Extraction: Principal Components (Marked loadings are > .70)			
Variable	**Factor1**	**Factor2**	**Factor3**	**Factor4**
Gender	**0.863**	-0.062	-0.144	-0.008
Circumf	**0.878**	0.053	-0.04	-0.145
L_Ulna	**0.829**	-0.001	0.031	-0.061
N_Degrees	0.109	0.35	-0.046	**-0.77**
F_zT	**0.744**	0.142	-0.202	0.303
F_x	-0.629	-0.313	0.074	-0.549
F_z	0.198	-0.035	**-0.96**	0.037
M_x	0.042	-0.694	0.575	0.242
M_y	0.044	**-0.899**	0.039	0.108
M_z	-0.181	**-0.928**	-0.104	0.033
Variance	3.2379	2.3998	1.3355	1.0839
% Var	0.324	0.24	0.134	0.108

The goal of having 10 variables for 50 measurements has been achieved. By excluding the variables that seem not to be affecting the factors, the remaining loads will be stronger. Between F_x and M_x, the first is omitted, as it influences the factors less than the second one. As a result, the Eigenvalues are:

Table 6.15: *The Eigenvalues of the Factors.*

	Eigenvalues	(Principal Components Analysis)	
	Eigenvalue	**Proportion(%)**	**Cumulative(%)**
1	3.1453	34.9	34.9
2	2.3775	26.4	61.4
3	1.1538	12.8	74.2
4	0.8147	9.1	83.2
5	0.5611	6.2	89.5
6	0.3423	3.8	93.3
7	0.2751	3.1	96.3
8	0.2177	2.4	98.8
9	0.1124	1.2	100

The Scree Plot of the Eigenvalues of the factors is represented in Figure 6.4.

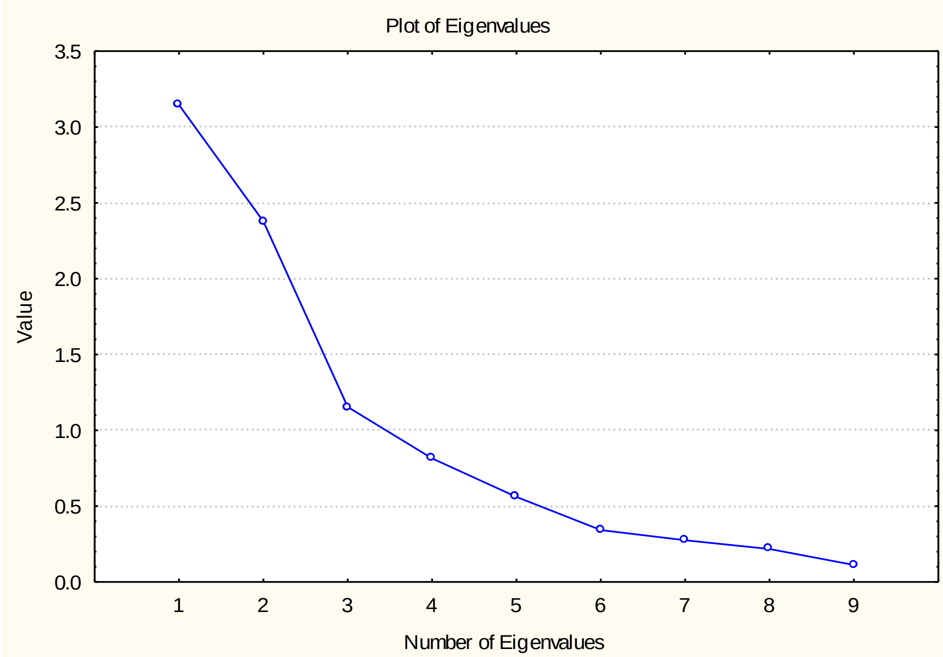


Figure 6.4: *The Scree Plot of the Eigenvalues.*

Following the same criteria as previously, four factors are extracted, which explain more than 80% of the total variance. The unrotated factor loadings are:

Table 6.16: *Principal Components: the factors' loadings.*

	Unrotated Factor Loadings Extraction: Principal Components (Marked loadings are > .70)			
Variable	**Factor1**	**Factor2**	**Factor3**	**Factor4**
Gender	**0.75**	0.454	0.034	-0.013
Circumf	**0.801**	0.339	0.169	-0.126
L_Ulna	**0.722**	0.398	0.225	0.16
N_Degrees	0.292	-0.474	0.071	**-0.817**
F_zT	**0.71**	0.304	-0.037	-0.037
F_z	0.421	0.046	**-0.885**	0.006
M_x	-0.473	**0.704**	0.385	-0.146
M_y	-0.384	**0.792**	-0.153	-0.166
M_z	-0.532	0.675	-0.336	-0.233
Variance	3.1453	2.3775	1.1538	0.8147
% Var	0.349	0.264	0.128	0.091

and after Varimax orthogonal rotation:

Table 6.17: *Principal Components: the factors' loadings.*

	Rotated Factor Loadings (Varimax Rotation) Extraction: Principal Components (Marked loadings are > .70)			
Variable	**Factor1**	**Factor2**	**Factor3**	**Factor4**
Gender	**0.866**	0.042	-0.134	0.004
Circumf	**0.879**	-0.059	-0.024	-0.151
L_Ulna	**0.851**	-0.087	0.05	0.145
N_Degrees	0.031	-0.24	-0.028	**-0.961**
F_zT	**0.745**	-0.041	-0.202	-0.054
F_z	0.205	0.015	**-0.959**	-0.004
M_x	0.025	**0.757**	0.546	0.134
M_y	0.037	**0.894**	0.011	0.155
M_z	-0.182	**0.921**	-0.132	0.089
Variance	2.8802	2.2922	1.2986	1.0203
% Var	0.32	0.255	0.144	0.113

As the four factors explain more than 80% of the total variance, the number of the factors can be reduced. Thus,

Table 6.18: *Principal Components: the factors' loadings.*

	Unrotated Factor Loadings Extraction: Principal components (Marked loadings are > .70)		
Variable	**Factor1**	**Factor2**	**Factor3**
Gender	0.75	0.454	0.034
Circumf	**0.801**	0.339	0.169
L_Ulna	**0.722**	0.398	0.225
N_Degrees	0.292	-0.474	0.071
F_zT	**0.71**	0.304	-0.037
F_z	0.421	0.046	**-0.885**
M_x	-0.473	**0.704**	0.385
M_y	-0.384	**0.792**	-0.153
M_z	-0.532	0.675	-0.336
Variance	3.1453	2.3775	1.1538
% Var	0.349	0.264	0.128

and after Varimax orthogonal rotation:

Table 6.19: *Principal Components: the factors' loadings.*

	Rotated Factor Loadings (Varimax Rotation) Extraction: Principal Components (Marked loadings are > .70)		
Variable	**Factor1**	**Factor2**	**Factor3**
Gender	**0.866**	0.04	-0.136
Circumf	**0.879**	-0.108	-0.027
L_Ulna	**0.852**	-0.031	0.051
N_Degrees	0.026	-0.559	-0.039
F_zT	**0.744**	-0.058	-0.204
F_z	0.203	0.008	**-0.96**
M_x	0.025	**0.759**	0.54
M_y	0.036	**0.892**	0.004
M_z	-0.183	**0.894**	-0.14
Variance	2.8787	2.5007	1.2972
% Var	0.32	0.278	0.144

Two variables, N_Degrees and F_zT, have reduced impact on the factors. Between them, N_Degrees has the weaker influence and can be omitted. Therefore, the Eigenvalues are:

Table 6.20: *The Eigenvalues of the Factors.*

	Eigenvalues	Principal Components Analysis	
	Eigenvalue	**Proportion(%)**	**Cumulative(%)**
1	3.0927	38.7	38.7
2	2.2166	27.7	66.4
3	1.152	14.4	80.8
4	0.565	7.1	87.8
5	0.3483	4.4	92.2
6	0.2787	3.5	95.7
7	0.2283	2.9	98.5
8	0.1184	1.5	100

The Scree Plot of the Eigenvalues of the factors is represented in Figure 6.5.

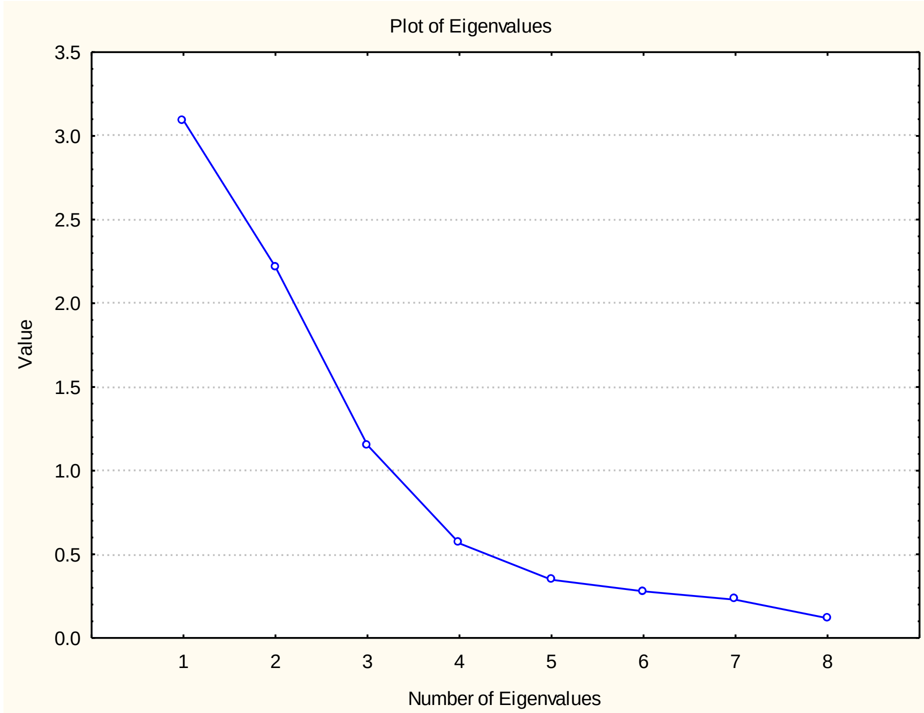


Figure 6.5: *The Scree Plot of the Eigenvalues.*

Three factors are extracted for the PCA model. The unrotated factor loadings are as follows:

Table 6.21: *Principal Components: the factors' loadings.*

	Unrotated Factor Loadings Extraction: Principal Components (Marked loadings are > .70)		
Variable	**Factor1**	**Factor2**	**Factor3**
Gender	**0.795**	0.371	0.031
Circumf	**0.827**	0.27	0.161
L_Ulna	**0.768**	0.297	0.231
F_zT	**0.74**	0.221	-0.038
F_z	0.429	-0.019	**-0.881**
M_x	-0.396	**0.771**	0.367
M_y	-0.296	**0.841**	-0.172
M_z	-0.46	**0.752**	-0.359
Variance	3.0927	2.2166	1.152
% Var	0.387	0.277	0.144

and after Varimax orthogonal rotation:

Table 6.22: *Principal Components: the factors' loadings.*

	Rotated Factor Loadings (Varimax Rotation) Extraction: Principal Components (Marked loadings are > .70)		
Variable	**Factor1**	**Factor2**	**Factor3**
Gender	**0.865**	0.047	-0.141
Circumf	**0.879**	-0.084	-0.036
L_Ulna	**0.852**	-0.053	0.049
F_zT	**0.743**	-0.056	-0.209
F_z	0.197	0.013	**-0.96**
M_x	0.027	**0.767**	0.545
M_y	0.035	**0.908**	0.01
M_z	-0.185	**0.925**	-0.134
Variance	2.8742	2.2825	1.3046
% Var	0.359	0.285	0.163

These are the final three factors with their loadings describing more than 80% of the total variance of the hand/wrist complex in the experimental grip in neutral wrist position. The analysis power is 80.4%.

6.2.6 Naming the factors

The first factor represents the gender, the "anthropometric" characteristics of the subjects and the normal loads produced by the hand on the gripping tool. The second factor consists of the moments exerted on the metacarpals and the third by the only force on the metacarpals that seems to be important: the F_z.

The 3D plot of the factor loadings is shown in Figure 6.6.

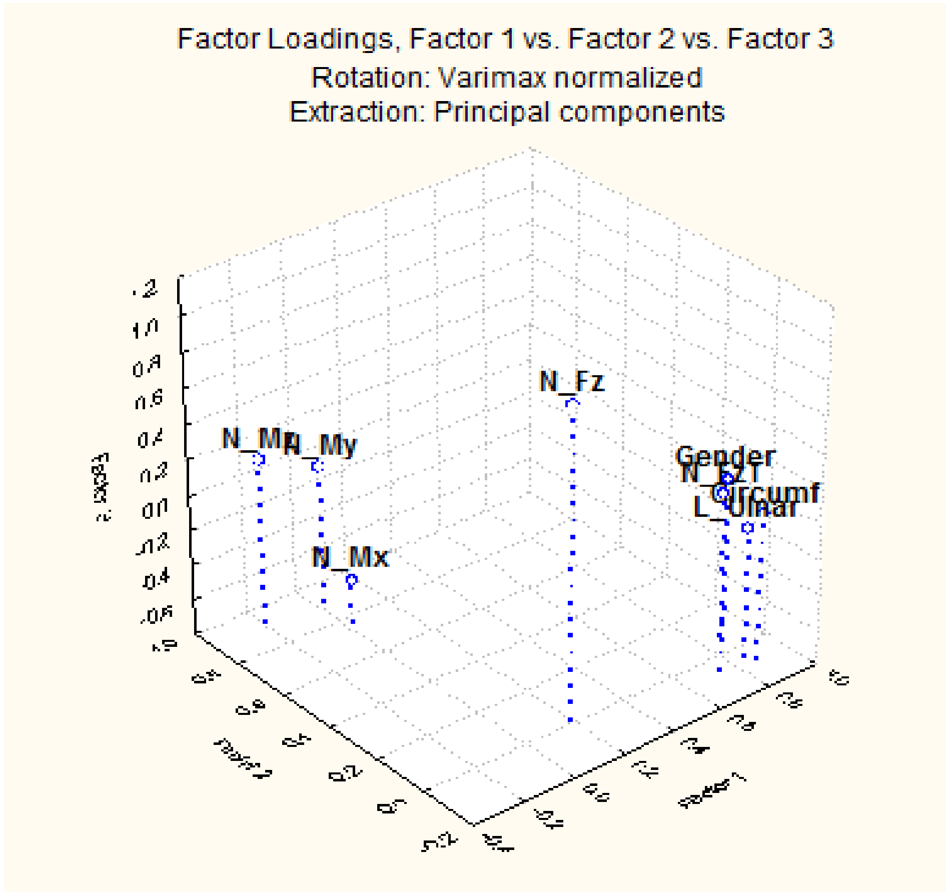


Figure 6.6: *The 3D Plot of the Factor loadings.*

6.3 Discussion

Three main principal components can represent more than 80% of the hand-wrist total variance. Mathematicaly, the total variance is the linear combination of the factors and in the present case, due to the nature of the experiment, expresses the ability of the hand to generate its maximal force in the specific grip.

The first factor, representing the most of the total variance (almost 36%), consists of four variables: the gender, the circumference of the forearm, the ulnar length, as well as the vertical force on the transducer. The gender, as discussed in the previous chapter, plays an important role in the strength generation of the hand: male subjects can produce statistically higher gripping force than females. Although gender is not a continuous variable, the PCA results remained the same by excluding it and therefore did not seem to affect the outcame of the statistical test.

Most of the muscles responsible for the gripping force have their origin at the distal end of the humerus and the proximal side of the radius and ulna, thus in the area around the elbow joint. Additionally, their muscle fibres are distributed around the forearm, and only their tendons continue below the wrist level. Therefore, the forearm circumference together with the ulnar length can represent the volume of the muscles that generate the gripping force. Consequently, the first principal component can be considered as “the anthropometric variables” one, responsible for the force generation during the grip trials, together with their direct expression: the vertical force on the transducers F_zT.

The second principal component, representing almost 29% of the total variance, consists of the moments around the metacarpophalangeal joints. The importance of these loads was discussed in the previous chapter.

The last principal component, representing almost 16% of the total variance, consists of the F_z force exerted on the metacarpophalangeal joints. This single force demonstrates the functional anatomy of the hand, as it showed in the previous chapter, tending to fold the fingers in to the centre of the palm.

There is no evidence of Principal Component Analysis of the hand and wrist complex in the literature. Since the purpose of this study was to measure the loads during maximal precision grip trials, the high load of the first factor, as well as the moments on the metacarpophalangeal joints were more or less presumable. However, the importance of the F_z on the metacarpophalangeal joints is a new, significant finding regarding the functionality of the hand.

Apart from the long muscles producing the maximal percentage of the hand grip strength, there are three groups of intrinsic muscles which also contribute to this strength: the dorsal interossei, the palmar interossei and the lumbricals. Dorsal interossei muscles abduct the fingers in the metacarpophalangeal joints, and palmar interossei adduct them, while both groups flex the metacarpophalangeal joints and concurrently extend all the interphalangeal joints (Eladoumikdachi et al, 2002; Oatis, 2008). Because of the last effect, they are considered by the rehabilitation therapists as the key muscles for the delicate positions of the fingers during the everyday activities (Kornatz et al, 2005; Kapandji, 1982). These muscles are often affected by several diseases, like rheumatoid arthritis (Rajagopalan and Burne, 2010; Flint-Wagner et al, 2009), Parkinson (Fellows et al, 1998), multiple sclerosis (Iyengar et al, 2009), cerebral palsy (Koman et al, 1990), peripheral nerve injuries (Sadeh et al, 2004; Meena et al, 2008; Atkins et al, 2009) etc., and cause severe damage in the functionality of the hand. In these cases, the rehabilitation concentrates on voluntary control of these muscles from the patients, as well as on strengthening them (Flint-Wagner et al, 2009; Merians et al, 2009; Timmermans et al, 2009; Sakzewski et al, 2009; Carlson 2008; Koman et al, 1990). However, there is no hierarchy in the rehabilitation programmes in the literature as regards the importance of these muscles.

Principal components analysis indicates that the palmar interossei muscles may be of higher importance than the others in this type of hand grip, by illustrating that the adduction force on the metacarpals is the only force on the metacarpophalangeal joints participating on the third component; there is also no literature reference about this finding. metacarpophalangeal joints, allow movement in two planes: sagittal (flexion-extension) and frontal (abduction-adduction) (there is also some rotation, but it is limited by ligaments). However, full range of motion on the frontal plane requires maximal extension on the metacarpophalangeal joints, and, on the other hand maximal flexion of the metacarpophalangeal joints requires maximal adduction of the fingers. In other words, as the flexion of the fingers in the metacarpophalangeal joints progresses, the joint becomes more adducted until the full flexed position, which requires maximal adduction of them (Kapandji, 1982).

The contribution of the intrinsic hand muscles in the total grip force varies in the literature, from 22-24% (Buford et al, 2005) to 49% (Kozin et al, 1999). However, this study illustrates that in a grip where the initial position of the fingers is abduction, palmar interossei muscles probably work much harder than the dorsal ones, in an attempt to bring the fingers in a more optimal position for maximum gripping force (adduction); as their activity level is perhaps higher than the dorsal interossei, they may produce much more flexion force.

Although the aforementioned statistical results need further experimental validation, they would suggest that in rehabilitation sciences, whenever the purpose of the therapy is towards strengthening of the gripping muscles, extra attention should be given to palmar interossei, as most of the everyday activities require gripping force and have a degree of abduction on the metacarpophalangeal joints. These muscles can be easily isolated from the others, by giving exercises concentrating on the adduction of the fingers.

Finally, the rest of the kinetic and kinematic variables describe less than 20% of the total hand-wrist variance. The principal components analysis suggests that, whenever a hand grip experiment in the neutral wrist position has to be constructed, from the plethora of hand and wrist variables that have to be measured, the ones participating in the aforementioned three components are the most crucial; the rest of the variables can –if necessary- be omitted, without losing much of the hand and wrist information.

CHAPTER 7: **Conclusions and Future Work**

Conclusions

The fact that wrist orientation is one of the most important factors which govern the ability of the fingers to generate maximal grip force is well known in the literature. However, the present study showed that there are coupled positions of wrist joint under maximal load: flexion was combined with radial deviation, extension with ulnar deviation, radial deviation with extension and ulnar deviation with flexion. The functional neutral wrist position was found to be extension combined with ulnar deviation. This is the wrist orientation where the subjects provided their maximal grip strength. This is a new proposal for the ideal position for joint fusion, where the surgeon is particularly interested in strength generation.

The mean radial deviation angle of the wrist was significantly smaller for females. Additionally, the functional neutral wrist position chosen by the female subjects was significantly more ulnary deviated than that chosen by the male ones. Although there is no evidence of that fact in the literature, a possible explanation would be that most of the females are of a different type of wrist than the male ones, and therefore should be differently treated by orthopaedic surgeons, rehabilitation scientists and clinicians in general. Females seem to be of a column type wrist with the scaphoid compressed in radial deviation, while their neutral wrist orientation is more ulnary deviated. This orientation places the joint in a more comfortable position for the scaphoid in order that the hand can generate its maximal grip force. It is noticed in the literature that females have more work injuries in the wrist than males, and therefore ergonomics scientists should take into account these gender differences in order to provide equally safe working environment for both genders. Finally, regarding the wrist kinematics, the remarkable geometry of the functional axes of the wrist, in comparison with the anatomical ones should be drawn. It is an interesting finding and remains to examine if it is also present in other grip types and in everyday dynamic activities.

In the present study, males exerted 27.8% greater mean resultant grip force (magnitude). Males also provided an average of 20.4% greater magnitude resultant moments than females. The force difference is 50-70% less than that found in other studies, which used different designs of gripping tool. However, this discrepancy is probably not only because of the gripping tool: all the studies in the literature regarding this topic are one-dimensional, while in the present study the magnitudes of the resultant loads were calculated in three dimensions. As the hand grip strength has been identified by many authors as a limiting factor for manual carrying, it is important the experiments with different gripping tools to re-conducted in three dimensions.

The percentage distribution of the resultant (normal on the transducer) force on the fingers was greatest for the index finger, followed by the middle, ring and little fingers. This finding applied to all the wrist orientations, and for both genders. Although the use of the above results in biomechanics is limited, they provide many other scientists like ergonomists and equipment designers with important information regarding the specific tool used in the present study.

The forces on the MCP joints tend to generate tension on the metacarpals of the fingers and compression on the metacarpal of the thumb. Additionally, they tend to extend the wrist and fold the fingers in the centre of the palm, following the functional anatomy of the hand. Significant shear force components are produced on the fingertips during simple grip activities and these can generate large moments at the finger joints. These moments tend –between others- to ulnary deviate the fingers on the metacarpophalangeal joints and internally rotate them all except the little finger. Such mechanical factors, under the biological conditions of rheumatoid arthritis, may produce severe deformations on the joints. Therefore, rheumatologists, rehabilitation scientists and arthroplasty implant designers should pay particular attention to the external loads on the metacarpophalangeal joints provided by the present work.

Finally, principal component analysis of the hand revealed the importance of the palmar interossei muscles in the specific grip. Although this is a statistical indication and needs further clinical investigation, rehabilitation scientists should focus on these muscles whenever the demand is the increase of hand strength.

Future work

- Part of the external loads measured on the metacarpal bones have already been used as input in a finite element analysis model of the whole wrist, in order to explore the load distribution across the joint (Gislason et al, 2009). However, more work remains to be done in the field, especially as regards the different wrist orientations.

- The external loads on the metacarpophalangeal joints provided in the present study can be used in order to calculate the three-dimensional internal loads on these joints in all the wrist orientations. Additionally, the calculation of the external and internal loads on the interphalangeal joints is an important future task.

- The hand and wrist complex, according the literature, seems to behave differently in the various type of grip. Therefore, the comparison of the hand and wrist biomechanics presented in this work with those conducted with other grip types and especially the cylinder grip is very important.

- The grip span, in the present research, was fixed at 50mm. However, the hand size of the subjects were obviously not the same. Although it is shown in the literature that the span size affects the maximal grip force, the topic is not investigated thoroughly. There is a challenging idea of conducting the same experiment with various span sizes, in order to correlate them mathematicaly with the hand sizes and the various wrist positions or the gender. Later, the same work could be done with different types of grip in order to compare the results. The ambitious idea of creating a mathematic formula that correlates the span size with the hand size would lead the industry in better equipement design, especially for athlets and patients, and help clinical scientists to choose patient-specific tools and equipements for their rehabilitation.

- The present experiment was designed as static, but everyday activities are mostly dynamic. It is interesting as a future work to investigate if the results of the present study are comparable with dynamic activities with the same type of grip. Additionally, it would be important to investigate if the hand and wrist complex behaves in the same with the present study biomechanical way in everyday tasks, which need submaximal gripping force.

- The thumb is considered as –clinicaly- the most important finger. With the data collected in the present work, the position of the thumb as it opposes the other fingers will be investigated. It is also interesting to compare the position of the thumb as it opposes the fingers in different grip types, and especially the cylinder grip.

- Finally, the positions of the forearm, elbow and shoulder were not investigated in the present study. The data collected, however, would be used to explore the positions of these joints chosen by the subjects as the most comfortable ones. Later in the future, an experiment in different positions of these joints would be conducted, especially in everyday activities, in order to examine the upper extremity as a whole kinematic chain.

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APPENDICES

APPENDIX (A): **Brief Anatomy and Kinesiology of the Hand and Wrist**

A1. Introduction

In the following chapters, a reader with no clinical background will find a basic anatomy of the hand and wrist, by means the bones, the joints and the muscles, as well as the basic kinesiology of the hand-wrist complex.

A2. The Carpus

A2.2 Carpal bones

The carpus is consisted by eight small bones in proximal and distal rows of four. In radial (lateral) to ulnar (medial) order, the proximal row is made up by the scaphoid, lunate, triquetrum and pisiform, and the distal row is made up by the trapezium, trapezoid, capitate and hamate (Figure A.1). With the exception of the pisiform, this articulates only with the palmar surface of the triquetrum, all the other carpal bones articulate with their neighbours. The other three proximal bones form a proximally convex arch that articulates with the radius and articular disc of the distal radio-ulnar joint. The four bones of the distal row articulate distally with the five metacarpals (Figure A.1)

A2.3 The Joints

A2.3.1 Radiocarpal (wrist) Joint

The radiocarpal joint is a biaxial and ellipsoid joint. It is formed by articulation of the distal end of the radius and the triangular articular disc (at the distal end of ulna) with the scaphoid, lunate and triquetrum. In the neutral wrist position, only the lunate and scaphoid are in contact with the radius and articular disc: the triquetrum comes into apposition with the disc only in full adduction (ulnar deviation) of the wrist joint.

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Figure A.0.1: *The carpal bones.*

A2.3.2 Carpal Joints

The interconnection of the carpal bones can be summarised as joints between the proximal row of carpal bones, between the distal row of carpal bones, and the midcarpal joint, a complex joint between the rows.

A2.3.2.1 Joints of the Proximal Carpal Row

The joints of the proximal carpal row are these between the scaphoid, lunate and triquetrum. The pisiform articulates with the palmar surface of the triquetrum

A2.3.2.2 Joints of the Distal Carpal Row

The joints of the distal carpal row are these between the trapezium, trapezoid, capitate and hamate.

A2.3.2.3 Midcarpal Joint

As midcarpal joint is described the joint between the proximal and distal carpal rows, namely between the scaphoid, lunate and triquetrum (proximally) and trapezium, trapezoid, capitate and hamate (distally) (Gray's Anatomy, 2008).

A2.4 Wrist Movements

Since the movements at the radiocarpal and intercarpal joints are both involved in all movements as well as being acted upon by the same muscles, they are considered together. Active movements are flexion, extension, adduction (ulnar deviation) and abduction (radial deviation) (Figure A.2)

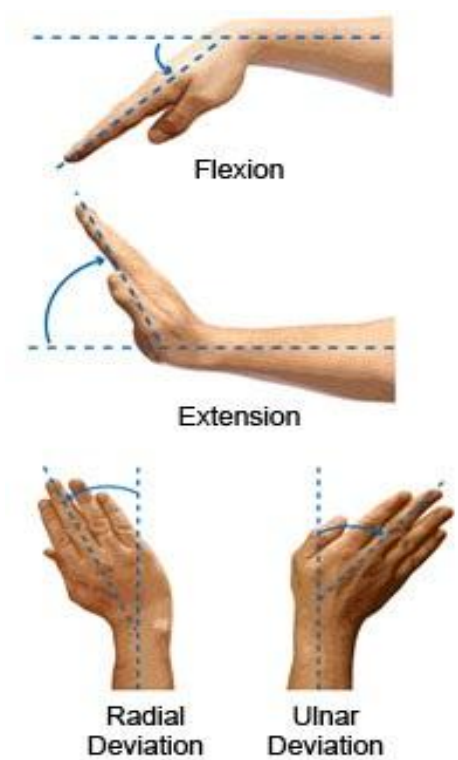

Figure A.0.2: *The wrist movements.*

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A2.5 Muscles

The wrist flexion is performed by the flexor carpi radialis, the flexor carpi ulnaris and palmaris longus, assisted by flexors digitorum superficialis and profundus and flexor pollicis longus. The extension of the wrist is achieved by the extensors carpi radialis longus, brevis and ulnaris, assisted by extensors digitorum, digiti minimi, indicis and pollicis longus. The wrist adduction (ulnar deviation) is executed by the flexor and extensor carpi ulnaris, while the wrist abduction (radial deviation) by the flexor carpi radialis, extensors carpi radialis longus and brevis, abductor pollicis longus and extensor pollicis brevis (see A4) (Gray's Anatomy, 2008).

A3. The Hand

A3.1 The Hand Bones

A3.1.1 The Metacarpal bones

The metacarpals are miniature long bones, with a distal head, shaft and expanded base. Their bases articulate with the distal carpal row and with each other, except the first and second.

A.3.1.2 The Phalanges

There are 14 phalanges, two in the thumb and three in each finger. Each has a head, shaft and proximal base.

A3.2 The Joints

A3.2.1 Carpometacarpal Joints

The carpometacarpal joint of the thumb is a sellar (saddle) joint between the first metacarpal base and trapezium. It has wide mobility due to its extensive articular surfaces and their topology. The second to fifth carpometacarpal joints are ellipsoid joints between the carpus and second to fifth metacarpals. The second metacarpal is mainly articulated with the trapezoid, the third with the capitate, while the forth and the fifth with the hamate (Figure A.1) (Gray's Anatomy, 2008).

A3.2.2 Metacarpophalangeal Joints

The metacarpophalangeal joints are usually considered ellipsoid.

A3.3 The Hand Movements

A3.3.1 Movements in the Carpometacarpal Joints

Unlike the almost complete absence of movement between the second to fifth metacarpal bones and the carpus, the thumb enjoys a wide range of motion in this joint. Thus, the carpometacarpal joint of the thumb can perform the movements of flexion, extension, adduction, abduction and opposition (Figure A.3) (Gray's Anatomy, 2008).

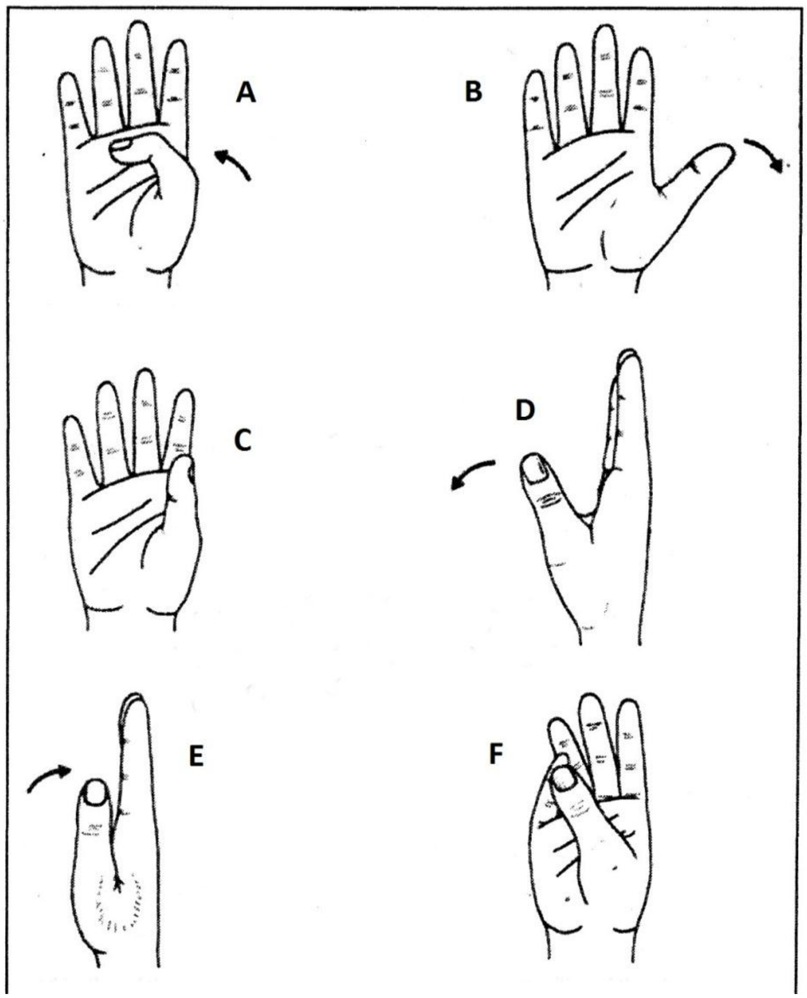

Figure A.0.3: *The thumb movements: flexion (A), extension (B), neutral (C), abduction (D), adduction (E) and opposition (F).*

A3.3.2 Movements in the Metacarpophalangeal Joints

At the metacarpophalangeal joints, all the movements of flexion, extension, adduction, abduction (Figure A.4), and limited rotation take place. Flexion is almost 90°, whereas extension is only a few degrees, and both movements are limited mostly by antagonistic muscles. As regards the metacarpophalangeal joint of the thumb, it has a flexion-extension range of 60°, which is almost entirely flexion. Regarding the adduction-abduction of the second to fifth metacarpophalangeal joints, the second is most mobile in adduction-abduction, followed by the fifth, fourth, and third (Gray's Anatomy, 2008).

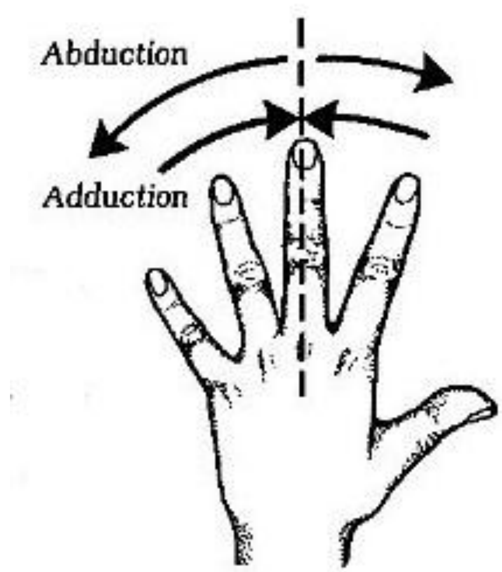

Figure A.0.4: *The abduction and adduction of the metacarpophalangeal joints.*

A3.4 The Muscles

A3.4.1 On the Carpometacarpal Joint of the Thumb

The muscles producing movements at the carpometacarpal joint of the thumb (see A4) are as follows (Gray's Anatomy, 2008):

- Flexion: the flexor pollicis brevis and opponens pollicis, aided by flexor pollicis longus when the other joints of the thumb are flexed.

- Extension: the abductor pollicis longus and extensors pollicis brevis and longus.
- Abduction: the abductors pollicis brevis and longus.
- Adduction: the adductor pollicis.
- Opposition: the opponens pollicis and flexor brevis pollicis simultaneously flex and medially rotate the abducted thumb.

A3.4.2 On the Metacarpophalangeal Joints

The muscles producing movements at the metacarpophalangeal joints (see A4) are as follows (Gray's Anatomy, 2008):

- Flexion: the flexors digitorum superficialis and profundus, assisted by the lumbricals and interossei and, in the minimus, flexor digiti minimi brevis. In the thumb, flexors pollicis longus and brevis and the first palmar interosseous.
- Extension: the Extensor digitorum, assisted in the second and fifth digits by extensor indicis and extensor digiti minimi respectively. In the thumb, extensors pollicis longus and brevis.
- Adduction: in extended fingers, palmar interossei; the long flexors are predominant during flexion. In the thumb, limited metacarpophalangeal adduction is possible and may be attributable to adductor pollicis and the first palmar interosseous.
- Abduction: When the fingers are flexed at the interphalangeal joints, active abduction is impossible, while if the long digital flexors are inactive, passive abduction is free. In extended fingers, dorsal interossei generates the movement, assisted by the long extensors (except in the middle finger), and abductor digiti minimi in the little finger. In the thumb, the abduction occurs due to abductor pollicis brevis.

A4. Figures of the muscles of the hand and wrist

A group of figures presenting the wrist and hand muscles follows.

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Figure A.0.5: *A simplified representation of the extensors of the hand and wrist (from Gray's Anatomy).*

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Figure A.0.6: *Extensor mechanism of the finger in three different views (from Gray's Anatomy)*.

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Figure A.0.7: *The finger flexors (from Gray's Anatomy).*

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Figure A.0.8: *Superficial dissection of muscles of the palm (from Gray's Anatomy).*

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Figure A.0.9: *The palmar interossei muscles (from Gray's Anatomy).*

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Figure A.0.10: *The dorsal interossei muscles (from Gray's Anatomy).*

APPENDIX (B): **Transducers Technical Characteristics**

Mechanical Description

The property of forces was first stated by Newton in his third law of motion: *To every action there is always opposed an equal reaction; or, the mutual action of two bodies upon each other are always equal, and directed to contrary parts.* The transducer reacts to applied forces and torques using Newton's third law.

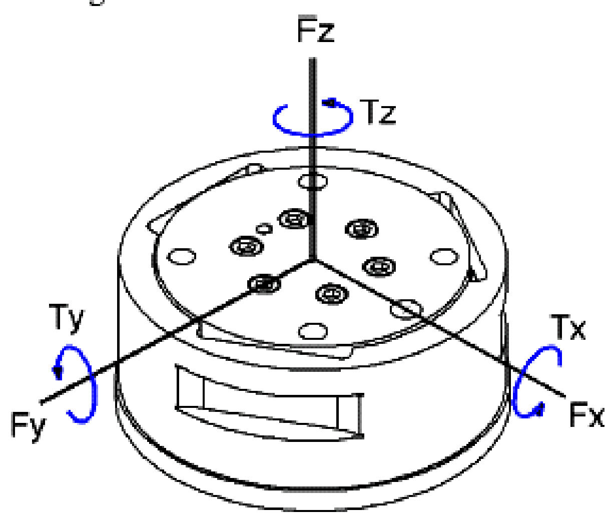


Figure 3.1—Applied force and torque vector on transducer

Semiconductor strain gauges are attached to the beams and are considered strain-sensitive resistors.

7.2 Transducer and Calibration Specifications

7.2.1 Nano17

	English (US)			Metric (SI)		
Calibration	**US-3-1**	**US-6-2**	**US-12-4**	**SI-12-0.12**	**SI-25-0.25**	**SI-50-0.5**
Rated Sensing Ranges						
Fx, Fy	±3 lb	±6 lb	±12 lb	±12.0 N	±25 N	±50 N
Fz	±4.25 lb	±8.5 lb	±17 lb	±17 N	±35 N	±70 N
Tx, Ty, Tz	±1 in-lb	±2 in-lb	±4 in-lb	±120 Nmm	±250 Nmm	±500 Nmm
Resolution*						
Fx, Fy	1/5120 lb	1/2560 lb	1/1280 lb	1/1280 N	1/320 N	1/160 N
Fz	1/5120 lb	1/2560 lb	1/1280 lb	1/1280 N	1/640 N	1/320 N
Tx, Ty	1/32000 in-lb	1/16000 in-lb	1/8000 in-lb	1/256 Nmm	1/128 Nmm	1/64 Nmm
Tz	1/32000 in-lb	1/16000 in-lb	1/8000 in-lb	1/256 Nmm	1/128 Nmm	1/64 Nmm

Physical Properties	**US**	**Metric**
Stiffness (Calculated)		
X-axis and Y-axis force (Kx, Ky)	53×10^3 lb/in	9.3×10^6 N/m
Z-axis force (Kz)	69×10^3 lb/in	12×10^6 N/m
X-axis and Y-axis torque (Ktx, Kty)	2.2×10^3 in-lb/rad	250 Nm/rad
Z-axis torque (Ktz)	3.5×10^3 in-lb/rad	390 Nm/rad
Resonant Frequency (Measured)		
Fx, Fy, Tz	7.2 kHz	
Fz, Tx, Ty	7.2 kHz	
Maximum Single-axis Load		
Fx, Fy	±79 lb	±350 N
Fz	±170 lb	±750 N
Tx, Ty	±21 in-lb	±2.4 Nm
Tz	±28 in-lb	±3.1 Nm
Weight		
Transducer with standard plates	0.021 lb	9.4 g
Material		
Transducer	Hardened Stainless Steel	
Mounting and tool adaptors	Aircraft Aluminum	

*Resolutions are typical for a 16-bit data acquisition system.

7.2.2 Nano25

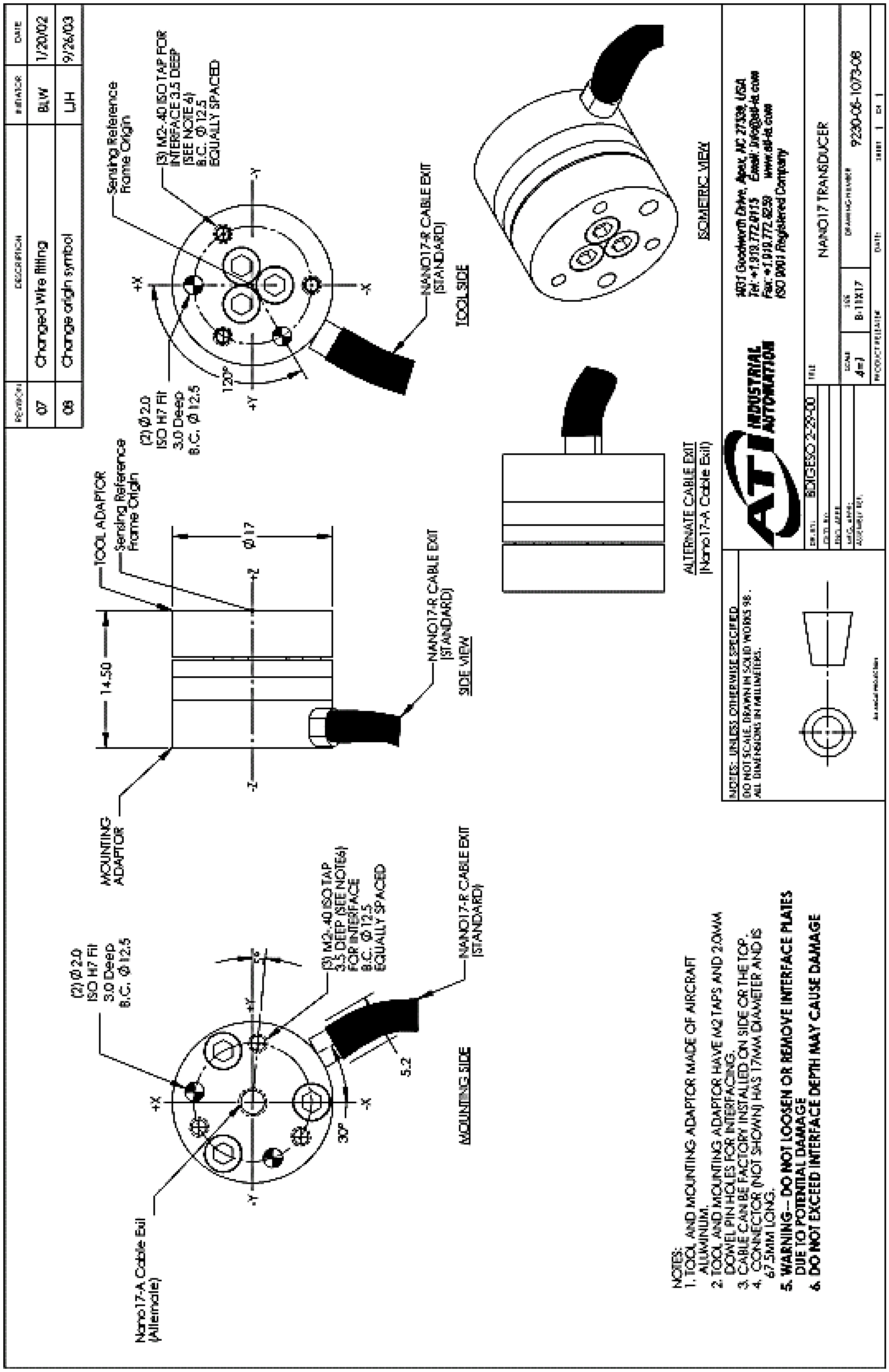
	English (US)		Metric (SI)	
Calibration	**US-25-25**	**US-50-50**	**SI-125-3**	**SI-250-6**
Rated Sensing Ranges				
Fx, Fy	±25 lb	±50 lb	±125 N	±250 N
Fz	±100 lb	±200 lb	±500 N	±1000 N
Tx, Ty	±25 in-lb	±50 in-lb	±3 Nm	±6 Nm
Tz	±25 in-lb	±30 in-lb	±3 Nm	±3.4 Nm
Resolution*				
Fx, Fy	1/896 lb	1/448 lb	1/192 N	1/96 N
Fz	3/896 lb	3/448 lb	1/64 N	1/32 N
Tx, Ty,	1/640 in-lb	1/320 in-lb	1/5280 Nm	1/2640 Nm
Tz	1/1280 in-lb	1/640 in-lb	1/10560 Nm	1/5280 Nm

Physical Properties	**US**	**Metric**
Stiffness (Calculated)		
X-axis and Y-axis force (Kx, Ky)	300×10^3 lb/in	53×10^6 N/m
Z-axis force (Kz)	630×10^3 lb/in	110×10^6 N/m
X-axis and Y-axis torque (Ktx, Kty)	57×10^3 in-lb/rad	6440 Nm/rad
Z-axis torque (Ktz)	82×10^3 in-lb/rad	9260 Nm/rad
Resonant Frequency (Measured)		
Fx, Fy, Tz	3.6 kHz	
Fz, Tx, Ty	3.8 kHz	
Maximum Single-axis Load		
Fx, Fy	±520 lb	±2300 N
Fz	±1400 lb	±6300 N
Tx, Ty	±310 in-lb	±35 Nm
Tz	±560 in-lb	±63 Nm
Weight		
Transducer with standard plates	0.14 lb	65 g
Material		
Transducer	Hardened Stainless Steel	
Mounting and tool adaptors	Hardened Stainless Steel	

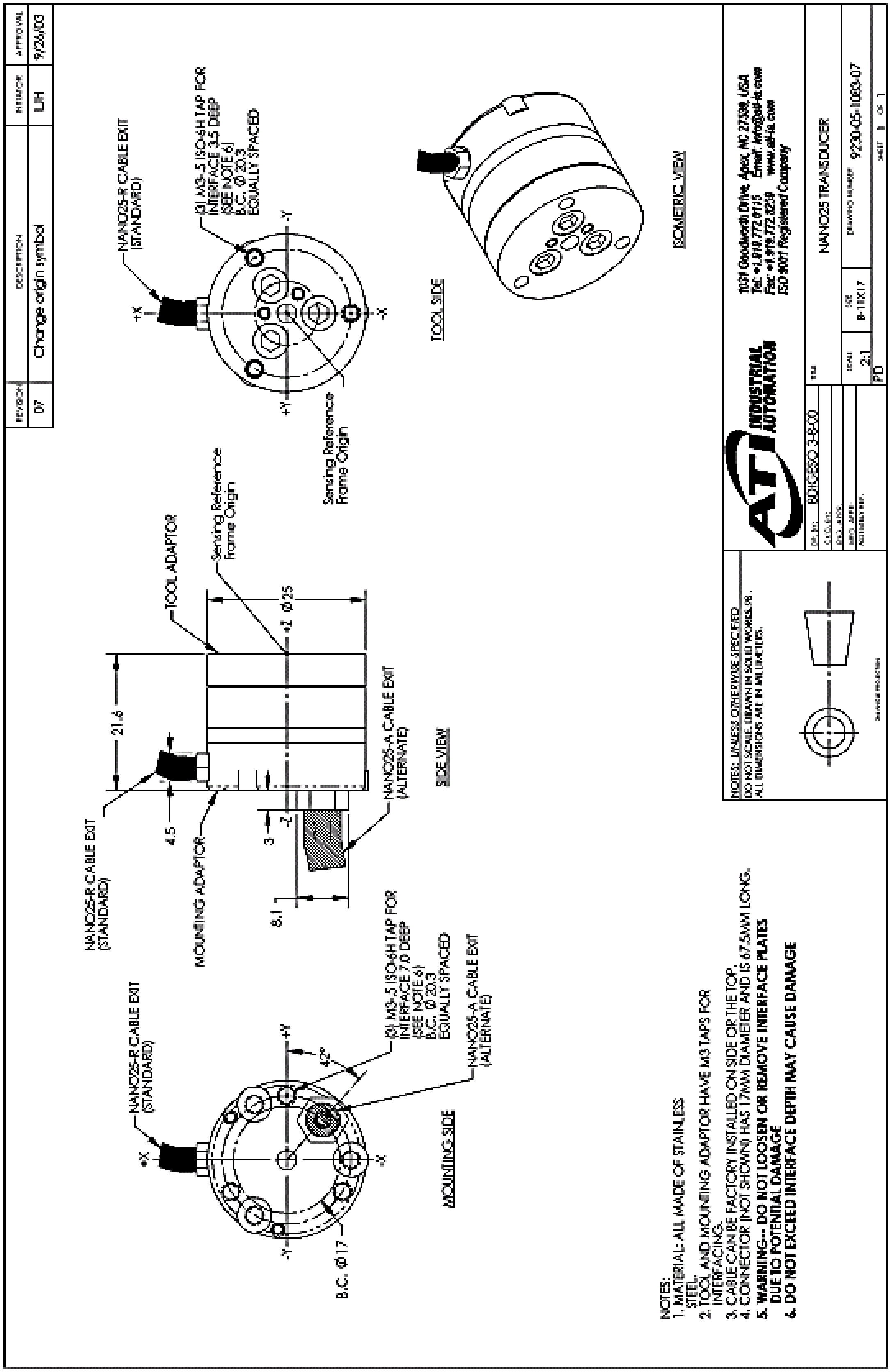
*Resolutions are typical for a 16-bit data acquisition system.

Note: Applying moments beyond ±30 in-lb (±3.4Nm) in Tz can cause hysteresis and permanent zero-point change in this transducer

Nano17 Transducer



Nano25 Transducer



APPENDIX (C): **Transducers Calibration Sheets**

ATI INDUSTRIAL AUTOMATION
ISO 9001 Registered

Six-Axis Force/Torque Transducer System
Calibration Accuracy Report

We appreciate your recent order for an F/T Six-Axis Force/Torque sensing system. As part of our commitment to quality, each ATI force/torque transducer undergoes rigorous accuracy testing. This process involves applying and verifying a rich set of loading cases designed to cover the transducer's entire six-axis calibrated range.

Our transducers often exceed our quality standards for measurement uncertainty. If your application demands high-accuracy measurements in some loading situations but not others, you may find it helpful to know which loading cases your transducer performed well on during testing.

This report summarizes the accuracy of your ATI F/T transducer during testing at our factory. The report is divided into three sections. The Full-Scale Loads section gives the maximum range for each axis. The second section, Applied Loads, gives the actual loads applied during calibration and testing. The final section, Full-Scale Error Report, shows measurement error as a percentage of full scale for each axis in each loading case.

If an ongoing guarantee of sensor accuracy is important to you we recommend that your sensor be verified, and calibrated if necessary, annually to ensure it has the best possible accuracy. We offer this service for a nominal fee.

ATI Industrial Automation, Inc.
Engineered Products for Manufacturing Productivity
Pinnacle Park • 1031 Goodworth Drive, Apex, NC 27539-3869 • Tel: 919.772.0115 •
Fax: 919.772.8259 •
• E-mail: info@ati-ia.com

Compound Loading Ranges of F/T Sensors

The F/T sensor's strain gauges are optimally placed to share information between the forces and torques applied to the sensor. Because of this sharing, it is possible to saturate the transducer with a complex load that has components below the rated load of the sensor. However, this arrangement allows a greater sensing range and resolution.

These graphs may be used to estimate a sensor's range under complex loading. Each page represents one sensor body, with either English or Metric units. The top graph represents combinations of forces in the x and/or y directions with torques about the z-axis. The bottom graph represents combinations of z-axis forces with x- and/or y-axis torques. The graphs contain several different calibrations, distinguished by line weight.

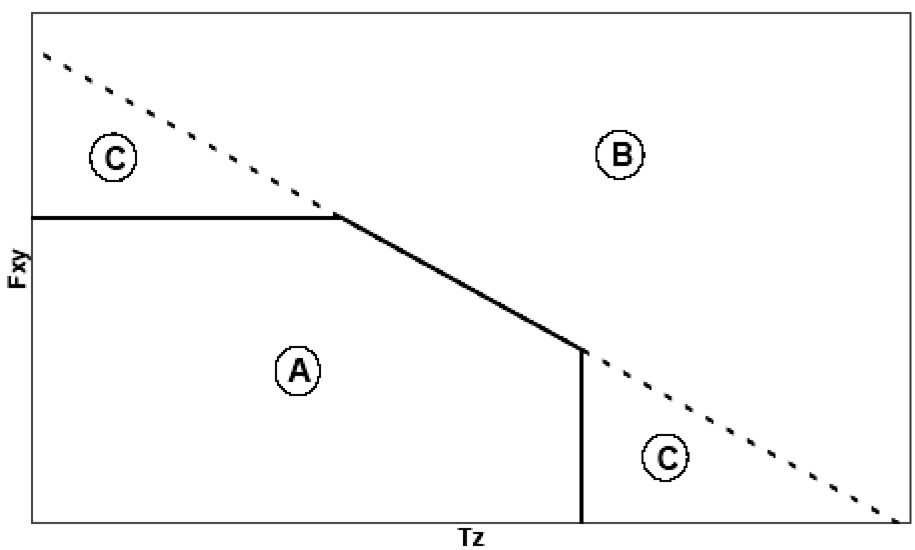
The following sample graph shows how operating ranges can change with complex loading. The labels indicate the following regions:

A. Normal operating region. You can expect to achieve rated accuracy in this region.

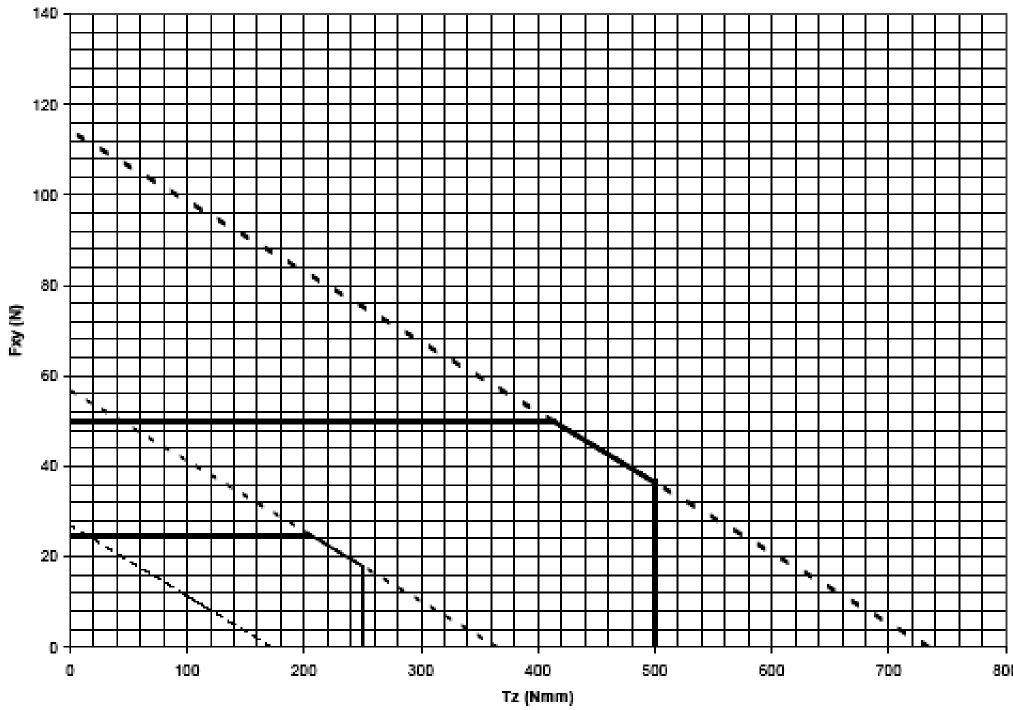
B. Saturation region. Any load in this region will report a gauge saturation condition.

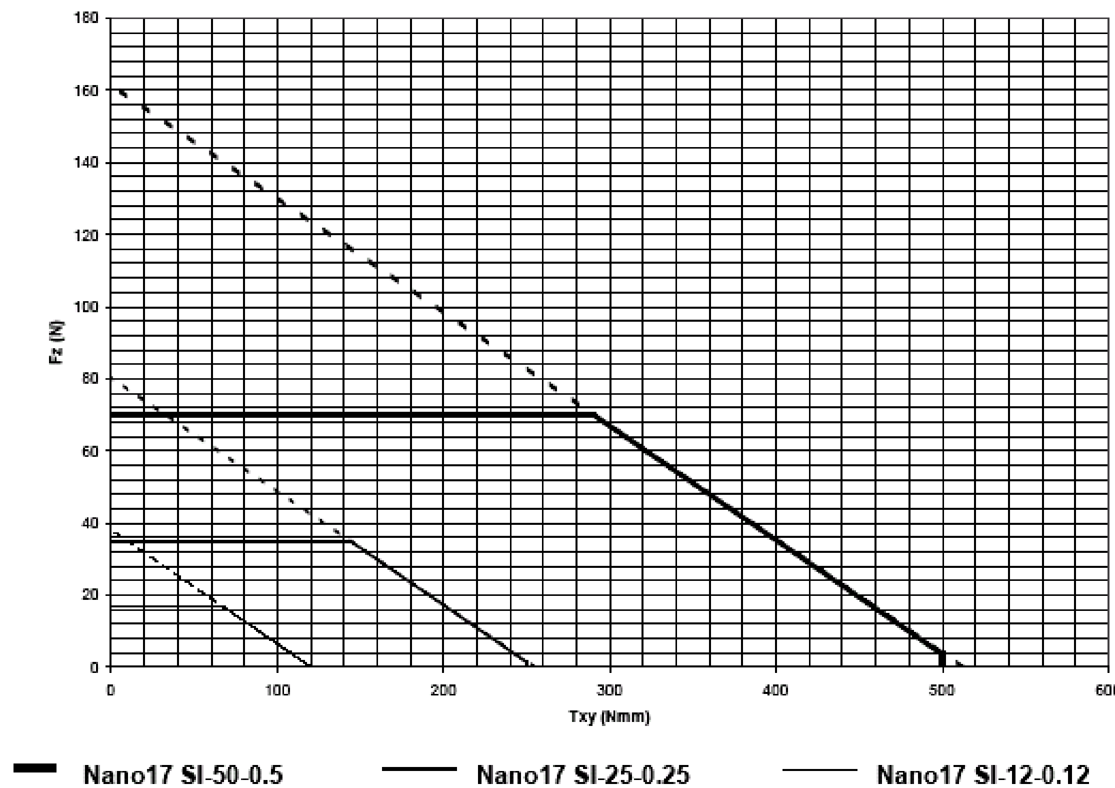
C. Extended operating region. In this region, the sensor will operate correctly, but the full-scale accuracy is not guaranteed.

Sample Graph

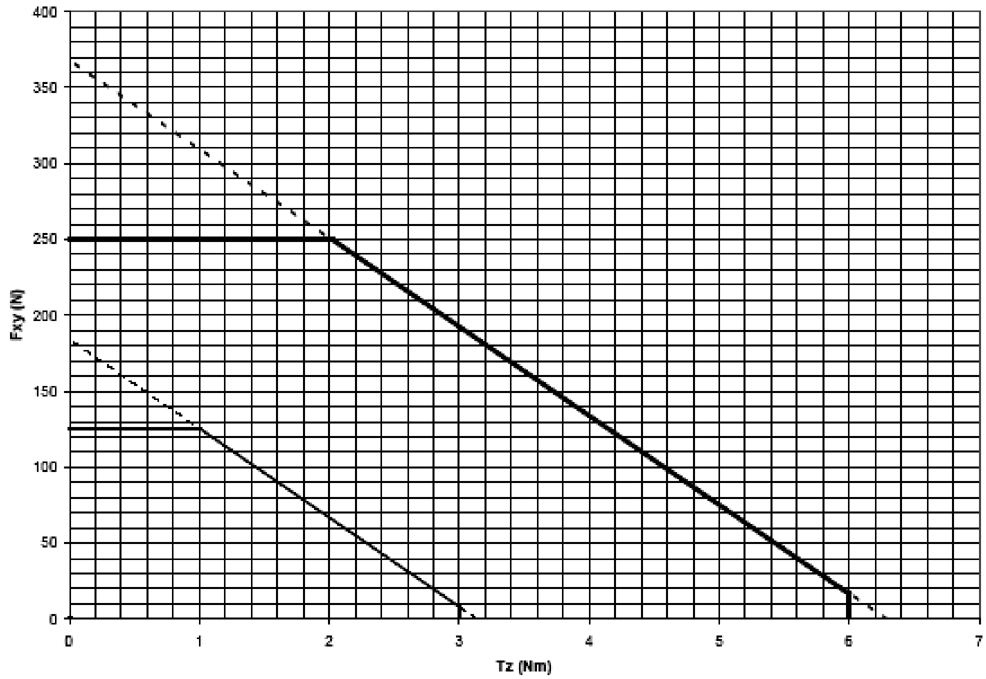


7.3.2 Nano17 (SI Calibration)

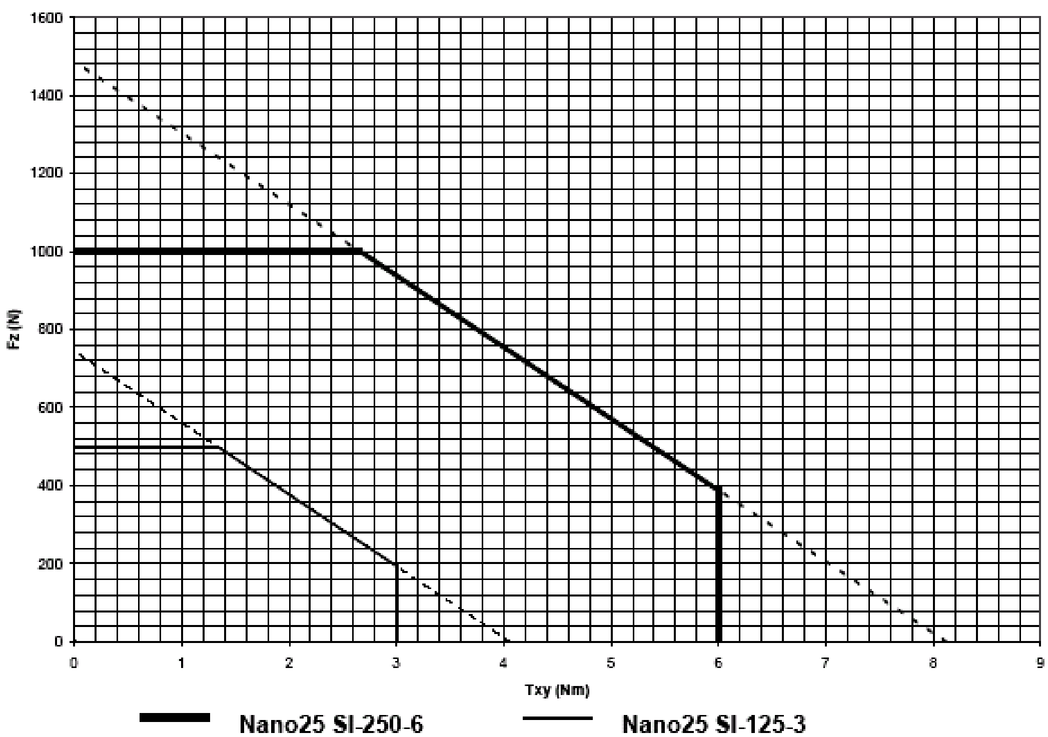




7.3.4 Nano25 (SI Calibration)



Note: Applying moments beyond ±30 in-lb (±3.4Nm) in Tz can cause hysteresis and permanent zero-point change in this transducer



Sensor System FT5524, Nano17 SI-50-0.
Calibration Accuracy Report
5Force units: N; Torque units: N-mm

Full-Scale Loads					
Fx	Fy	Fz	Tx	Ty	Tz
50	50	70	500	500	500

	Applied Loads					
	Fx	Fy	Fz	Tx	Ty	Tz
1	0.000	9.452	0.000	-360.139	0.000	0.000
2	-9.452	0.000	0.000	0.000	-360.139	0.000
3	0.000	-9.452	0.000	360.139	0.000	0.000
4	9.452	0.000	0.000	0.000	360.139	0.000
5	0.000	40.034	0.000	67.113	0.000	0.000
6	-40.034	0.000	0.000	0.000	67.113	0.000
7	0.000	-40.034	0.000	-67.113	0.000	0.000
8	40.034	0.000	0.000	0.000	-67.113	0.000
9	0.000	11.121	0.000	67.791	0.000	-423.693
10	0.000	11.121	0.000	67.791	0.000	423.693
11	-11.121	0.000	0.000	0.000	67.791	-426.518
12	-11.121	0.000	0.000	0.000	67.791	426.504
13	0.000	-11.121	0.000	-67.791	0.000	-423.693
14	0.000	-11.121	0.000	-67.791	0.000	423.693
15	11.121	0.000	0.000	0.000	-67.791	-426.504
16	11.121	0.000	0.000	0.000	-67.791	426.518
17	0.000	0.000	13.345	-355.902	0.000	0.000
18	0.000	0.000	13.345	0.000	-355.902	0.000
19	0.000	0.000	13.345	355.902	0.000	0.000
20	0.000	0.000	13.345	0.000	355.902	0.000
21	0.000	0.000	53.379	0.000	0.000	0.000
22	0.000	0.000	-53.379	0.000	0.000	0.000
23	0.000	0.000	-13.345	355.902	0.000	0.000
24	0.000	0.000	-13.345	0.000	355.902	0.000
25	0.000	0.000	-13.345	-355.902	0.000	0.000
26	0.000	0.000	-13.345	0.000	-355.902	0.000

Full-Scale Error Report						
	Fx	Fy	Fz	Tx	Ty	Tz
1	-0.22%	0.35%	0.40%	0.56%	0.30%	-0.26%
2	-0.20%	0.41%	0.40%	-0.24%	0.11%	-0.17%
3	-0.07%	0.23%	0.46%	0.13%	-0.45%	0.29%
4	-0.12%	0.17%	0.58%	0.11%	-0.28%	-0.14%
5	0.00%	0.27%	0.17%	0.06%	-0.06%	0.51%
6	-0.40%	0.25%	0.19%	0.05%	0.00%	0.17%
7	-0.08%	-0.23%	0.16%	0.10%	0.06%	0.46%
8	0.08%	0.34%	0.13%	0.04%	0.12%	0.32%
9	-0.24%	-0.32%	0.01%	0.33%	0.19%	-0.30%
10	-0.28%	-0.47%	-0.01%	-0.24%	-0.02%	0.27%
11	0.27%	0.27%	-0.04%	-0.14%	0.19%	0.28%
12	0.35%	0.22%	-0.03%	0.51%	0.13%	-0.20%
13	-0.24%	0.67%	0.00%	0.46%	0.14%	-0.40%
14	-0.15%	0.55%	0.00%	-0.12%	0.25%	0.04%
15	-0.54%	0.03%	0.02%	-0.19%	0.03%	0.02%
16	-0.67%	0.35%	0.02%	0.31%	0.19%	-0.52%
17	0.04%	-0.02%	0.09%	0.02%	-0.26%	0.22%
18	0.07%	-0.07%	0.25%	-0.01%	-0.24%	-0.06%
19	0.01%	0.11%	0.20%	0.35%	0.15%	-0.23%
20	-0.13%	0.03%	0.13%	0.02%	0.07%	0.05%
21	0.09%	-0.11%	0.21%	0.05%	0.27%	-0.03%
22	0.06%	-0.07%	-0.07%	0.01%	0.18%	-0.03%
23	0.05%	0.15%	0.37%	0.27%	0.40%	-0.08%
24	-0.12%	0.00%	0.46%	-0.14%	-0.13%	-0.12%
25	0.15%	-0.12%	0.55%	0.14%	-0.01%	0.09%
26	0.01%	-0.14%	0.51%	0.29%	-0.20%	0.10%

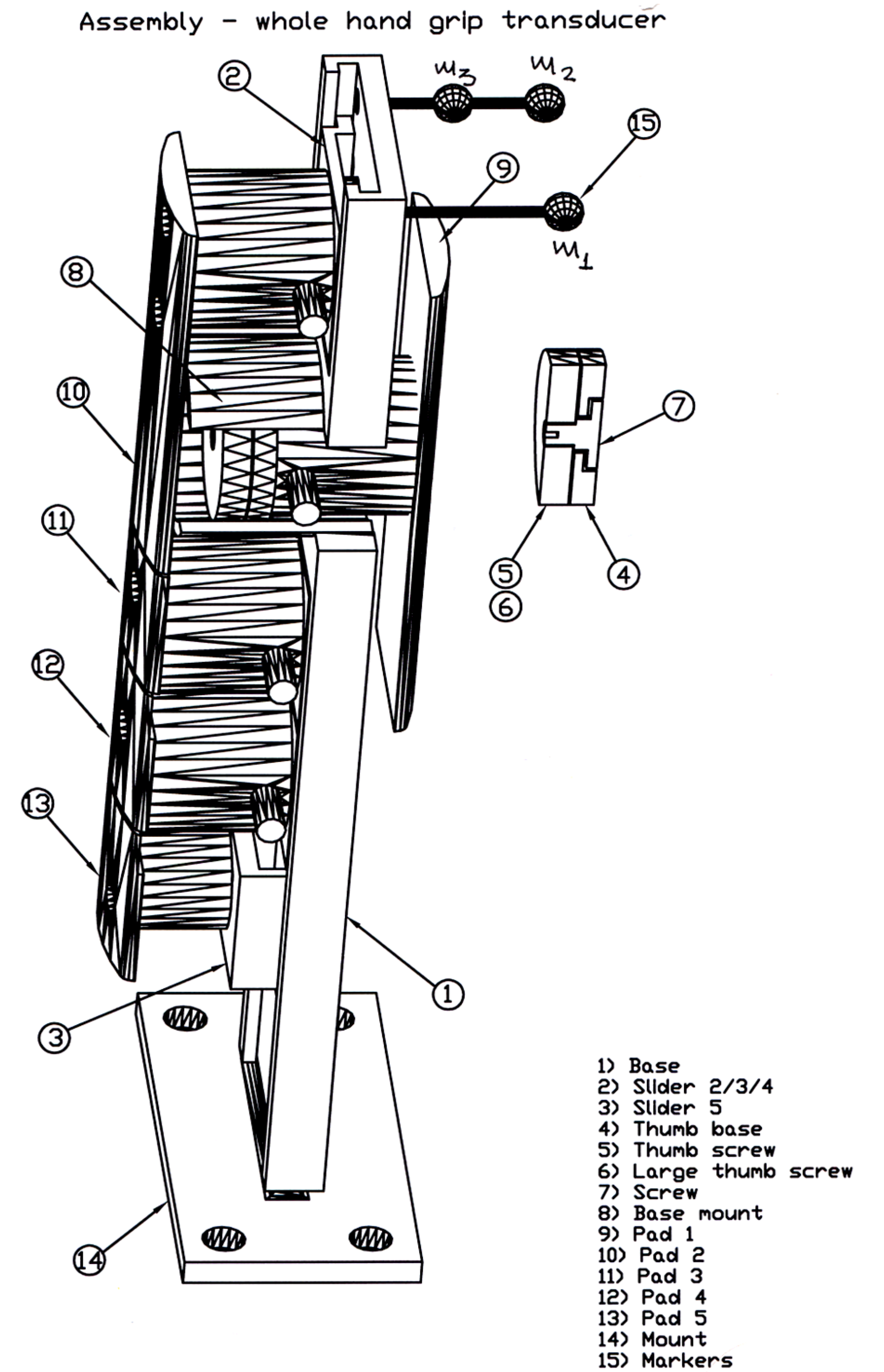
Sensor System FT5525, FT5528, FT5529, FT5530,Nano25 SI-125-3
Calibration Accuracy Report
Force units: N; Torque units: N-m

Full-Scale Loads					
Fx	Fy	Fz	Tx	Ty	Tz
125	125	500	3	3	3

	Applied Loads					
	Fx	Fy	Fz	Tx	Ty	Tz
1	0.000	20.017	0.000	-2.497	0.000	0.000
2	-20.017	0.000	0.000	0.000	-2.497	0.000
3	0.000	-20.017	0.000	2.497	0.000	0.000
4	20.017	0.000	0.000	0.000	2.497	0.000
5	0.000	62.275	0.000	-2.534	0.000	0.000
6	-80.068	0.000	0.000	0.000	-2.614	0.000
7	0.000	-62.275	0.000	2.534	0.000	0.000
8	80.068	0.000	0.000	0.000	2.614	0.000
9	26.689	0.000	0.000	0.000	0.562	-2.307
10	26.689	0.000	0.000	0.000	0.562	2.303
11	-26.689	0.000	0.000	0.000	-0.562	-2.303
12	-26.689	0.000	0.000	0.000	-0.562	2.307
13	0.000	0.000	33.362	-2.542	0.000	0.000
14	0.000	0.000	33.362	2.543	0.000	0.000
15	0.000	0.000	444.822	0.001	0.000	0.000
16	0.000	0.000	-444.822	-0.001	0.000	0.000
17	0.000	0.000	-33.362	-2.543	0.000	0.000
18	0.000	0.000	-33.362	2.542	0.000	0.000
19	0.000	-26.689	0.000	0.562	0.000	2.307
20	0.000	-26.689	0.000	0.562	0.000	-2.303
21	0.000	26.689	0.000	-0.562	0.000	-2.307
22	0.000	26.689	0.000	-0.562	0.000	2.303
23	0.000	0.000	33.362	0.000	-2.542	0.000
24	0.000	0.000	33.362	0.000	2.543	0.000
25	0.000	0.000	-33.362	0.000	-2.543	0.000
26	0.000	0.000	-33.362	0.000	2.542	0.000

Full-Scale Error Report						
	Fx	Fy	Fz	Tx	Ty	Tz
1	0.02%	0.00%	-0.02%	0.08%	0.13%	0.24%
2	-0.19%	0.00%	0.09%	-0.73%	0.16%	0.02%
3	0.12%	0.02%	0.02%	-0.14%	-0.88%	0.09%
4	-0.13%	0.17%	0.07%	0.27%	0.11%	0.33%
5	0.06%	0.03%	0.06%	-0.22%	-0.44%	-0.06%
6	-0.20%	0.22%	0.19%	-0.11%	0.35%	0.56%
7	0.11%	-0.03%	0.07%	-0.01%	-0.22%	0.06%
8	-0.14%	0.14%	0.19%	-0.20%	0.31%	0.31%
9	-0.09%	0.02%	0.01%	-0.21%	0.00%	0.20%
10	-0.07%	0.19%	0.06%	-0.23%	-0.01%	0.18%
11	0.06%	0.00%	0.03%	-0.16%	-0.12%	-0.20%
12	0.05%	0.07%	0.02%	0.26%	-0.09%	0.03%
13	-0.03%	0.02%	0.01%	0.22%	-0.54%	0.13%
14	0.11%	0.05%	0.00%	0.13%	0.17%	-0.23%
15	-0.53%	0.35%	-0.03%	-0.81%	0.28%	-0.09%
16	-0.57%	0.38%	-0.03%	-0.85%	0.21%	0.09%
17	0.33%	0.07%	0.03%	-0.26%	0.01%	-0.82%
18	0.08%	0.05%	0.01%	-0.12%	0.02%	-0.40%
19	-0.01%	-0.04%	-0.02%	-0.28%	0.10%	-0.03%
20	-0.10%	0.12%	0.01%	0.00%	-0.08%	-0.20%
21	0.10%	0.02%	0.02%	0.09%	-0.02%	0.17%
22	-0.01%	-0.08%	0.00%	-0.02%	-0.21%	-0.25%
23	-0.09%	0.01%	0.07%	-0.04%	0.02%	-0.19%
24	-0.10%	0.15%	0.06%	-0.61%	-0.05%	0.07%
25	0.01%	-0.01%	0.05%	0.37%	0.19%	-0.44%
26	-0.04%	-0.26%	0.07%	0.17%	0.29%	-0.87%

APPENDIX (D): **The custom-built strength grip force tool design**



APPENDIX (E): **The Axis Systems**

In the following Figures the transducers (Figure E.2) and the metacarpal axis systems (Figure E.1) are presented graphically.

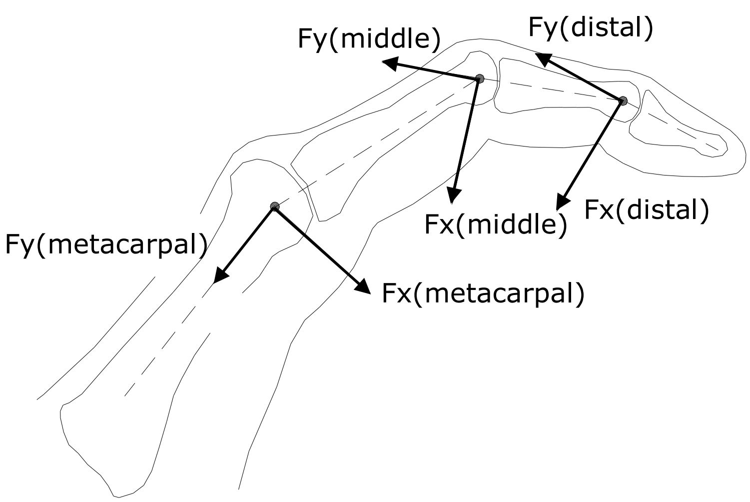


Figure E.1 : Axis systems for finger segments (Fz is directed radially in the right hand).

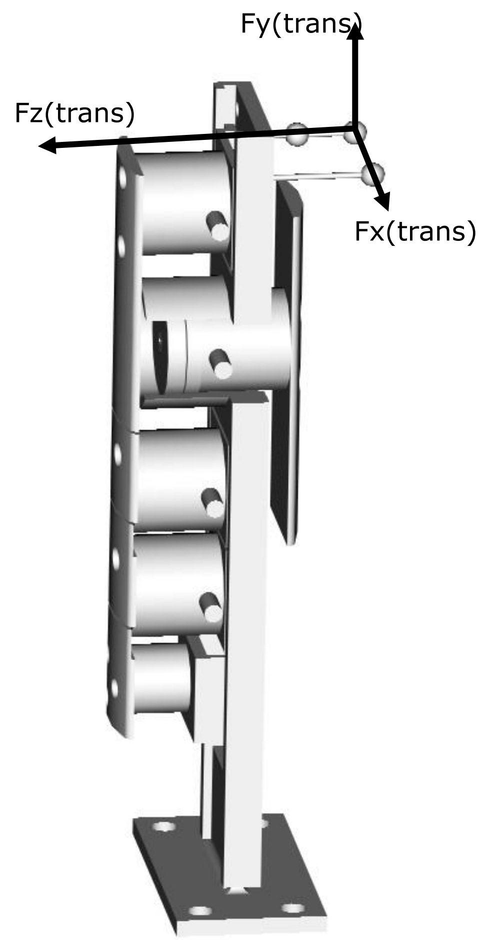


Figure E.2 : Axis system for the grip tool.

APPENDIX (F): **Wrist Joint Laxity**

F1. The wrist joint laxity scores

The wrist joint laxity scores, by gender, for both right and left hands are shown in the following table (with asterisk the excluded wrist due to previous injuries).

	Males		Females	
Subject Number	Right Hand (N=25)	Left Hand (N=22)	Right Hand (N=25)	Left Hand (N=23)
1	5	12	64	78
2	17	*	67	67
3	60	70	42	46
4	87	74	41	50
5	37	45	25	16
6	46	46	47	*
7	59	*	65	63
8	84	70	61	46
9	42	41	83	86
10	52	46	74	76
11	59	*	60	67
12	54	55	53	55
13	63	68	53	53
14	65	54	56	46
15	72	52	25	22
16	67	63	58	63
17	48	38	53	51
18	46	47	69	69

19	67	58	55	51
20	46	41	68	*
21	61	49	36	46
22	29	30	63	66
23	33	30	65	48
24	54	58	77	78
25	33	51	21	14

F2. Statistics on the wrist joint laxity scores (WJLS).

F2.1 Males, Right Hand

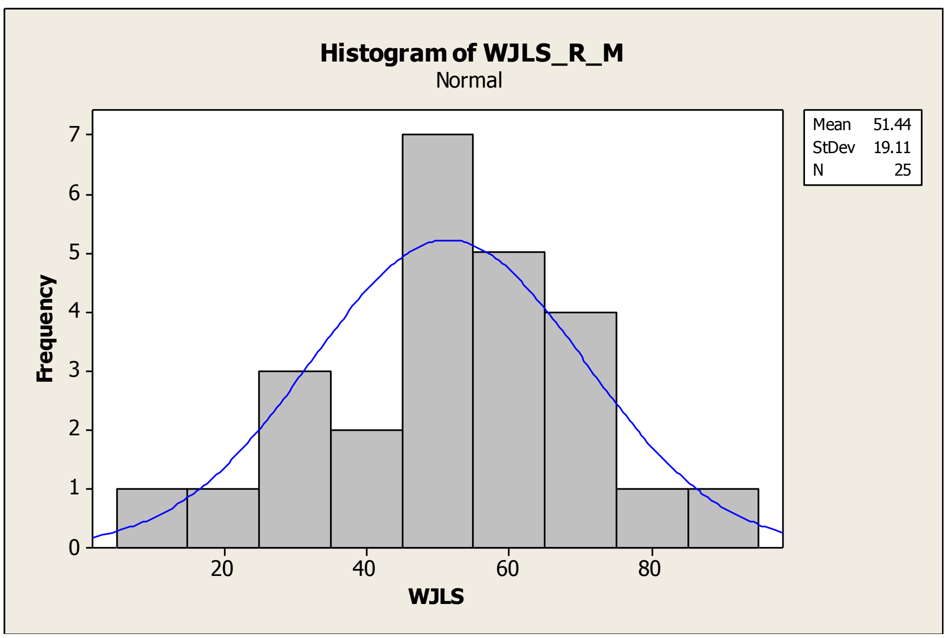


Figure F.0.1: *The histogram of the WJLS of the male right hands. The blue line represents the normal distribution.*

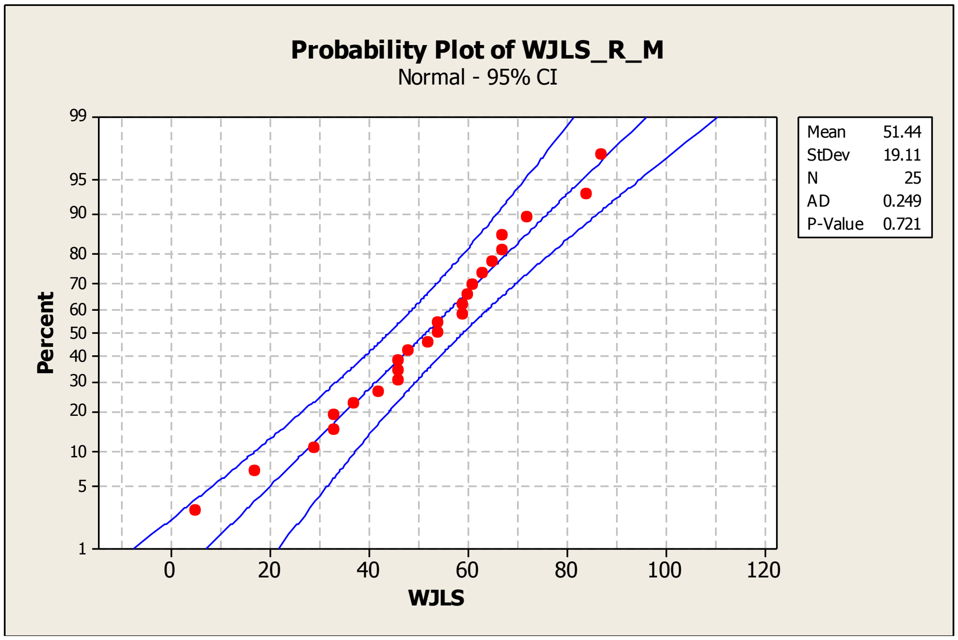


Figure F.0.2: *The probability plot of the WJLS of the male right hands. The blue line represents the 95% Confidence Interval. The Anderson-Darling normality test (AD), as it is shown in the graph, indicates normal distribution (p=0.721).*

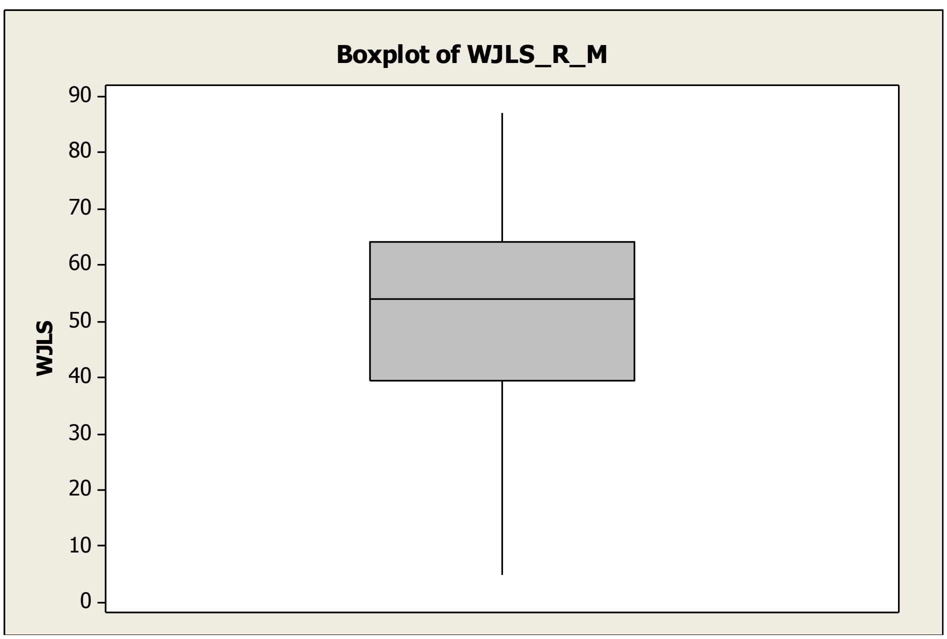


Figure F.0.3: *The Boxplot of the WJLS of the male right hands. There are no outliers.*

F2.2 Males, Left Hand

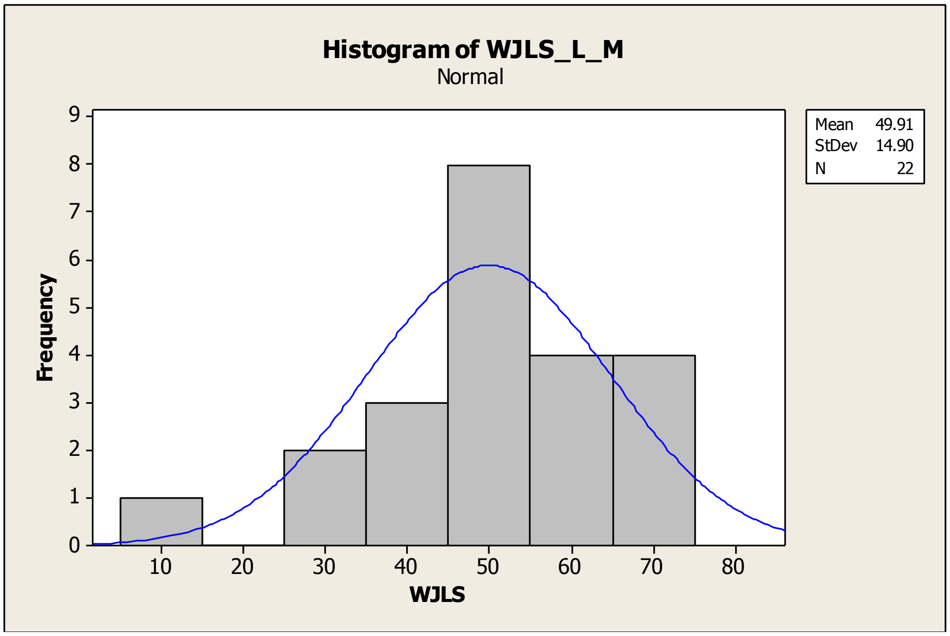


Figure F.0.4: *The histogram of the WJLS of the male right hands. The blue line represents the normal distribution.*

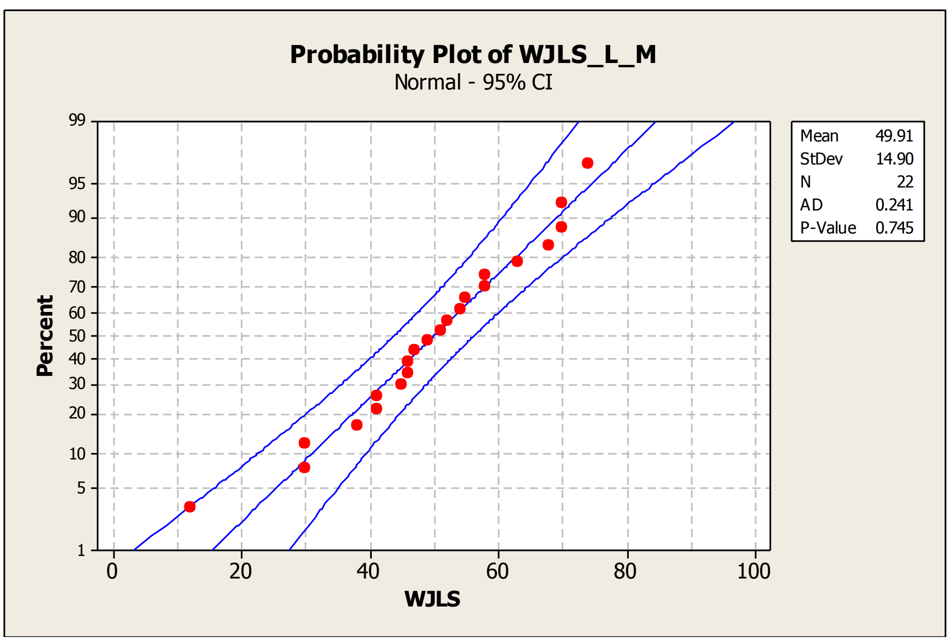


Figure F.0.5: *The probability plot of the WJLS of the male left hands. The blue line represents the 95% Confidence Interval. The Anderson-Darling normality test (AD), as it is shown in the graph, indicates normal distribution (p=0.745).*

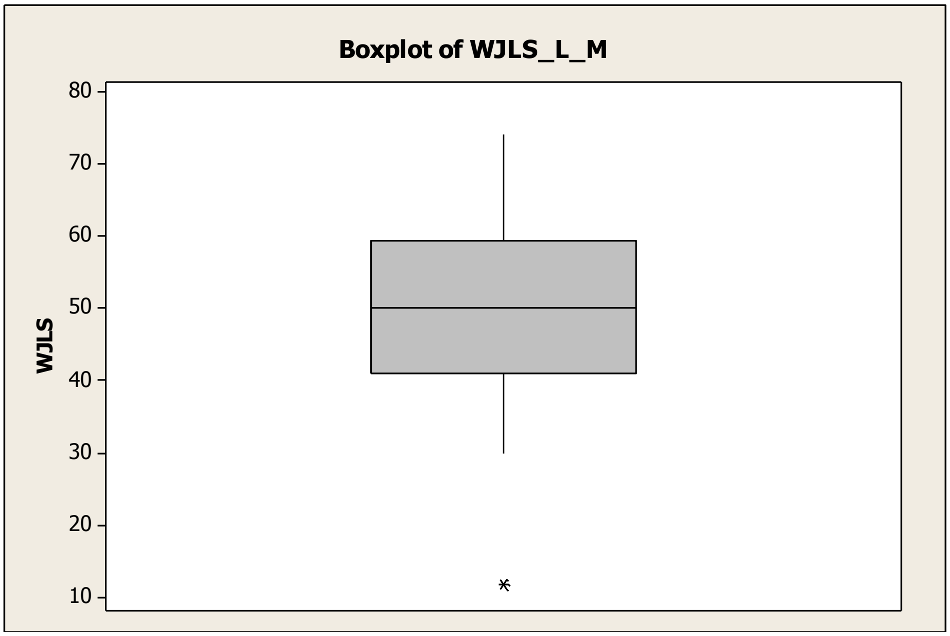


Figure F.0.6: *The Boxplot of the WJLS of the male left hands. There is one outlier.*

F2.3 Females, Right Hand

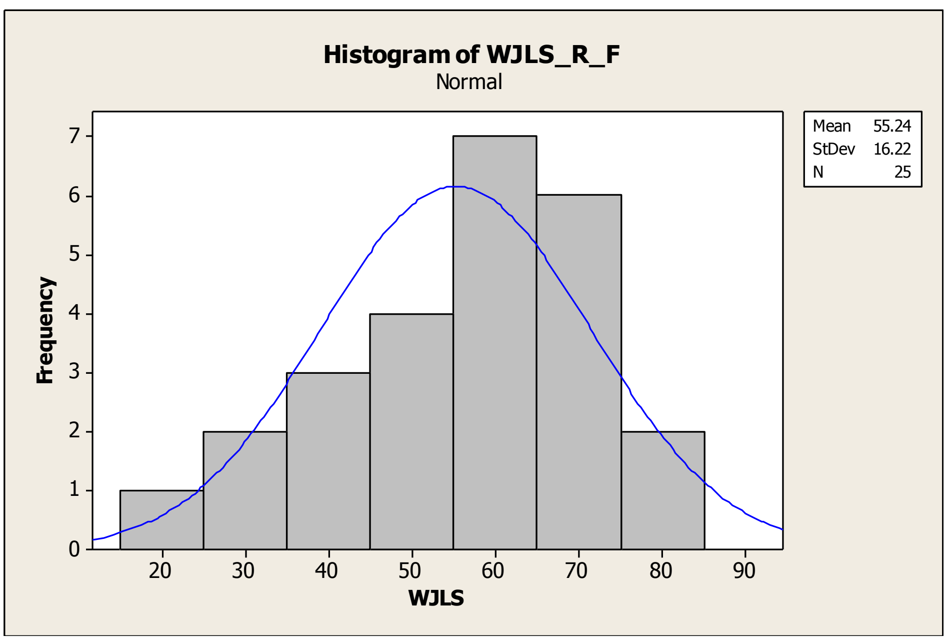


Figure F.0.7: *The histogram of the WJLS of the male right hands. The blue line represents the normal distribution.*

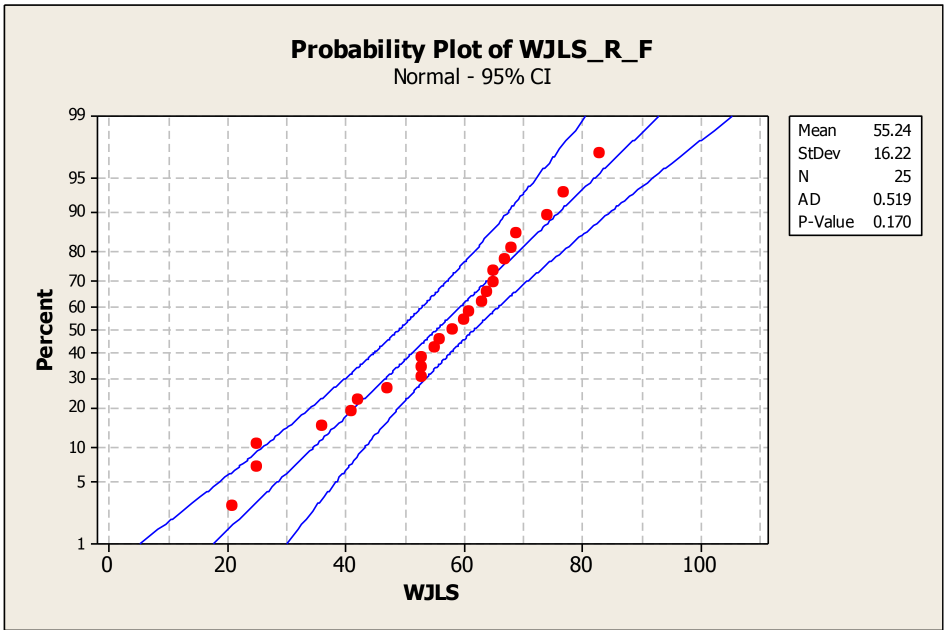


Figure F.0.8: *The probability plot of the WJLS of the female right hands. The blue line represents the 95% Confidence Interval. The Anderson-Darling normality test (AD), as it is shown in the graph, indicates normal distribution (p=0.17).*

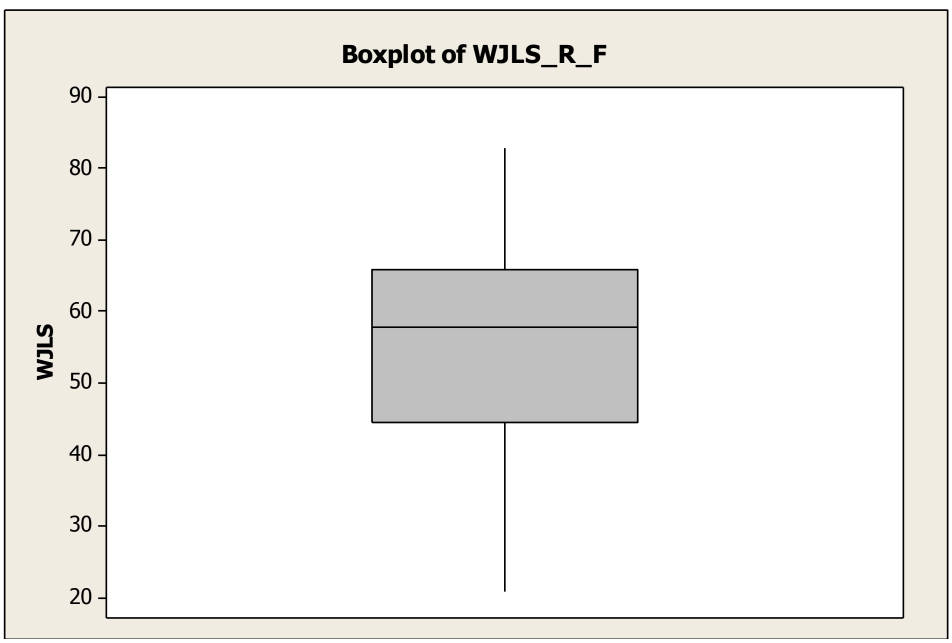


Figure F.0.9: *The Boxplot of the WJLS of the female right hands. There are no outliers.*

F2.4 Females, Left Hand

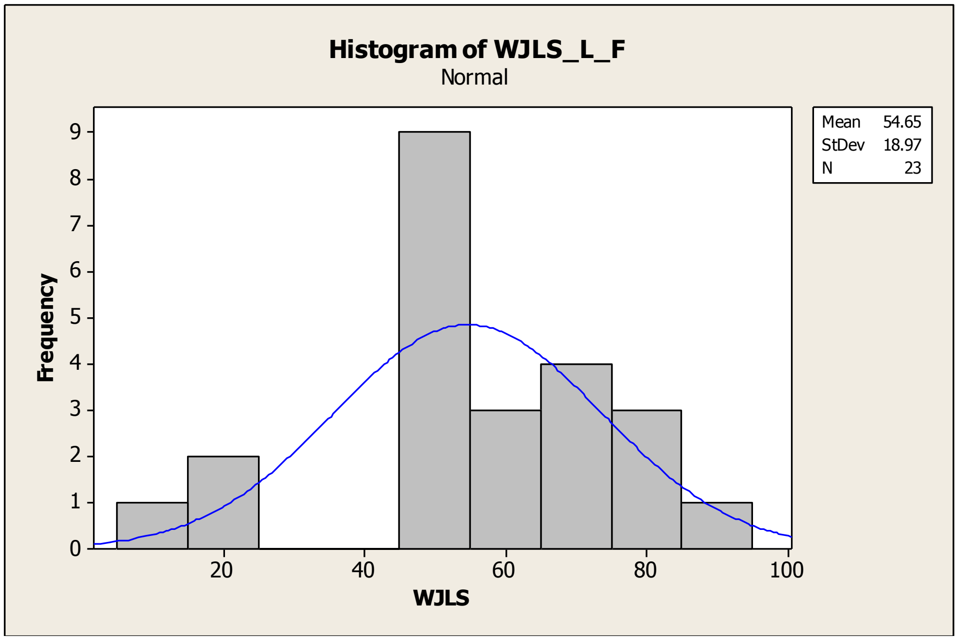


Figure F.0.10: *The histogram of the WJLS of the male right hands. The blue line represents the normal distribution.*

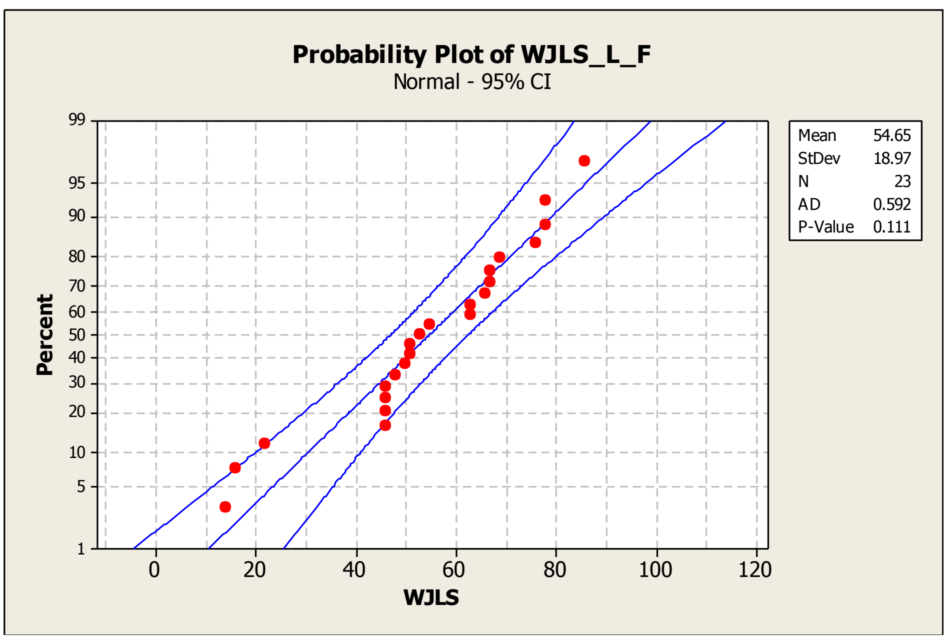


Figure F.0.11: *The probability plot of the WJLS of the female left hands. The blue line represents the 95% Confidence Interval. The Anderson-Darling normality test (AD), as it is shown in the graph, indicates normal distribution (p=0.111).*

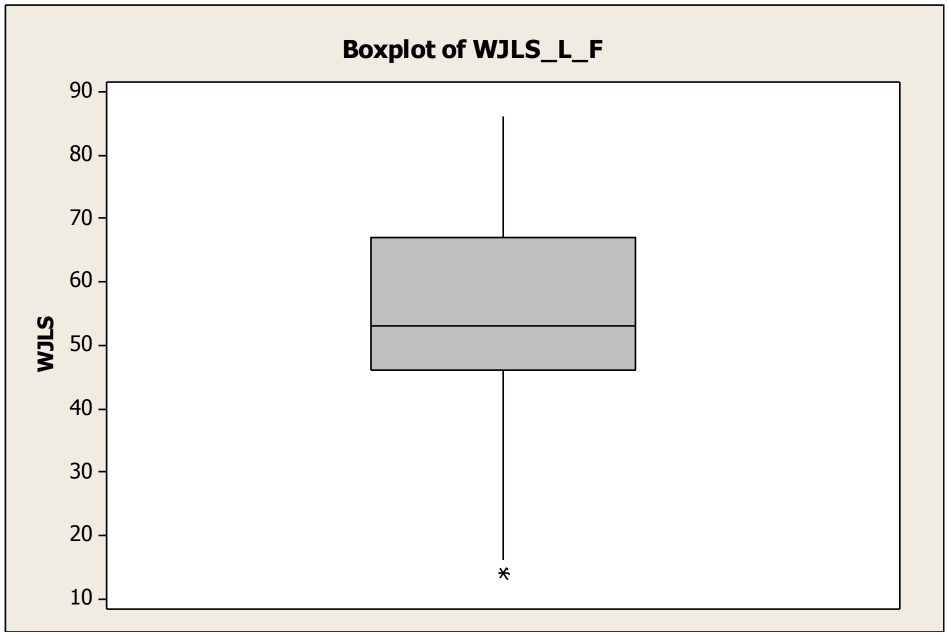


Figure F.0.12: *The Boxplot of the WJLS of the female left hands. There is one outlier.*

F2.5 All Subjects, Right Hand

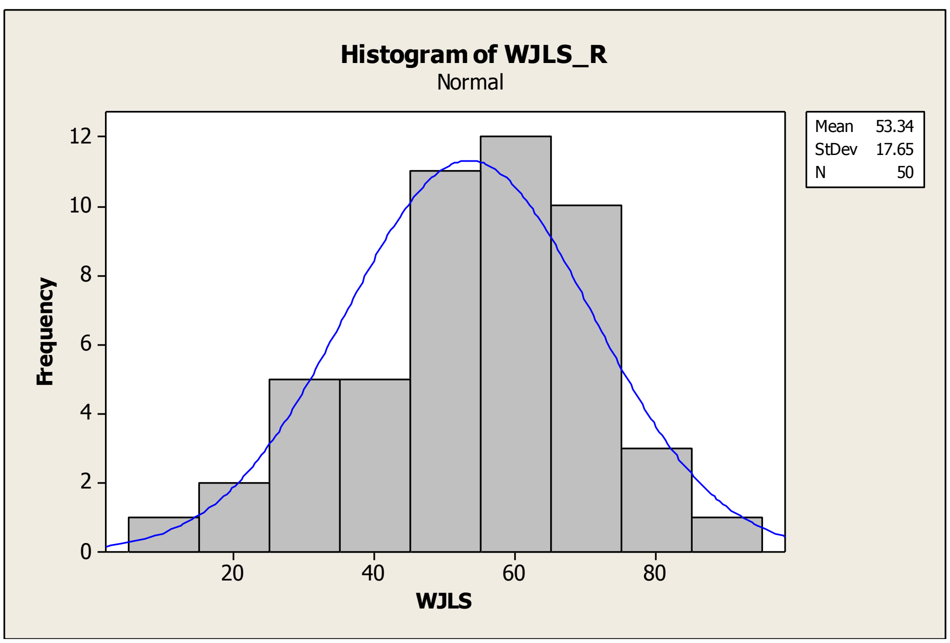


Figure F.0.13: *The histogram of the WJLS of the male right hands. The blue line represents the normal distribution.*

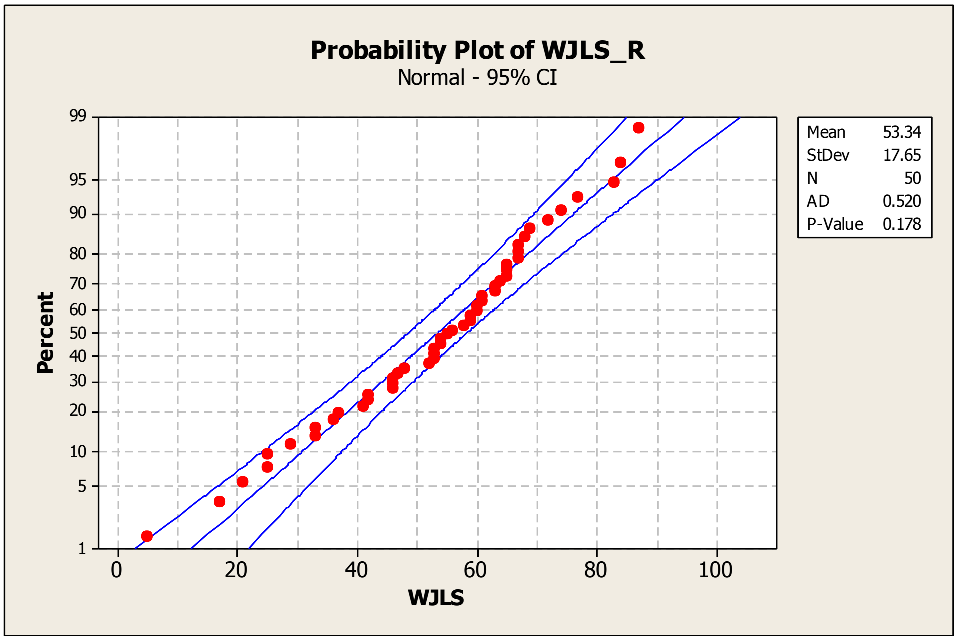


Figure F.0.14: *The probability plot of the WJLS of the whole group right hands. The blue line represents the 95% Confidence Interval. The Anderson-Darling normality test (AD), as it is shown in the graph, indicates normal distribution (p=0.178).*

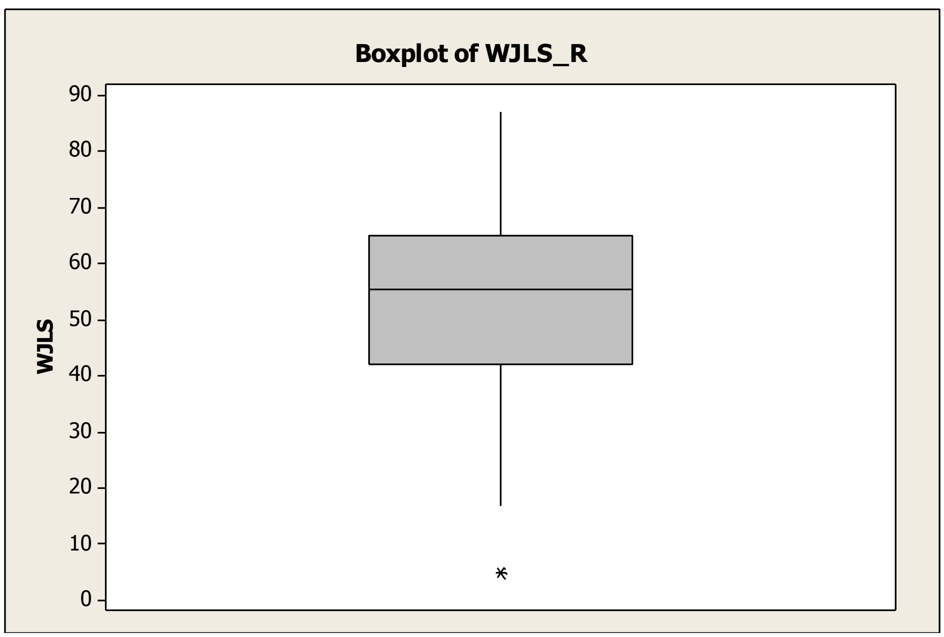


Figure F.0.15: *The Boxplot of the WJLS of the whole group right hands. There is one outlier.*

F2.5 All Subjects, Left Hand

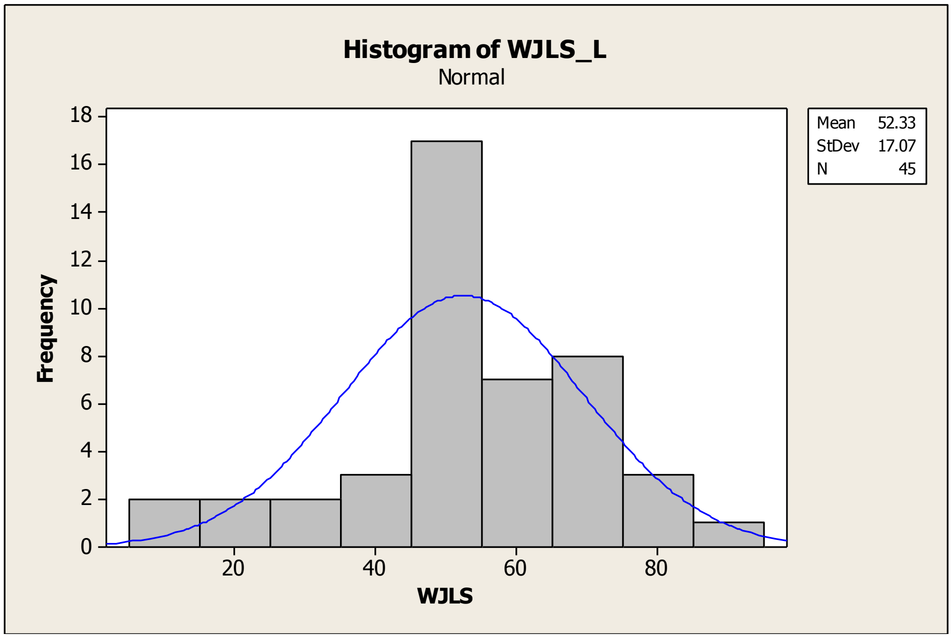


Figure F.0.16: *The histogram of the WJLS of the male right hands. The blue line represents the normal distribution.*

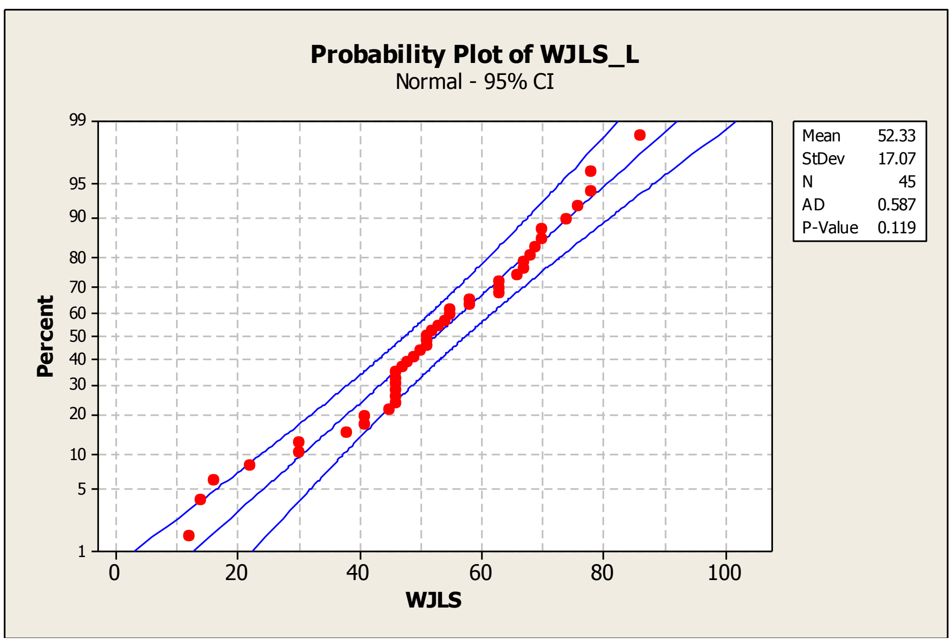


Figure F.0.17: *The probability plot of the WJLS of the whole group left hands. The blue line represents the 95% Confidence Interval. The Anderson-Darling normality test (AD), as it is shown in the graph, indicates normal distribution (p=0.119).*

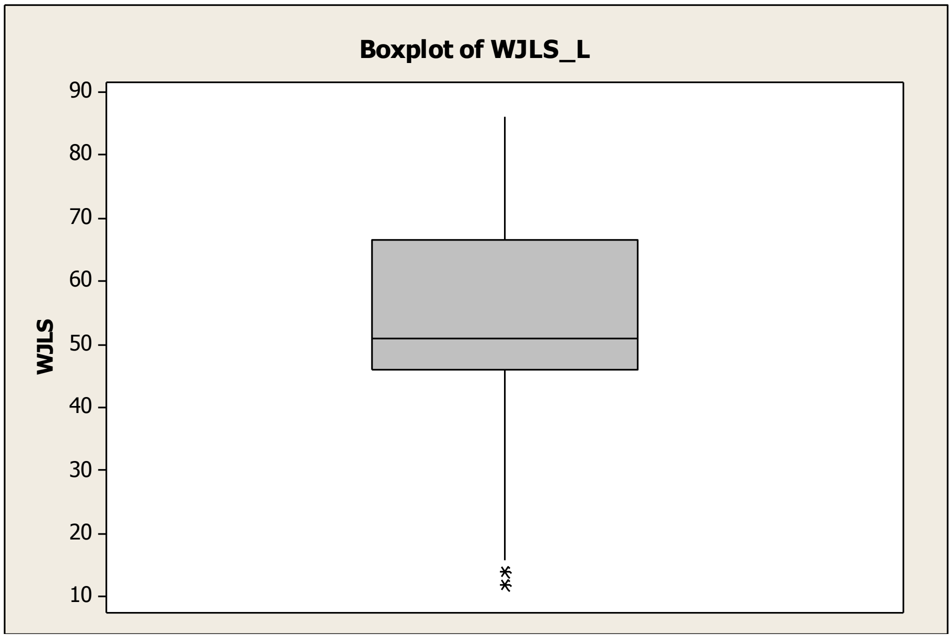


Figure F.0.18: *The Boxplot of the WJLS of the whole group left hands. There are two outliers.*

APPENDIX (G): **Kinematics**

G1. The sample size.

Fifty four normal subjects were participated in this study, and fifty of them provided reliable data. However, in some wrist orientation, and especially in the Ulnar Deviated trials, the markers were hidden between the hand and the table and therefore the acquirement of the data was problematic. Thus, the sample size (N) was different for every wrist orientation, as it is shown in the following tables (by gender and in total).

Wrist Position (Males)

Cases	Flexion	Extension	Radial	Ulnar	Neutral
N	22	25	23	16	25

Wrist Position (Females)

Cases	Flexion	Extension	Radial	Ulnar	Neutral
N	24	23	22	19	25

Wrist Position (Total)

Cases	Flexion	Extension	Radial	Ulnar	Neutral
N	46	48	45	35	50

G2: The kinematic results of the wrist, by gender

A. Males: The following Table shows the average of the three trials angle of the wrist in every joint orientation (raw data), together with the position in the combined planes (in degrees). (F-RUD=the Radioulnar Deviation combined with Flexion, E-RUD=the Radioulnar Deviation combined with Extension, N-RUD=the Radioulnar Deviation combined with Neutral, R-FE= the Flexion-Extension combined with the Radial Deviation and U-FE= the Flexion-Extension combined with the Ulnar Deviation). The missing trial results represent corrupted kinematic data, and the underlined ones represent extremes.

No	Flexion	F-RUD	Extension	E-RUD	Radial	R-FE	Ulnar	U-FE	Neutral	N-RUD
1	36.8	-0.1	-61.8	10.7	-14.7	-41.8	31.4	-31.0	-31.1	-4.5
2	62.4	-21.7	-54.5	14.2	-18.3	-1.2	34.2	7.3	-42.6	14.0
3	55.8	-19.8	-44.0	12.4	-21.1	5.9	16.0	28.0	1.2	-8.7
4	70.6	-22.6	-42.3	6.5	-16.6	-31.2	26.3	32.6	-30.5	8.8
5	46.1	-26.6	-71.6	-1.2	-14.2	0.9	15.9	-6.7	-40.8	9.2
6	64.1	0.9	-34.8	31.8	-20.3	-4.2	18.1	14.1	-2.2	5.1
7	16.7	-26.0	-33.8	1.9	-9.6	-10.3	9.7	-18.4	18.3	-7.5
8	64.6	-4.8	-50.9	1.3	-16.4	-1.7	25.5	27.4	-45.3	0.8
9	54.0	-4.9	-54.4	18.6	21.4	-53.8	23.0	8.3	-41.7	9.5
10	36.5	-16.4	-61.3	22.4	-18.8	1.1	63.5	-54.9	-46.2	19.9
11	66.8	-0.8	-44.8	12.9	-11.7	34.3	20.9	7.3	-16.1	-7.1
12	70.4	-17.3	-99.0	1.4	-2.3	-25.3	16.6	9.1	-83.9	18.7
13	56.0	-11.5	-42.8	22.9	-15.0	-23.5	26.2	-10.7	-35.1	14.2
14	70.0	-7.0	-58.8	6.8	-16.5	-2.6	33.9	7.6	-44.4	10.1
15	44.9	-8.8	-49.4	8.8	-10.0	-24.7	29.1	-10.9	-29.3	5.4
16	28.1	-15.5	-55.9	16.9	-22.5	-6.3	57.7	-13.1	-25.5	-1.3
17	71.3	-11.0	-40.7	14.0	-17.7	-31.2			8.1	-25.8
18	62.7	-16.4	-62.5	-3.3	-21.2	4.5			-58.5	-9.1
19	65.9	-22.1	-61.2	16.6	-7.5	-20.4			-37.7	19.2
20	67.8	-15.9	-49.5	12.8	-10.7	2.7			-40.9	5.7
21	58.7	-6.6	-58.1	6.9	-18.7	-6.0			-47.0	10.1
22	51.2	-20.0	-53.5	19.4	-14.8	-10.5			-32.9	12.7
23			-55.7	2.5	-16.8	-14.4			-49.8	-2.6
24			-55.5	4.8					-29.8	9.2
25			-50.0	0.9					-19.6	1.1

B. Females: The following Table shows the average of the three trials angle of the wrist in every joint orientation (raw data), together with the position in the combined planes (in degrees). (F-RUD=the Radioulnar Deviation combined with Flexion, E-RUD=the Radioulnar Deviation combined with Extension, N-RUD=the Radioulnar Deviation combined with Neutral, R-FE= the Flexion-Extension combined with the Radial Deviation and U-FE= the Flexion-Extension combined with the Ulnar Deviation). The missing trial results represent corrupted kinematic data and the underlined ones represent extremes..

No	Flexion	F-RUD	Extension	E-RUD	Radial	R-FE	Ulnar	U-FE	Neutral	N-RUD
1	60.5	-4.2	-47.1	4.8	-10.8	-3.2	24.4	4.1	-30.1	11.3
2	63.3	-17.6	-56.7	12.0	-12.7	-9.4	27.4	-6.8	-25.0	4.3
3	58.1	-17.8	-53.8	12.6	-5.6	-6.1	24.8	23.6	-36.3	6.2
4	14.5	30.5	-45.8	16.0	-10.4	-4.4	25.4	-4.6	-28.0	6.9
5	79.8	-12.7	-48.2	6.8	-13.9	-8.1	23.3	14.8	-39.0	10.0
6	49.7	-17.0	-40.8	23.3	-17.1	-8.2	35.0	-5.4	-7.7	-2.8
7	56.5	-20.5	-52.9	19.5	-8.9	-13.6	34.3	-4.0	-20.7	13.9
8	72.4	-6.4	-49.5	26.7	-1.6	1.1	16.3	83.6	-38.7	22.5
9	61.9	-17.0	-47.6	15.9	-11.1	-8.6	20.9	-5.3	-36.2	25.1
10	62.8	-26.6	-54.9	5.3	23.2	21.7	13.8	24.0	-25.9	13.6
11	80.2	-17.7	-46.3	-0.3	26.1	-6.6	39.8	16.8	-39.7	8.0
12	59.9	-13.3	-61.4	7.2	-19.5	-7.0	6.7	114.8	-32.8	3.1
13	47.1	-21.4	-66.1	23.2	-12.6	-19.8	15.2	22.3	-37.8	3.0
14	43.9	-29.7	-52.4	25.1	-7.1	-34.2	34.8	-0.3	-37.4	17.2
15	75.5	-11.6	-85.2	9.8	-14.8	-0.3	17.6	13.8	-32.2	25.2
16	83.9	-14.4	-51.3	0.2	-27.8	-33.8	12.4	14.3	-58.7	17.8
17	68.2	-3.1	-87.3	5.8	-10.2	-19.2	27.9	-2.0	-35.9	-1.0
18	75.1	-6.4	-71.8	9.5	-15.8	-10.9	26.0	25.0	-66.4	3.9
19	57.6	-18.3	-30.9	24.8	-5.5	-12.8	30.6	-9.9	-47.6	-4.6
20	72.0	-26.2	-31.6	19.2	-5.1	-7.2			-32.1	14.8
21	41.7	-23.1	-40.8	28.2	-23.0	-4.9			-11.9	12.8
22	61.2	-24.8	-38.8	15.7	-0.3	-30.6			-19.6	14.4
23	75.8	-10.1	-47.4	16.4					-31.3	19.8
24	-54.1	-5.1							-27.4	16.7
25									-31.7	8.4

G3: The Boxplots of the accumulated kinematic results

A. The Neutral position

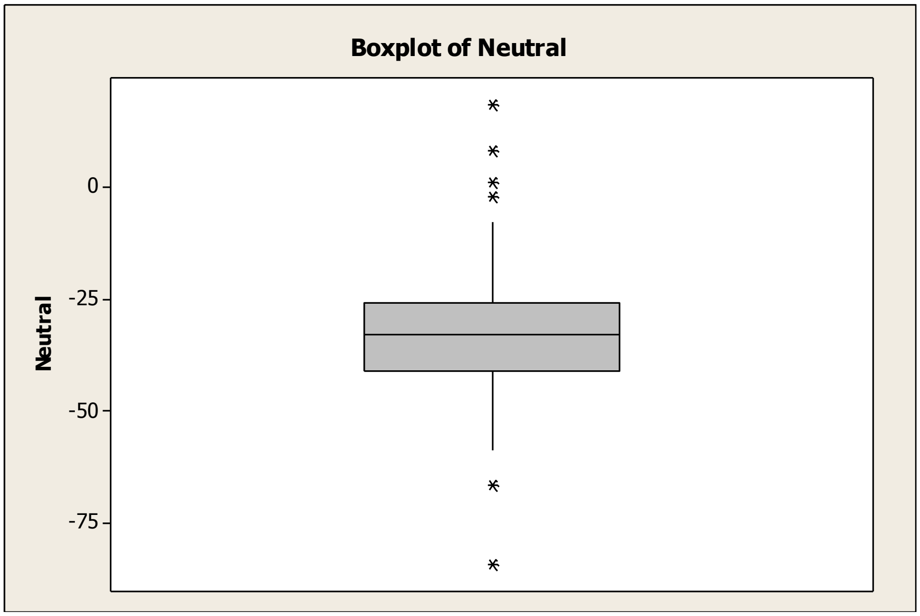


Figure G.1: *The Boxplot of the Neutral wrist position (the asterisks indicate the extremes)*

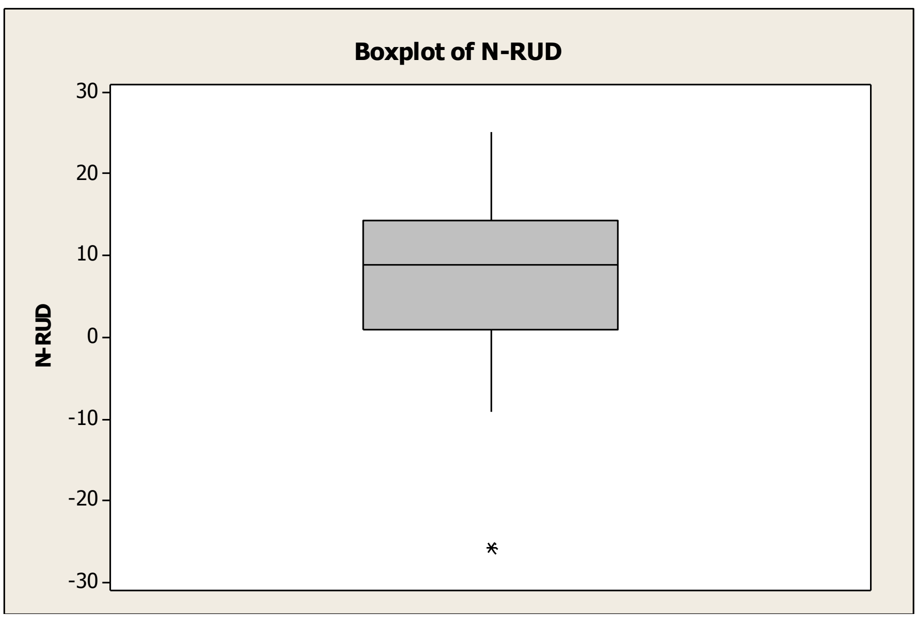


Figure G.2: *The Boxplot of the combined with Neutral Radioulnar Deviation (the asterisk indicate the extreme)*

B. The Extension position

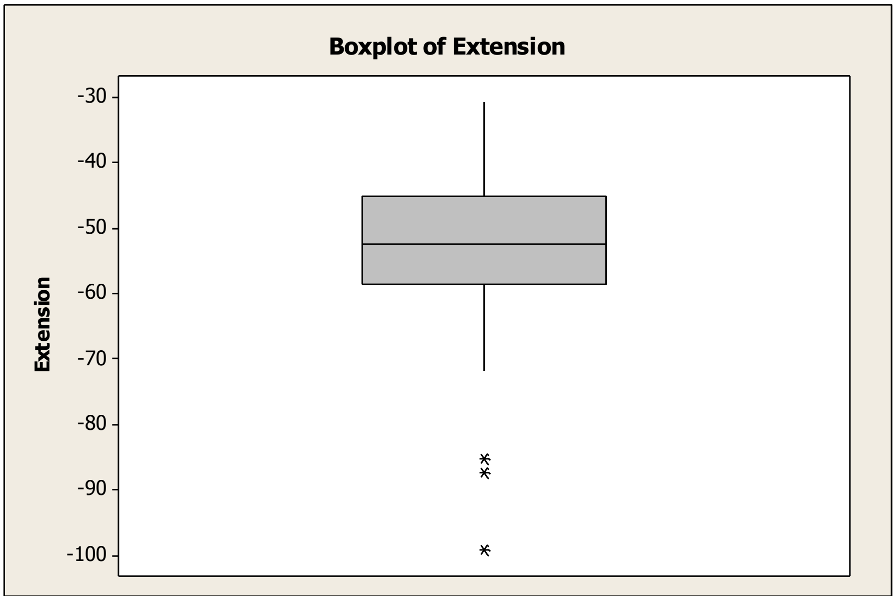


Figure G.3: *The Boxplot of the Extension wrist position (the asterisks indicate the extremes)*

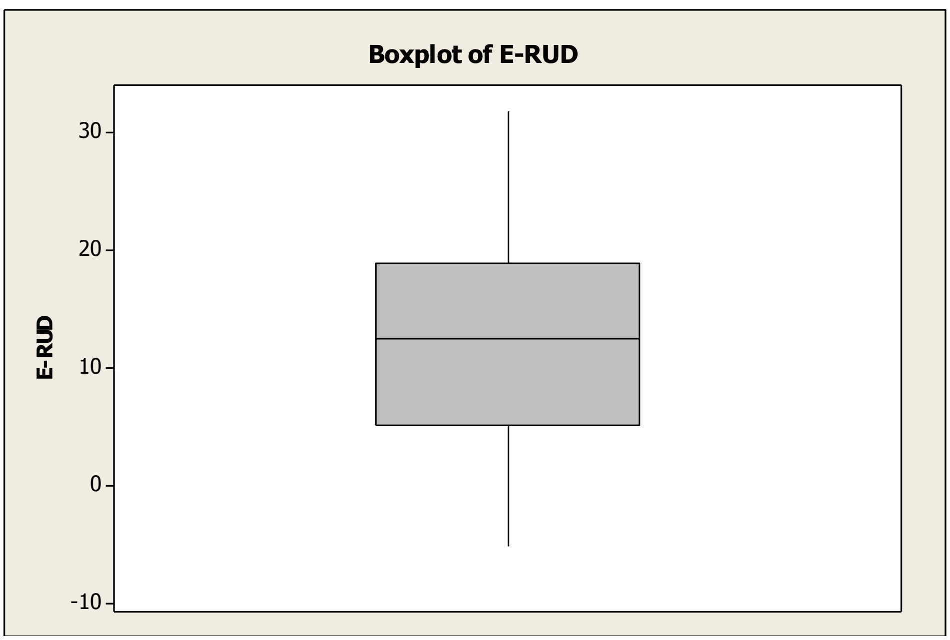


Figure G.4: *The Boxplot of the combined with Extension Radioulnar Deviation*

C. The Flexion position

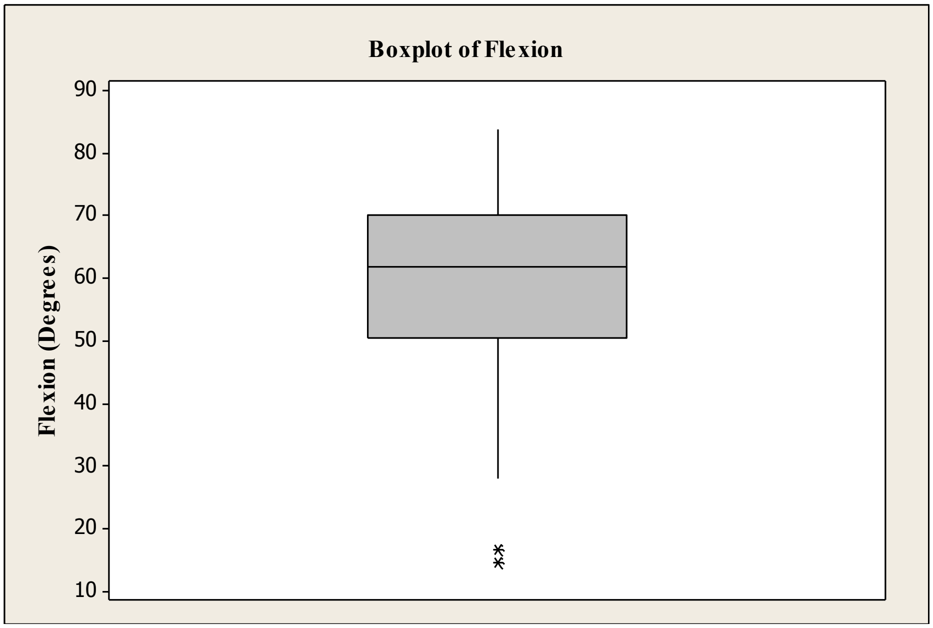


Figure G.5: *The Boxplot of the Flexion wrist position (the asterisks indicate the extremes)*

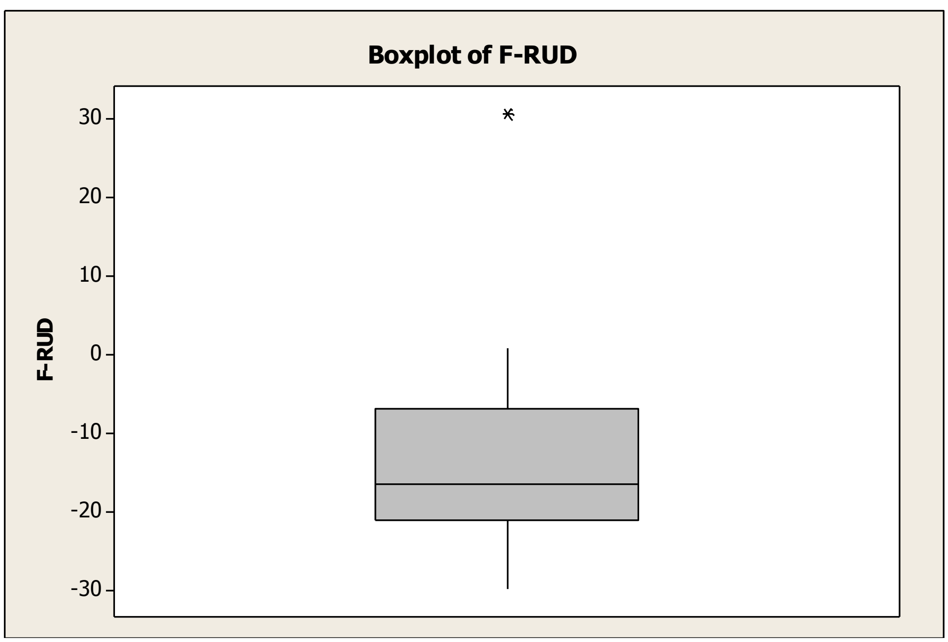


Figure G.6: *The Boxplot of the combined with Flexion Radioulnar Deviation (the asterisk indicates the extreme)*

D. The Radial Deviation position

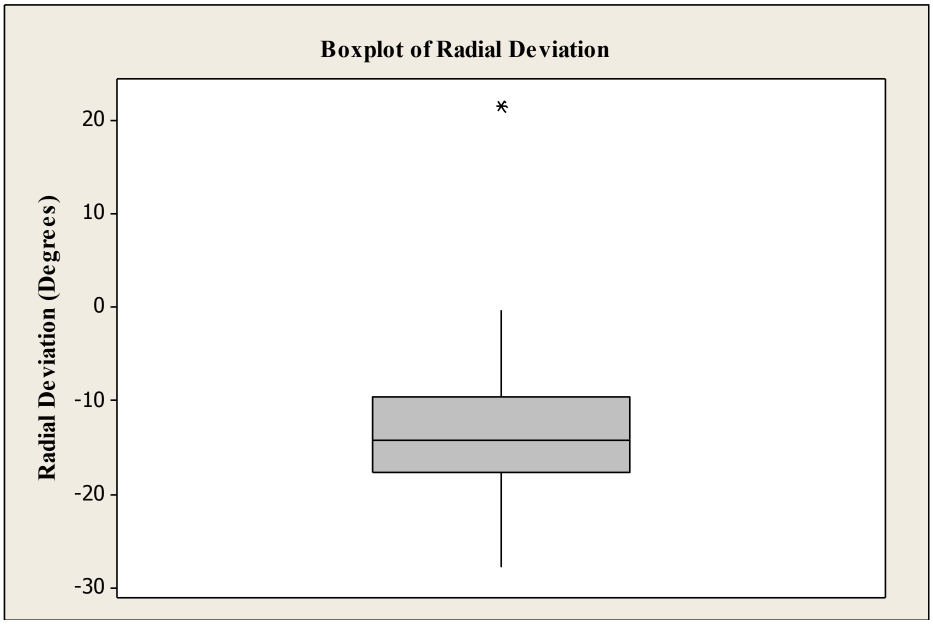


Figure G.7: *The Boxplot of the Radial Deviation wrist position (the asterisk indicates the extreme)*

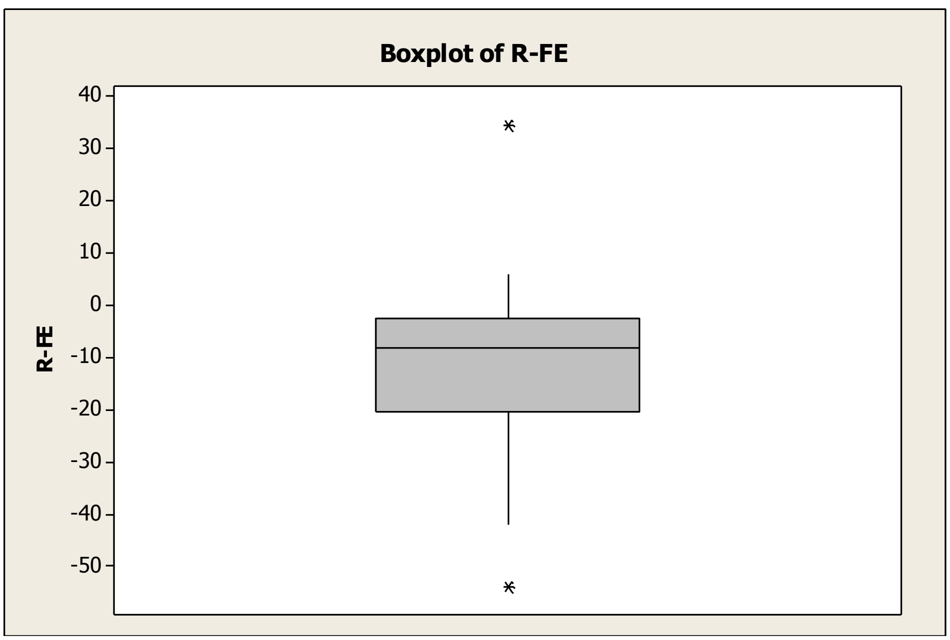


Figure G.8: *The Boxplot of the combined with Radial Deviation Flexion-Extension (the asterisks indicate the extremes)*

E. The Ulnar Deviation Position

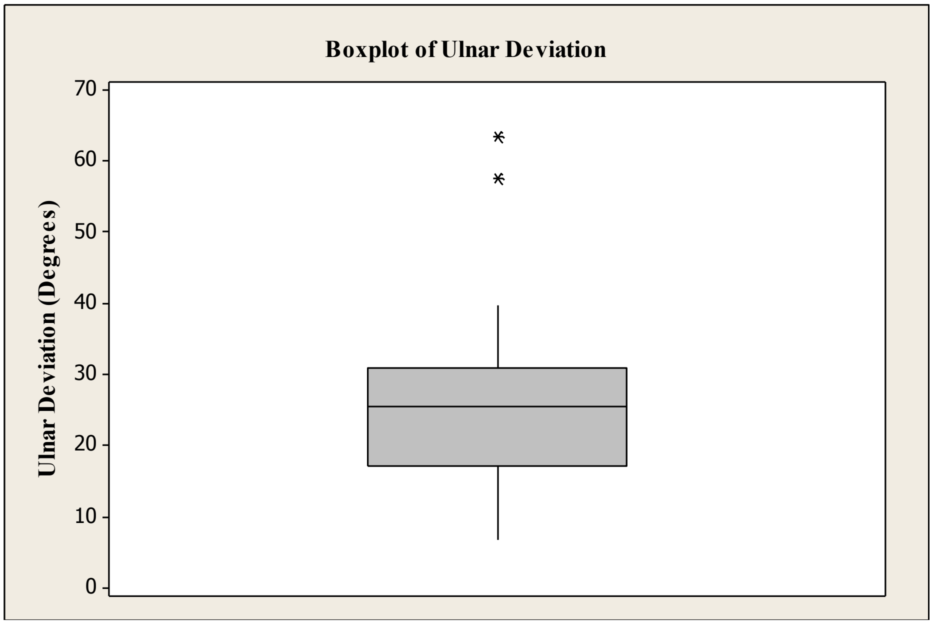


Figure G.9: *The Boxplot of the Ulnar Deviation wrist position (the asterisks indicate the extremes)*

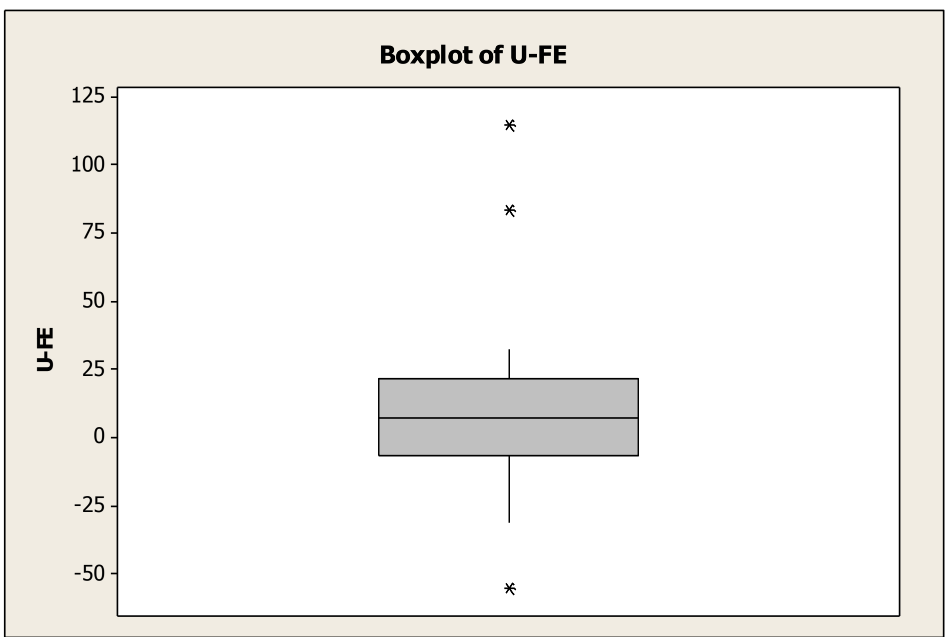


Figure G.10: *The Boxplot of the combined with Ulnar Deviation Flexion-Extension (the asterisks indicate the extremes)*

G4: The Distributions

The above presented Boxplots showed extreme values in most of the wrist positions and the combined with them planes. These extremes were greatly affecting the distribution of the data (and therefore the statistical analysis tests, which should be used). Although there are non-parametric statistical tests robust against outliers or extremes, it was decided that it would be preferable to perform the correlation between some of the variables with parametric tools, and so they were excluded. The probability distribution of the data after this exclusion follows:

A. Neutral Wrist Position

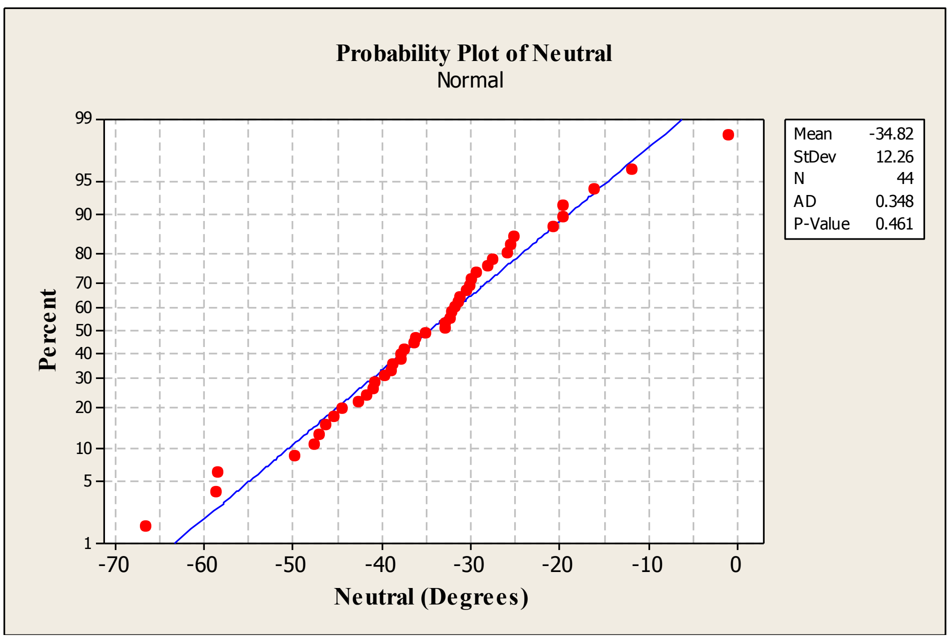


Figure G.11: *The Probability Plot of the Neutral wrist positions: the Anderson-Darling test shows normality (p=0.461).*

B. Extension Wrist Position

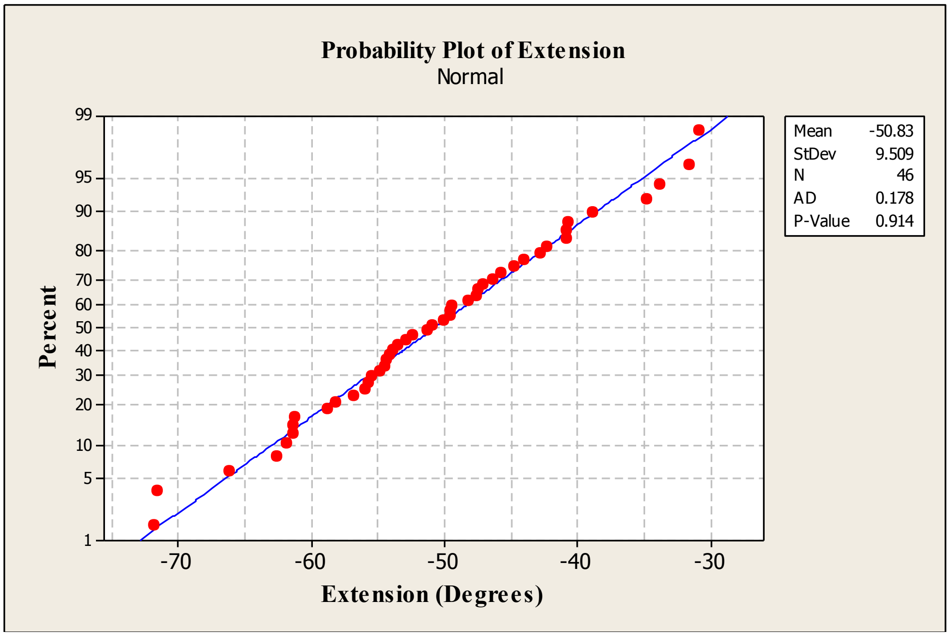


Figure G.12: *The Probability Plot of the Extended wrist positions: the Anderson-Darling test shows normality (p=0.914).*

C. Flexion Wrist Position

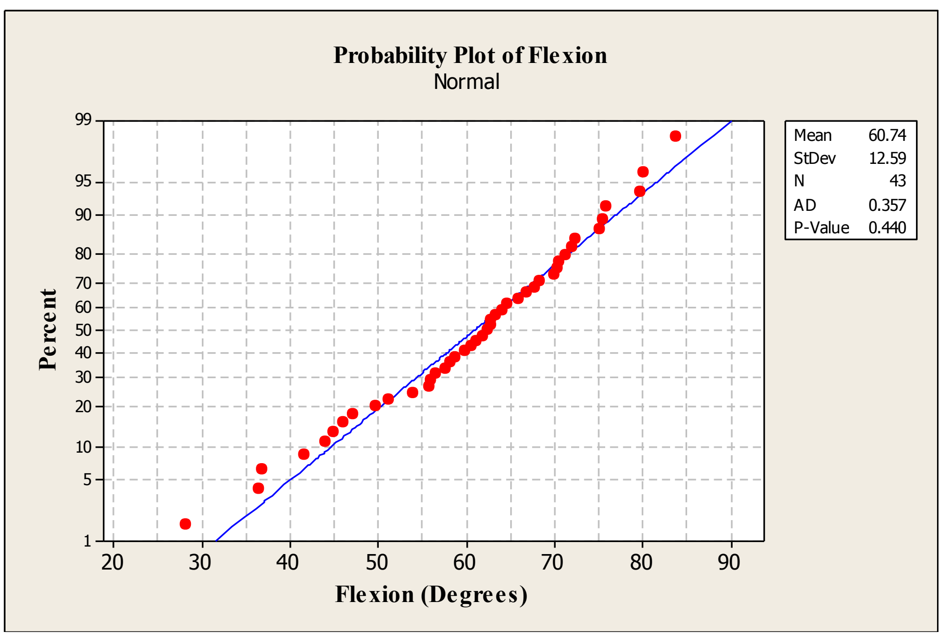


Figure G.13: *The Probability Plot of the Flexed wrist positions: the Anderson-Darling test shows normality (p=0.44).*

D. Radial Deviation Wrist Position

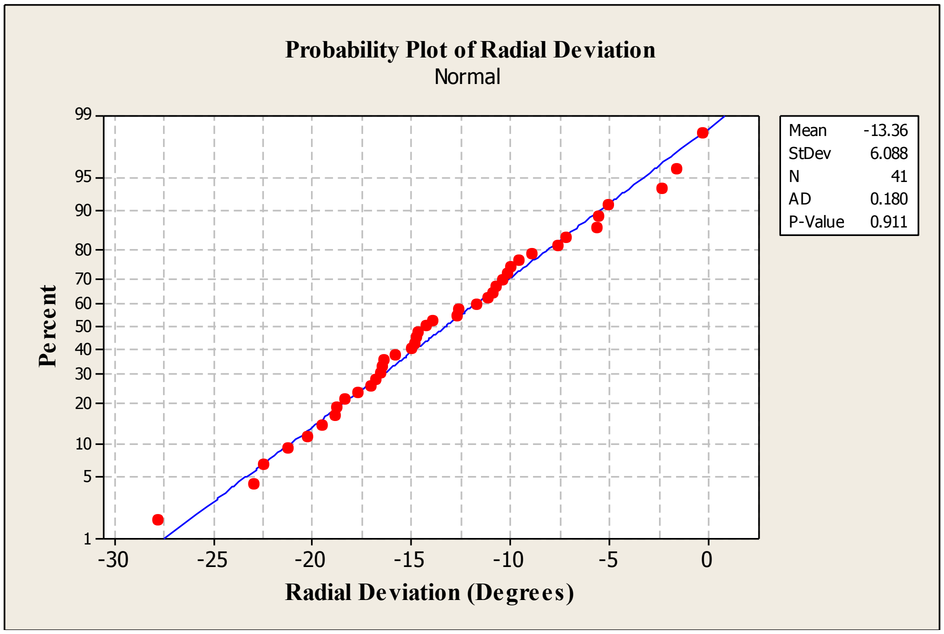


Figure G.14: *The Probability Plot of the radial Deviated wrist positions: the Anderson-Darling test shows normality (p=0.911).*

E. Ulnar Deviation Wrist Position

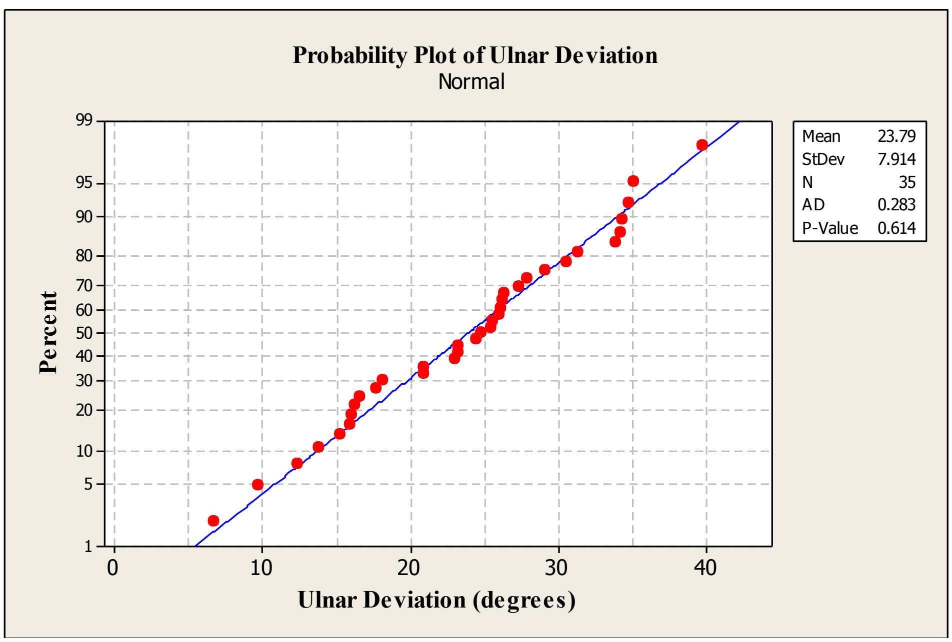


Figure G.15: *The Probability Plot of the Ulnar Deviated wrist positions: the Anderson-Darling test shows normality (p=0.614).*

G5: Statistics of the kinematic results between genders.

The Mann-Whitney W test was used to define any differences between the genders in the wrist positions chosen by the subjects. As a non-parametric statistical tool, it is robust against the outliers described above, so the whole dataset was used. The null hypothesis (Ho) was that there is no difference between the genders in the chosen angles in the five wrist positions.

A. Neutral wrist position

	Median (degrees)			
	Males	**Females**	**W**	**P value**
Neutral (-)	-35.12	-32.19	613.0	0.6415
Combined Radial (-)-Ulnar (+)	5.690	11.337	534.0	0.0457

B. Extension

	Median (degrees)			
	Males	**Females**	**W**	**P value**
Extension (-)	-54.36	-49.48	575.0	0.4451
Combined Radial (-)-Ulnar (+)	10.685	15.655	541.0	0.1428

C. Flexion

	Median (degrees)			
	Males	**Females**	**W**	**P value**
Flexion (+)	60.55	61.56	467.0	0.2764
Combined Radial (-)-Ulnar (+)	-15.729	-17.008	548.0	0.5024

D. Radial Deviation

	Median (degrees)			
	Males	**Females**	**W**	**P value**
Radial Deviation (-)	-16.40	-10.59	432.0	0.0284
Combined Flexion (+)-Extension (-)	-6.34	-8.15	544.0	0.7420

E. Ulnar Deviation

	Median (degrees)			
	Males	**Females**	**W**	**P value**
Ulnar Deviation (+)	25.86	24.79	301.0	0.6789
Combined Flexion (+)-Extension (-)	7.33	13.80	244.0	0.1497

The test shows that there is no statistical difference between the genders in all the wrist positions chosen by them, except the Radial deviation (0.0284) and the Radioulnar Deviation accompanies the Neutral (p=0.0457).

G6: Correlations between WJLS and wrist positions

Because WJLS are normally distributed (see Appendix X) while wrist positions are not (with the extremes), the dataset with the excluded extremes was used in this study in order to perform parametric statistical tests for better results. The tests showed no correlation between these variables, as in the following graphs:

A. Extension vs. WJLS

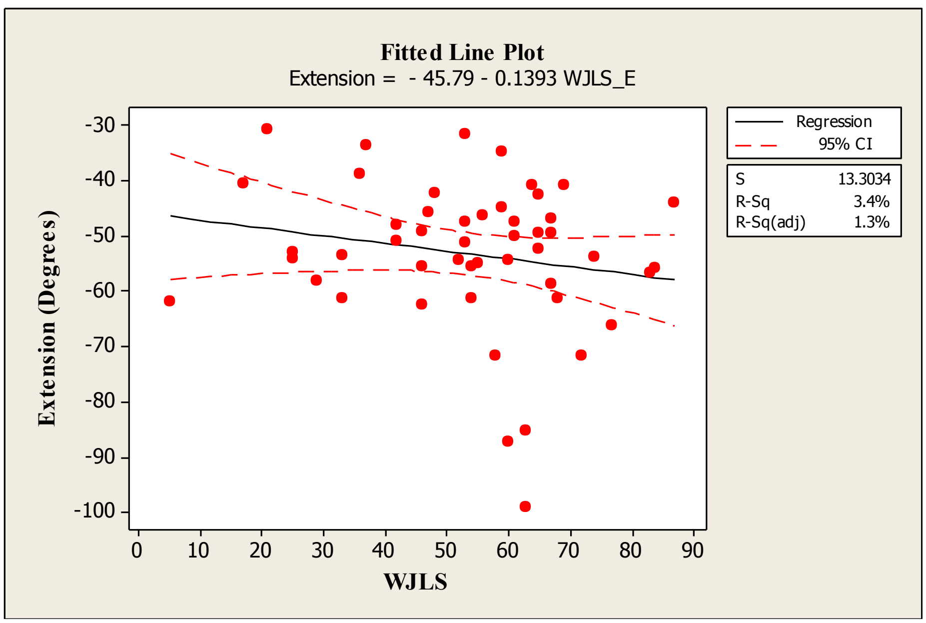


Figure G.16: *The Extension vs. WJLS showed no correlation (R-Sq=3.4%)*

B. Neutral vs. WJLS

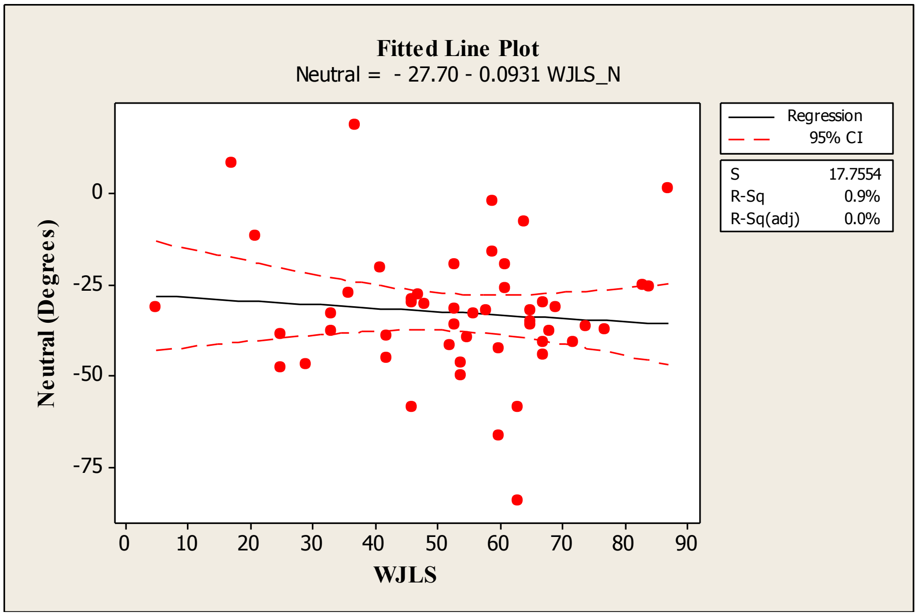


Figure G.17: *The Neutral vs. WJLS showed no correlation (R-Sq=0.9%)*

C. Flexion vs. WJLS

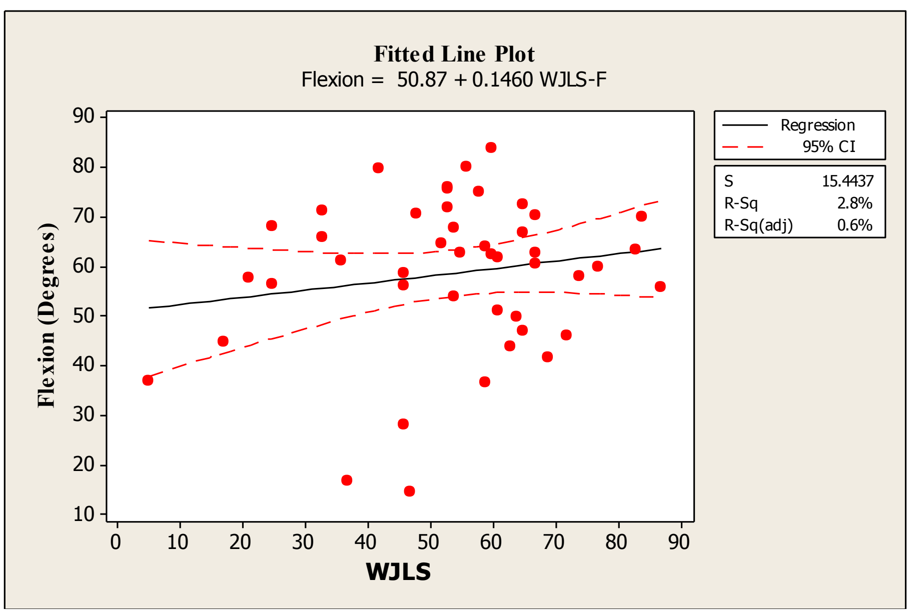


Figure G.18: *The Flexion vs. WJLS showed no correlation (R-Sq=2.8%)*

D. Radial Deviation vs. WJLS

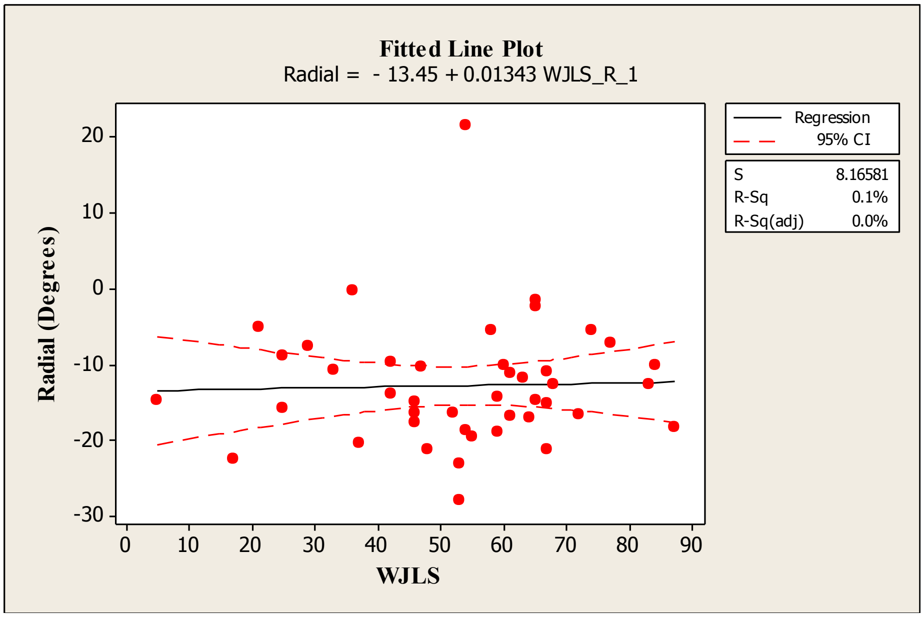


Figure G.19: *The Radial Dev. vs. WJLS showed no correlation (R-Sq=0.1%)*

E. Ulnar Deviation vs. WJLS

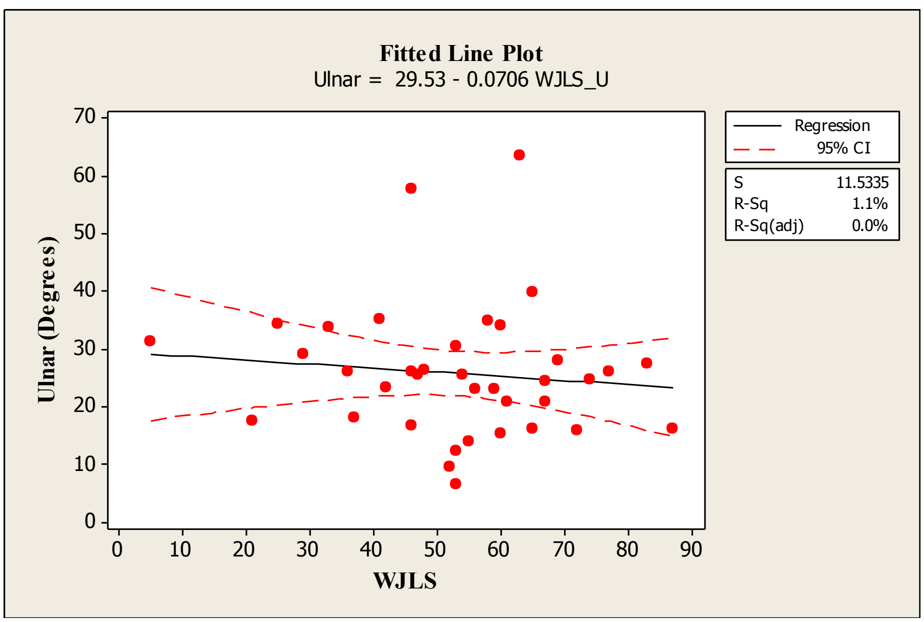


Figure G.20: *The Ulnar Dev. vs. WJLS showed no correlation (R-Sq=1.1%)*

G7: Correlations between Wrist positions and maximal passive wrist angles

The maximal passive Flexion and extension of the wrist joint used in order to define the WJLS of each subject. A statistical analysis follows to decide if there is an underlying correlation between this variables and the wrist position in Flexion and extension. The results indicate no correlation between these variables.

A. Maximal Passive Extension vs. Extension

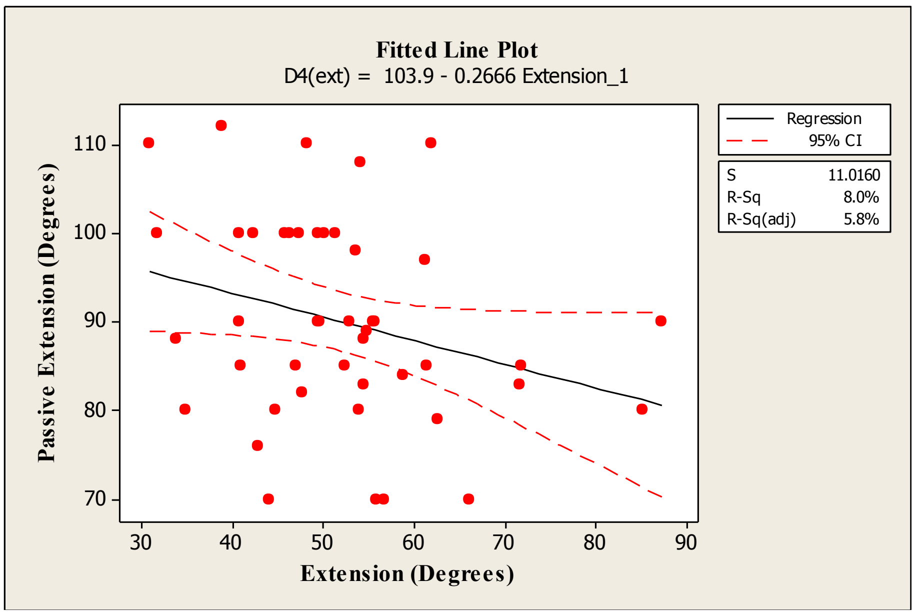


Figure G.21: *The Maximal passive Extension vs. Extension showed no correlation (R-Sq=8.0%)*

B. Maximal Passive Extension vs. Neutral

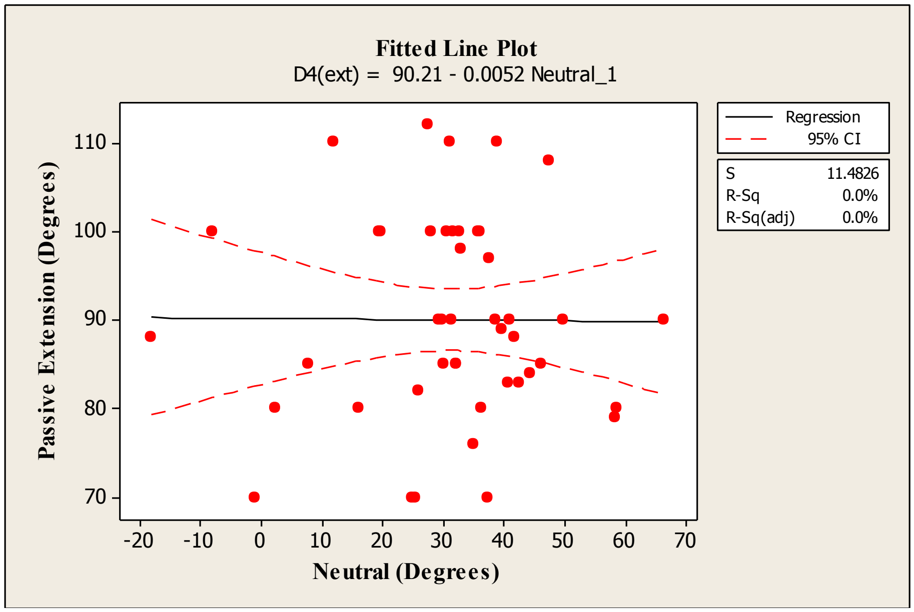


Figure G.22: *The Maximal passive Extension vs. Neutral showed no correlation (R-Sq=0.0%)*

C. Maximal Passive Flexion vs. Flexion

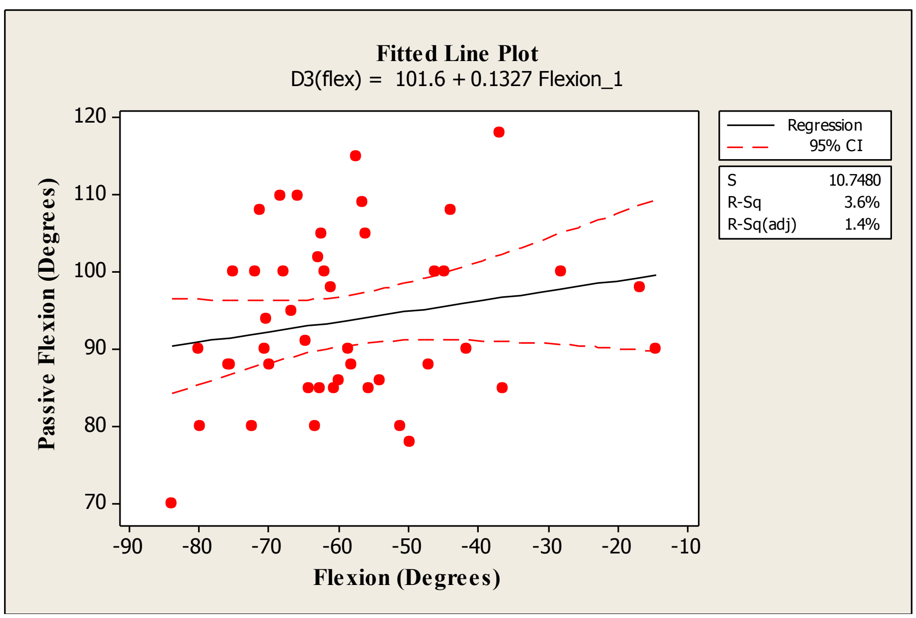


Figure G.23: *The Maximal passive Flexion vs. Flexion showed no correlation (R-Sq=3.6%)*

APPENDIX (H): **Kinetics: Load Distribution across the Fingers**

H1: The sample size.

Fifty four normal subjects were participated in this study, and fifty of them provided reliable data. However, in some wrist orientation, and especially in the Ulnar Deviated trials, the markers were hidden between the hand and the table and therefore the acquirement of the data was problematic. Thus, the sample size (N) was different for every wrist orientation, as it is shown in the following tables (by gender and in total).

Wrist Position (Males)

Cases	Flexion	Extension	Radial	Ulnar	Neutral
N	22	25	23	16	25

Wrist Position (Females)

Cases	Flexion	Extension	Radial	Ulnar	Neutral
N	23	24	20	21	25

Wrist Position (Total)

Cases	Flexion	Extension	Radial	Ulnar	Neutral
N	45	49	43	37	50

H2: The F_zT, for each finger, by gender, in every wrist orientation

A. The following Tables show the F_zT (the maximals of the three trials were chosen), for every finger, in every wrist orientation. The missing trial results represent corrupted kinematic data, and the underlined ones represent extremes.

	Flexion							
	Index (N)		Middle (N)		Ring (N)		Little (N)	
No	Males	Females	Males	Females	Males	Females	Males	Females
1	-14.7	-19.6	-16.0	-15.0	-9.1	-11.2	-5.3	-12.2
2	-13.4	-16.7	-15.8	-8.2	-10.4	-8.0	-4.7	-11.3
3	-21.9	-11.2	-26.9	-20.1	-20.9	-10.2	-7.6	-7.8
4	-12.1	-10.6	-22.5	-7.6	-9.6	-4.3	-11.1	-3.3
5	-19.3	-12.9	-24.9	-12.6	-19.8	-9.2	-13.7	-11.8
6	-16.2	-11.3	-14.3	-10.3	-7.2	-9.2	-2.9	-8.6
7	-11.7	-18.9	-25.8	-17.4	-20.8	-11.8	-19.3	-14.5
8	-19.3	-10.2	-20.6	-15.7	-15.7	-8.7	-5.8	-6.8
9	-19.5	-23.8	-19.2	-8.9	-11.6	-13.5	-7.5	-4.2
10	-40.6	-18.6	-25.9	-11.3	-19.1	-8.6	-22.5	-11.5
11	-30.4	-13.7	-16.5	-8.0	-18.9	-9.2	-18.0	-7.1
12	-9.67	-12.9	-12.7	-14.4	-11.7	-4.0	-7.9	-4.0
13	-21.2	-18.7	-31.9	-11.6	-21.0	-8.3	-7.7	-4.3
14	-16.3	-17.1	-11.4	-12.9	-6.5	-7.3	-5.2	-9.9
15	-42.4	-14.9	-14.9	-14.7	-11.3	-13.5	-2.0	-5.3
16	-33.2	-11.5	-5.7	-22.8	-7.1	-10.9	-4.3	-8.1
17	-26.2	-13.3	-27.6	-9.8	-21.9	-7.0	-6.7	-9.1
18	-9.1	-11.6	-11.5	-11.0	-8.4	-4.2	-4.1	-3.0
19	-24.3	-12.2	-26.7	-1.6	-11.5	-0.7	-9.4	0.1
20	-25.0	-10.9	-26.6	-11.4	-18.2	-9.7	-13.8	-12.3
21	-21.3	-12.7	-19.7	-17.6	-10.4	-11.8	-12.3	-5.5
22	-25.4	-12.3	-32.4	-12.3	-20.2	-5.3	-33.1	-7.9
23		-11.8		-12.7		-8.1		-7.6
24								
25								

	Extension							
	Index (N)		Middle (N)		Ring (N)		Little (N)	
No	Males	Females	Males	Females	Males	Females	Males	Females
1	-23.8	-22.5	-17.4	-12.2	-6.1	-11.2	-4.6	-8.5
2	-16.3	-15.3	-15.4	-18.7	-11.5	-17.8	-6.4	-11.2
3	-25.4	-12.9	-10.5	-27.6	-12.1	-23.7	-13.0	-11.9
4	-23.3	-20.7	-16.4	-14.6	-13.3	-14.3	-14.2	-9.7
5	-25.9	-18.1	-24.5	-19.2	-18.2	-11.6	-5.9	-7.0
6	-19.4	-22.4	-22.2	-5.3	-13.7	-7.9	-9.4	-6.6
7	-31.7	-23.5	-49.8	-37.1	-28.7	-23.1	-12.9	-9.6
8	-19.4	-18.7	-30.5	-12.2	-38.6	-14.7	-25.2	-11.4
9	-39.0	-20.8	-24.2	-8.5	-22.2	-12.5	-19.1	-6.8
10	-42.0	-14.2	-5.5	-16.8	-10.9	-12.5	-6.0	-9.0
11	-28.4	-14.2	-39.7	-6.4	-28.3	-12.5	-18.8	-7.9
12	-20.2	-18.4	-25.6	-15.6	-19.5	-15.0	-11.8	-10.1
13	-47.4	-15.5	-15.5	-14.6	-13.1	-4.9	-12.8	-2.1
14	-16.8	-17.8	-14.1	-9.4	-15.5	-6.2	-7.3	-3.9
15	-31.4	-13.7	-35.0	-13.1	-26.1	-8.8	-18.6	-11.4
16	-23.5	-19.2	-16.3	-16.7	-9.3	-18.2	-4.0	-10.5
17	-27.1	-16.7	-47.7	-14.8	-6.3	-14.0	-11.3	-6.7
18	-21.4	-23.2	-11.9	-14.9	-10.1	-13.5	-3.7	-15.2
19	-29.2	-11.3	-13.1	-8.8	-15.9	-5.0	-11.7	-6.0
20	-11.9	-11.1	-7.9	-6.7	-7.0	-4.0	-4.4	-2.0
21	-27.5	-9.1	-55.6	-8.0	-47.6	-14.5	-32.9	-8.4
22	-34.7	-15.4	-19.8	-13.3	-19.2	-12.3	-18.3	-11.8
23	-30.5	-15.6	-24.9	-12.1	-21.9	-10.0	-26.2	-7.1
24	-13.4	-20.1	-13.6	-15.3	-14.2	-20.9	-7.4	0.002
25	-33.5		-34.7		-21.7		-17.4	

	Neutral							
	Index (N)		Middle (N)		Ring (N)		Little (N)	
No	**Males**	**Females**	**Males**	**Females**	**Males**	**Females**	**Males**	**Females**
1	-21.7	-22.5	-14.4	-15.8	-7.2	-13.9	-7.1	-11.7
2	-18.7	-18.9	-29.1	-15.0	-21.5	-18.2	-9.6	-20.4
3	-31.8	-14.4	-23.9	-19.9	-18.5	-18.2	-17.8	-14.5
4	-22.6	-26.9	-17.3	-11.4	-16.9	-16.8	-19.3	-5.0
5	-19.9	-21.8	-24.8	-24.0	-14.1	-18.6	-6.2	-11.3
6	-22.9	-14.1	-26.8	-10.6	-16.5	-8.2	-8.3	-8.6
7	-31.2	-28.1	-52.8	-18.6	-22.0	-11.6	-4.2	-2.8
8	-14.1	-30.0	-41.0	-24.7	-43.4	-22.7	-16.7	-11.6
9	-33.7	-22.8	-31.1	-19.8	-21.5	-21.6	-12.0	-14.6
10	-44.8	-28.3	-19.1	-26.6	-7.7	-22.4	-20.3	-8.4
11	-40.7	-23.0	-48.5	-12.7	-30.7	-13.1	-19.8	-16.3
12	-27.6	-16.5	-33.1	-26.5	-28.4	-13.9	-9.4	-9.6
13	-40.3	-19.0	-22.2	-18.5	-17.3	-15.5	-13.1	-7.1
14	-17.5	-20.8	-14.9	-31.6	-19.2	-11.1	-14.8	-3.3
15	-39.0	-24.2	-40.9	-20.8	-25.3	-11.9	-22.7	-3.7
16	-44.2	-17.9	-17.1	-27.1	-11.9	-14.7	-4.7	-9.7
17	-40.0	-17.9	-22.3	-17.0	-19.3	-10.6	-6.3	-4.4
18	-22.0	-23.7	-13.9	-19.5	-7.1	-8.5	-11.2	-6.3
19	-38.4	-24.6	-24.5	-20.8	-15.8	-16.0	-7.6	-12.3
20	-10.5	-15.3	-14.8	-21.4	-12.2	-11.6	-3.1	-7.5
21	-32.3	-13.7	-52.9	-15.7	-45.1	-7.7	-35.0	-2.4
22	-48.3	-34.1	-31.5	-30.4	-14.8	-11.1	-18.7	-2.5
23	-41.3	-20.9	-36.9	-24.1	-19.5	-14.1	-15.6	-9.0
24	-25.5	-15.6	-7.9	-11.6	-25.4	-5.3	-7.6	-7.8
25	-36.0	-22.5	-30.0	-13.5	-50.0	-15.4	-25.5	-6.8

	Radial Deviation							
	Index (N)		Middle (N)		Ring (N)		Little (N)	
No	Males	Females	Males	Females	Males	Females	Males	Females
1	-19.4	-21.0	-21.0	-10.4	-12.1	-10.9	-8.3	-6.1
2	-26.4	-23.2	-16.1	-8.9	-10.9	-9.3	-4.0	-11.8
3	-16.7	-26.1	-19.9	-23.3	-24.6	-10.7	-12.2	-7.5
4	-29.7	-25.5	-18.3	-11.3	-14.5	-9.6	-7.5	-6.4
5	-17.0	-23.2	-16.2	-11.9	-13.2	-6.0	-4.2	-2.3
6	-27.7	-19.2	-25.9	-9.9	-15.9	-5.2	-9.4	-3.6
7	-41.0	-19.7	-14.5	-17.9	-10.5	-18.0	-16.0	-8.9
8	-45.7	-19.4	-11.2	-13.1	-12.0	-11.7	-5.2	-11.8
9	-45.5	-33.0	-3.5	-21.0	-7.9	-24.2	-7.8	-11.3
10	-31.7	-14.8	-21.1	-16.2	-10.1	-7.3	-2.8	-6.6
11	-48.1	-19.4	-7.8	-17.2	0.7	-8.8	-6.8	-5.7
12	-43.4	-32.0	-13.7	-8.6	-8.1	-3.3	-14.1	-2.5
13	-29.3	-23.7	-7.3	-11.7	-11.2	-6.8	-13.0	-0.8
14	-18.2	-21.9	-15.6	-13.0	-9.9	-12.5	-5.5	-7.0
15	-29.1	-11.2	-19.2	-17.1	-12.0	-7.2	-3.7	-11.9
16	-30.5	-23.1	-23.8	-16.4	-9.3	-12.5	-5.5	-7.2
17	-34.6	-11.9	-1.2	-10.2	-5.5	-6.6	-0.6	-6.1
18	-13.4	-8.7	-2.8	-13.8	-5.0	-6.4	-5.2	-2.0
19	-35.5	-11.0	-22.8	-13.0	-8.4	-10.4	-7.4	-7.7
20	-34.4	-14.6	-30.4	-11.9	-13.2	-4.4	-9.8	-2.3
21	-34.0		-26.4		-12.9		-4.7	
22	-30.9		-10.7		-7.0		-8.4	
23	-36.8		-16.7		-8.4		-12.8	
24								
25								

	Ulnar Deviation							
	Index (N)		Middle (N)		Ring (N)		Little (N)	
No	Males	Females	Males	Females	Males	Females	Males	Females
1	-24.6	-18.7	-11.5	-12.8	-3.9	-22.6	-3.8	-10.8
2	-17.4	-25.5	-12.4	-17.5	-9.3	-13.5	-9.6	-11.8
3	-28.2	-18.3	-11.6	-23.0	-8.0	-30.4	-10.5	-8.1
4	-21.8	-27.7	-17.8	-16.1	-20.9	-7.7	-19.4	-12.4
5	-21.6	-22.3	-18.4	-11.5	-15.2	-13.9	-8.2	-12.7
6	-17.3	-32.3	-35.3	-8.2	-17.2	-3.9	-8.9	-4.2
7	-67.9	-13.1	-22.4	-16.6	-22.3	-9.9	-6.9	-6.5
8	-36.0	18.6	-10.5	16.4	-9.9	9.6	-3.4	6.9
9	-42.1	-30.7	-13.0	-6.5	-13.5	-23.8	-15.1	-8.4
10	-30.6	-14.5	-25.2	-18.6	-16.9	-13.7	-7.7	-10.4
11	-24.9	-15.6	-20.7	-13.4	-12.6	-11.4	-13.5	-9.8
12	-27.5	-20.0	-28.1	-5.9	-15.6	-8.4	-12.9	-8.6
13	-34.9	-19.5	-7.0	-8.9	-7.9	-5.6	-5.9	-7.2
14	-56.9	-18.4	-12.6	-16.7	-9.0	-11.0	-12.8	-8.3
15	-78.2	-29.9	-21.2	-10.1	-24.1	-13.1	-7.4	-2.2
16	-33.9	-13.7	-11.2	-7.1	-9.0	-4.5	-11.8	-9.1
17		-14.4		-10.0		-5.1		-4.9
18		-13.8		-19.5		-14.1		-10.6
19		-23.6		-13.5		-13.1		-8.9
20		-13.9		-15.6		-6.9		-8.8
21		-45.2		-15.5		-11.5		0.7
22								
23								
24								
25								

B. The percentage distribution of the ΣFzT on the fingers, by gender, for every wrist orientation follows.

	Flexion							
	Index (%)		Middle (%)		Ring (%)		Little (%)	
No	Males	Females	Males	Females	Males	Females	Males	Females
1	32.5	33.7	35.5	25.8	20.3	19.4	11.8	21.1
2	30.2	37.6	35.6	18.5	23.4	18.2	10.7	25.7
3	28.3	22.7	34.7	40.7	27.1	20.7	9.9	15.9
4	21.9	40.8	40.6	29.4	17.5	16.8	20.1	13.0
5	24.8	27.8	32.1	27.0	25.5	19.8	17.6	25.5
6	39.8	28.6	35.2	26.0	17.8	23.4	7.2	22.0
7	15.0	30.2	33.3	27.7	26.8	18.9	24.9	23.1
8	31.3	24.6	33.5	37.8	25.6	21.2	9.6	16.5
9	33.6	47.1	33.2	17.7	20.2	26.8	13.0	8.3
10	37.5	37.1	23.9	22.6	17.7	17.3	20.9	23.0
11	36.2	36.0	19.7	21.0	22.6	24.3	21.5	18.7
12	23.0	36.5	30.2	40.7	27.9	11.4	18.9	11.4
13	25.9	43.4	38.9	27.0	25.7	19.5	9.5	10.1
14	41.3	36.2	28.9	27.2	16.6	15.6	13.3	21.1
15	59.9	30.6	21.1	30.3	16.1	28.0	2.9	11.1
16	65.8	21.5	11.3	42.7	14.2	20.5	8.6	15.3
17	31.7	33.9	33.5	24.9	26.6	17.9	8.2	23.3
18	27.3	38.8	34.6	36.9	25.6	14.2	12.5	10.1
19	33.7	84.9	37.0	11.4	16.1	4.9	13.2	-1.2
20	29.9	24.5	31.8	25.8	21.8	22.0	16.5	27.8
21	33.4	26.7	30.9	36.9	16.4	24.8	19.4	11.6
22	22.8	32.5	29.2	32.6	18.2	14.1	29.8	20.9
23		29.3		31.5		20.2		19.0
24								
25								

	Extension							
	Index (%)		Middle (%)		Ring (%)		Little (%)	
No	Males	Females	Males	Females	Males	Females	Males	Females
1	45.8	41.2	33.5	22.4	11.8	20.7	8.9	15.7
2	32.8	24.3	31.0	29.7	23.2	28.3	13.0	17.8
3	41.5	17.0	17.2	36.2	19.9	31.1	21.4	15.7
4	34.6	34.8	24.5	24.7	19.8	24.2	21.1	16.3
5	34.7	32.4	32.8	34.3	24.5	20.7	8.0	12.5
6	30.0	53.1	34.3	12.6	21.1	18.7	14.5	15.7
7	25.8	25.1	40.5	39.8	23.3	24.8	10.5	10.3
8	17.1	32.7	26.8	21.4	33.9	25.9	22.2	19.9
9	37.3	42.8	23.2	17.4	21.3	25.7	18.3	14.1
10	65.1	27.2	8.5	32.0	16.9	23.7	9.4	17.1
11	24.7	34.6	34.5	15.7	24.6	30.4	16.3	19.3
12	26.2	31.1	33.2	26.3	25.2	25.4	15.4	17.1
13	53.3	41.7	17.5	39.4	14.8	13.2	14.4	5.8
14	31.3	47.8	26.2	25.2	28.8	16.6	13.7	10.5
15	28.3	29.2	31.5	27.8	23.5	18.7	16.8	24.3
16	44.3	29.7	30.6	25.9	17.5	28.2	7.6	16.3
17	29.3	31.9	51.6	28.3	6.8	26.9	12.3	12.9
18	45.3	34.7	25.4	22.3	21.5	20.2	7.8	22.8
19	41.7	36.2	18.8	28.5	22.7	16.1	16.8	19.2
20	38.1	46.4	25.3	28.2	22.3	16.8	14.3	8.6
21	16.8	22.8	34.0	20.1	29.1	36.1	20.1	21.1
22	37.7	29.1	21.5	25.1	20.9	23.4	19.9	22.3
23	29.4	34.8	24.0	27.0	21.2	22.4	25.4	15.8
24	27.6	35.7	28.0	27.2	29.1	37.1	15.3	0.0
25	31.2		32.3		20.2		16.2	

	Index (%)		Middle (%)		Ring (%)		Little (%)	
			Neutral					
No	Males	Females	Males	Females	Males	Females	Males	Females
1	43.1	35.2	28.5	24.7	14.2	21.8	14.1	18.3
2	23.7	26.0	36.8	20.7	27.2	25.2	12.2	28.1
3	34.6	21.6	26.0	29.7	20.1	27.1	19.3	21.6
4	29.8	44.8	22.7	19.0	22.2	28.0	25.3	8.3
5	30.7	28.9	38.1	31.7	21.6	24.6	9.6	14.9
6	30.8	34.0	35.9	25.4	22.2	19.7	11.1	20.8
7	28.4	46.0	47.9	30.5	19.9	19.0	3.8	4.5
8	12.3	33.7	35.6	27.8	37.7	25.5	14.5	13.0
9	34.3	28.9	31.6	25.2	21.9	27.4	12.2	18.5
10	48.8	33.0	20.8	31.0	8.3	26.2	22.1	9.8
11	29.1	35.4	34.7	19.6	22.0	20.1	14.2	25.0
12	28.1	24.8	33.6	39.8	28.8	20.9	9.5	14.5
13	43.4	31.6	23.8	30.8	18.6	25.7	14.1	11.9
14	26.4	31.1	22.5	47.3	28.9	16.6	22.3	5.0
15	30.5	40.0	32.0	34.3	19.8	19.6	17.8	6.0
16	56.8	25.7	21.9	39.0	15.3	21.2	6.0	14.0
17	45.5	35.9	25.4	34.0	22.0	21.2	7.1	8.9
18	40.6	40.8	25.6	33.6	13.1	14.6	20.7	10.9
19	44.4	33.4	28.4	28.3	18.3	21.7	8.8	16.6
20	26.0	27.4	36.5	38.4	30.0	20.8	7.5	13.4
21	19.6	34.7	32.0	39.7	27.3	19.5	21.2	6.1
22	42.6	43.7	27.8	39.0	13.1	14.2	16.5	3.1
23	36.4	30.7	32.6	35.4	17.2	20.7	13.8	13.2
24	38.4	38.8	11.9	28.8	38.2	13.1	11.5	19.3
25	25.5	38.6	21.2	23.1	35.3	26.5	18.0	11.7

	Radial Deviation							
	Index (%)		Middle (%)		Ring (%)		Little (%)	
No	Males	Females	Males	Females	Males	Females	Males	Females
1	31.9	43.4	34.5	21.6	19.9	22.5	13.6	12.5
2	46.0	43.7	28.1	16.8	19.0	17.4	6.9	22.1
3	22.8	38.6	27.1	34.4	33.4	15.8	16.7	11.1
4	42.4	48.2	26.1	21.4	20.8	18.2	10.7	12.2
5	33.6	53.5	32.1	27.4	26.0	13.7	8.3	5.3
6	35.1	50.8	32.8	26.0	20.1	13.6	12.0	9.6
7	50.0	30.5	17.7	27.8	12.8	27.9	19.5	13.9
8	61.7	34.6	15.1	23.4	16.2	20.9	7.1	21.1
9	70.3	36.8	5.4	23.5	12.2	27.1	12.1	12.7
10	48.3	32.9	32.1	36.1	15.4	16.2	4.2	14.8
11	77.5	37.9	12.6	33.7	-1.1	17.3	11.0	11.2
12	54.8	68.9	17.2	18.6	10.2	7.2	17.8	5.3
13	48.2	55.1	11.9	27.2	18.4	15.9	21.4	1.9
14	36.9	40.2	31.8	23.9	20.0	23.0	11.2	12.9
15	45.5	23.6	30.0	36.1	18.8	15.1	5.7	25.2
16	44.2	39.0	34.4	27.7	13.5	21.1	7.9	12.2
17	82.6	34.1	2.8	29.4	13.1	18.9	1.5	17.7
18	50.7	28.1	10.7	44.7	18.9	20.8	19.7	6.4
19	47.9	26.1	30.8	30.9	11.3	24.7	10.0	18.3
20	39.2	44.0	34.6	35.9	15.1	13.3	11.1	6.8
21	43.5		33.8		16.5		6.1	
22	54.3		18.8		12.2		14.7	
23	49.3		22.4		11.3		17.1	
24								
25								

	Ulnar Deviation							
	Index (%)		Middle (%)		Ring (%)		Little (%)	
No	Males	Females	Males	Females	Males	Females	Males	Females
1	56.1	28.9	26.3	19.7	9.0	34.8	8.7	16.6
2	35.7	37.3	25.5	25.6	19.1	19.8	19.7	17.3
3	48.3	23.0	19.9	28.8	13.8	38.1	17.9	10.1
4	27.3	43.4	22.3	25.2	26.1	12.1	24.3	19.3
5	34.1	36.8	29.1	19.0	24.0	23.1	12.8	21.0
6	22.0	66.3	44.9	16.9	21.8	8.2	11.4	8.6
7	56.8	28.4	18.7	35.9	18.6	21.5	5.8	14.2
8	60.2	36.1	17.5	31.9	16.6	18.6	5.7	13.5
9	50.3	44.3	15.6	9.3	16.1	34.3	18.1	12.1
10	38.0	25.4	31.3	32.5	21.1	23.9	9.6	18.2
11	34.7	31.1	28.8	26.6	17.6	22.8	18.9	19.5
12	32.7	46.6	33.4	13.8	18.5	19.7	15.4	20.0
13	62.5	47.4	12.6	21.5	14.3	13.7	10.6	17.4
14	62.3	33.8	13.8	30.7	9.9	20.2	14.0	15.2
15	59.7	54.0	16.2	18.3	18.5	23.6	5.6	4.0
16	51.5	39.9	16.9	20.8	13.7	13.1	17.9	26.3
17		41.8		29.1		15.0		14.1
18		23.7		33.7		24.3		18.3
19		39.8		22.9		22.1		15.1
20		30.7		34.4		15.3		19.5
21		63.3		21.7		16.1		-1.1
22								
23								
24								
25								

C. The Probability plots of the percentage distribution of the ΣFzT across the fingers follows. On the graph titles, the first letter indicates the gender (M=Males, F=Females), the second the wrist position (F=Flexion, E=Extension, N=Neutral, RD=Radial Deviation, and UD=Ulnar Deviation) and the number indicates the finger (2=Index, 3=Middle, 4=Ring and 5=Little). Inside the box on the right of each graph, is the Anderson-Darling normality test (AD) value as well as its p.

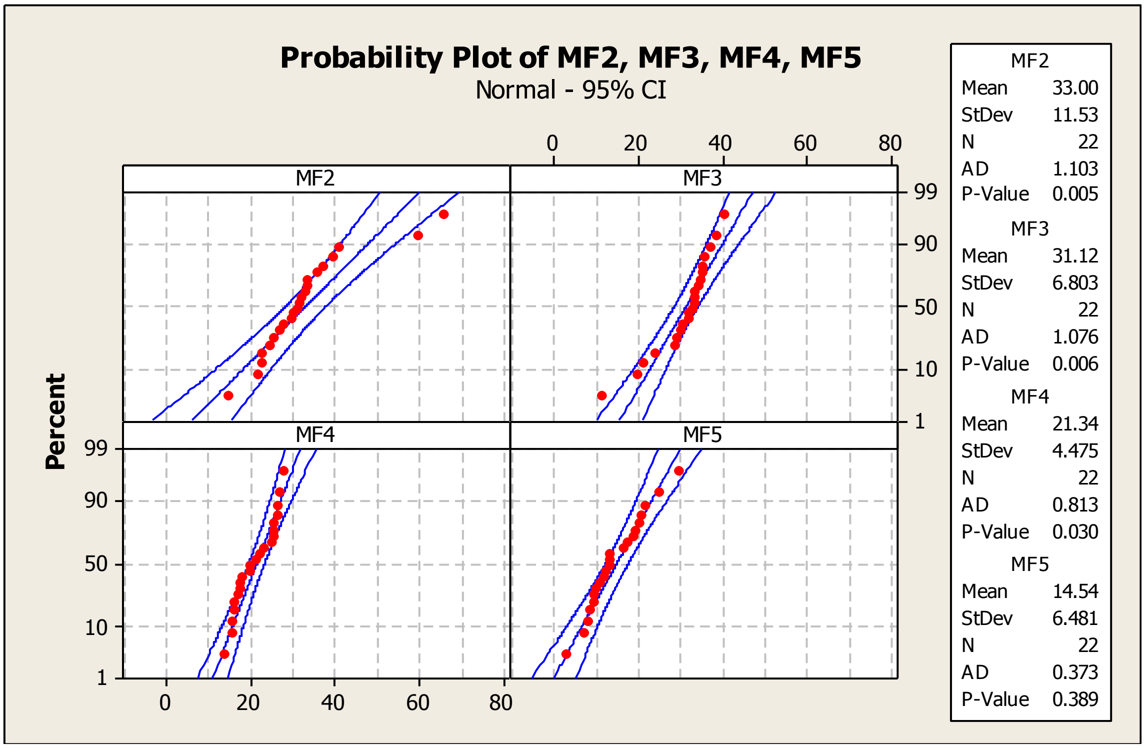


Figure H.1: *The probability plot of the males' fingers, in flexed wrist position.*

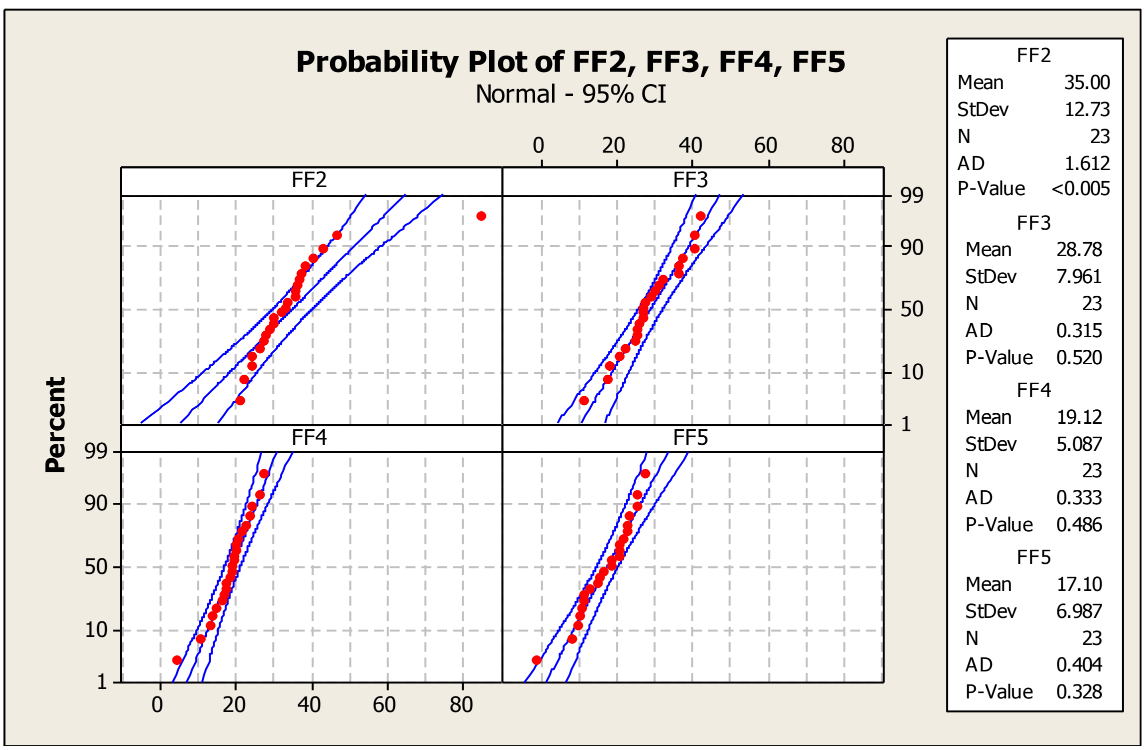


Figure H.2: *The probability plot of the females' fingers, in flexed wrist position.*

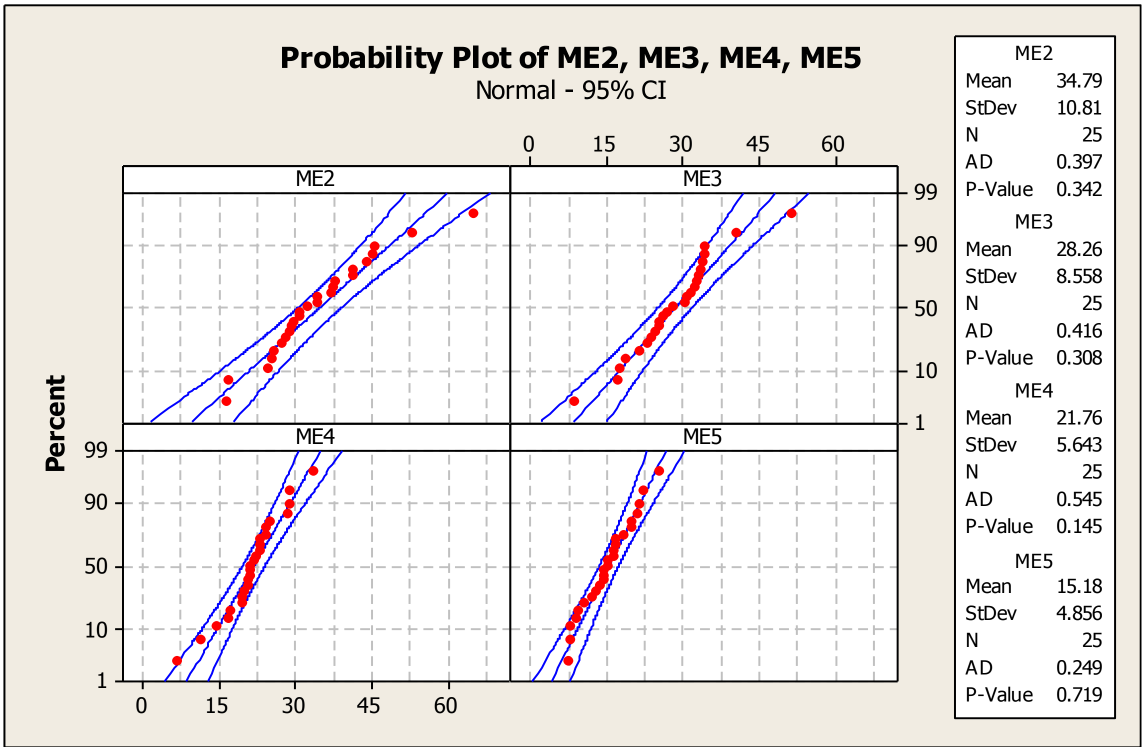


Figure H.3: *The probability plot of the males' fingers, in extension of the wrist.*

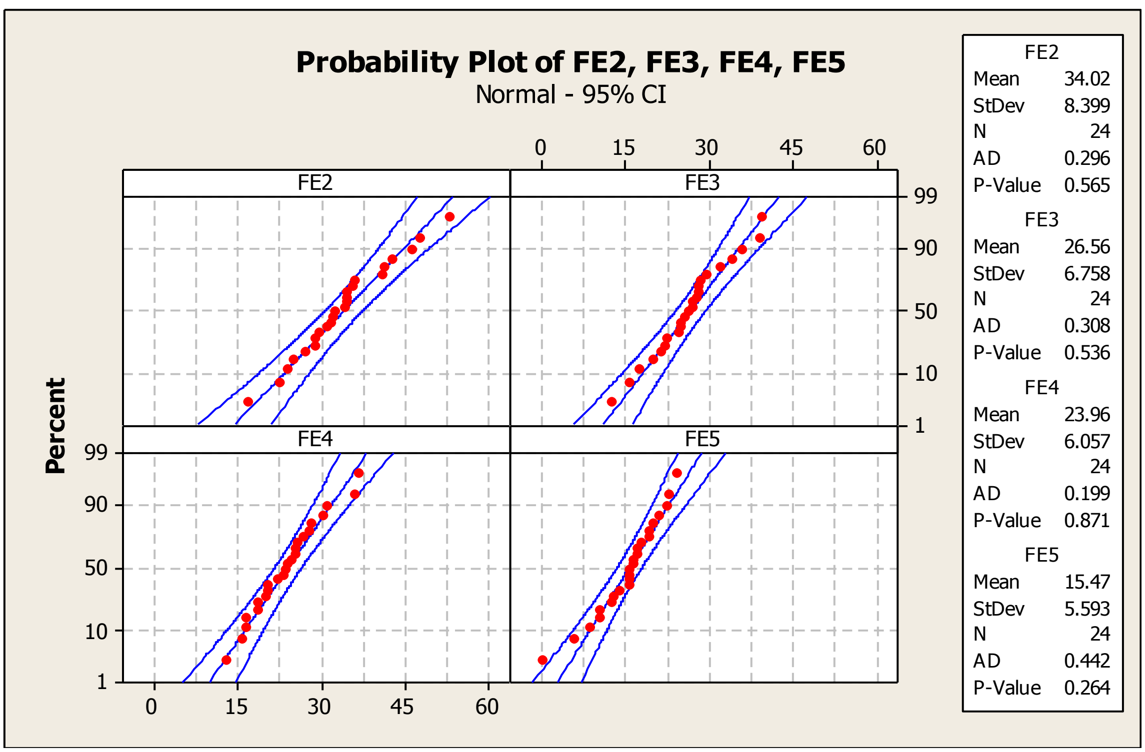


Figure H.4: *The probability plot of the females' fingers, in extension of the wrist.*

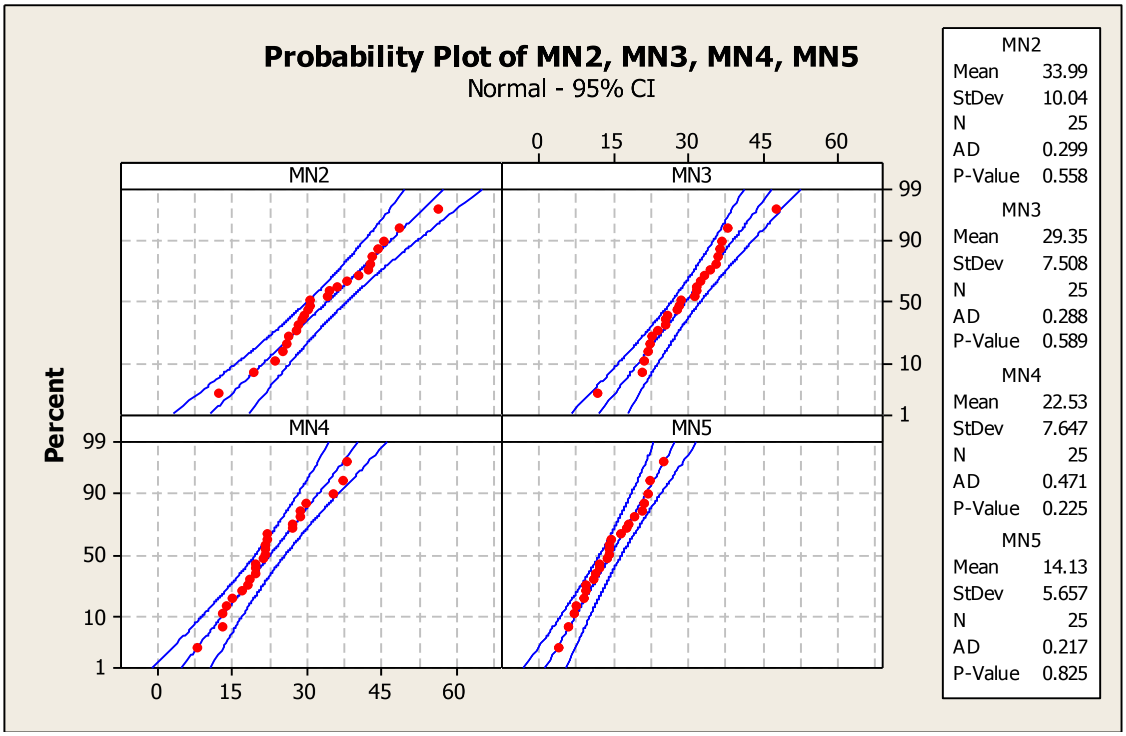


Figure H.5: *The probability plot of the males' fingers, in neutral wrist position.*

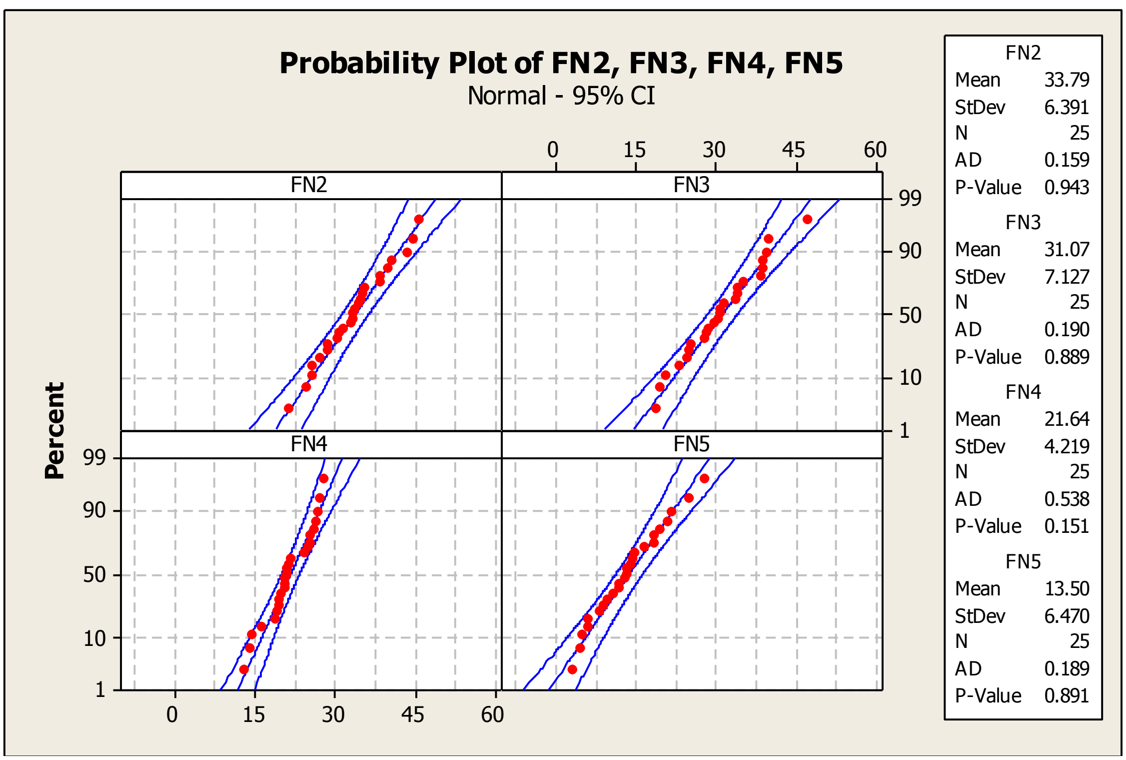


Figure H.6: *The probability plot of the females' fingers, in neutral wrist position.*

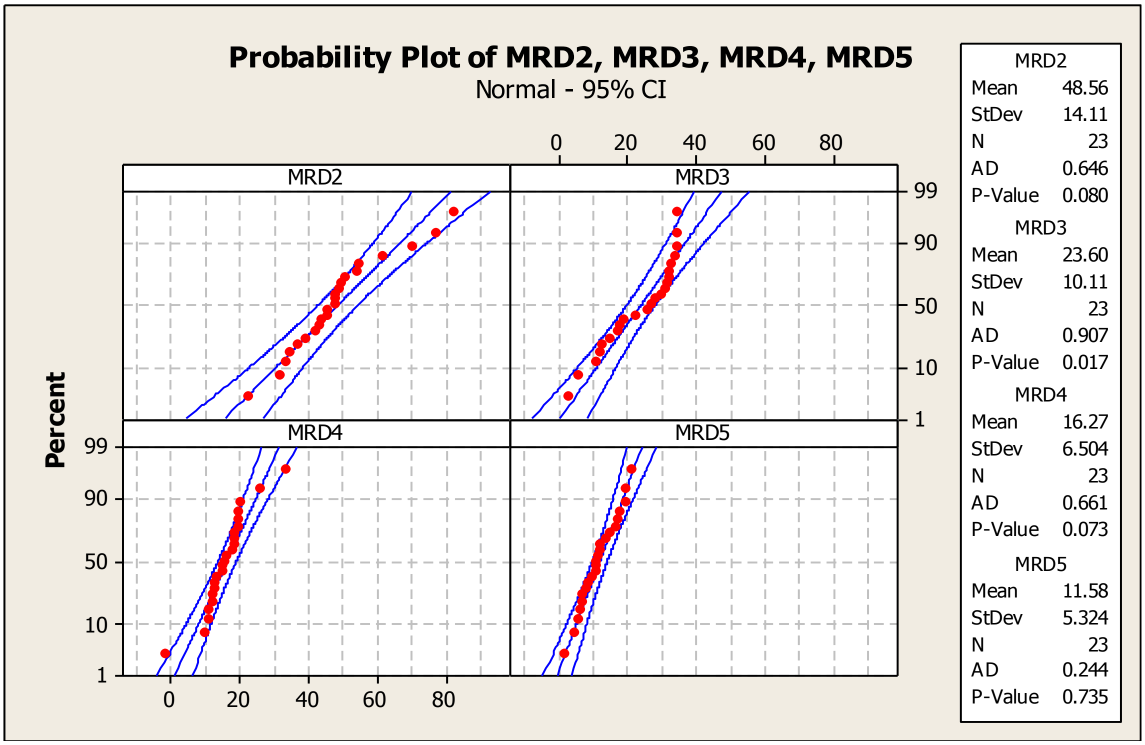


Figure H.7: *The probability plot of the males' fingers, in radial deviation of the wrist.*

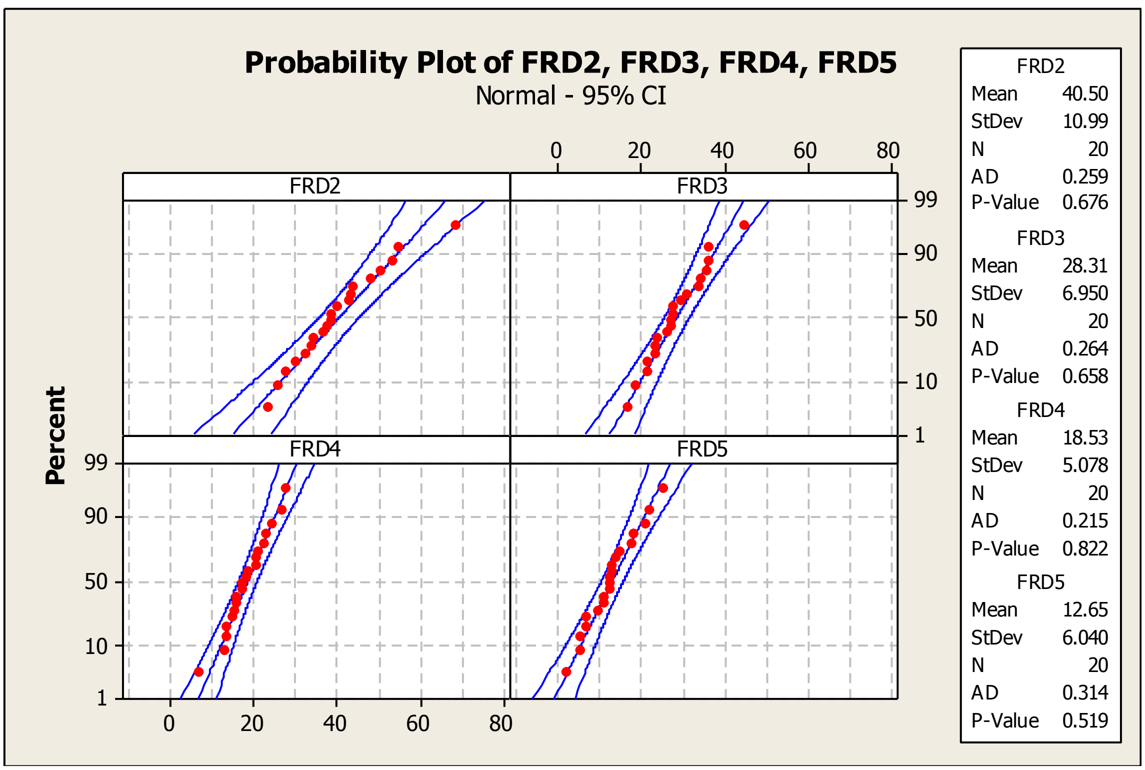


Figure H.8: *The probability plot of the females' fingers, in radial deviation of the wrist.*

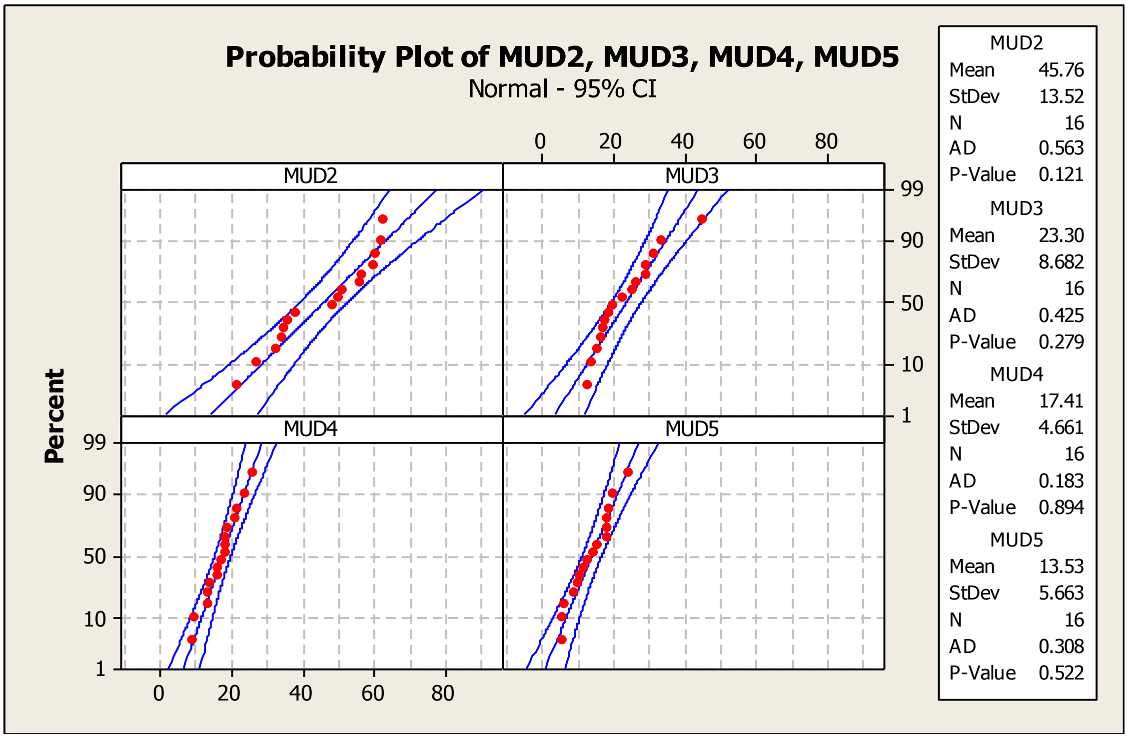


Figure H.9: *The probability plot of the males' fingers, in ulnar deviation of the wrist.*

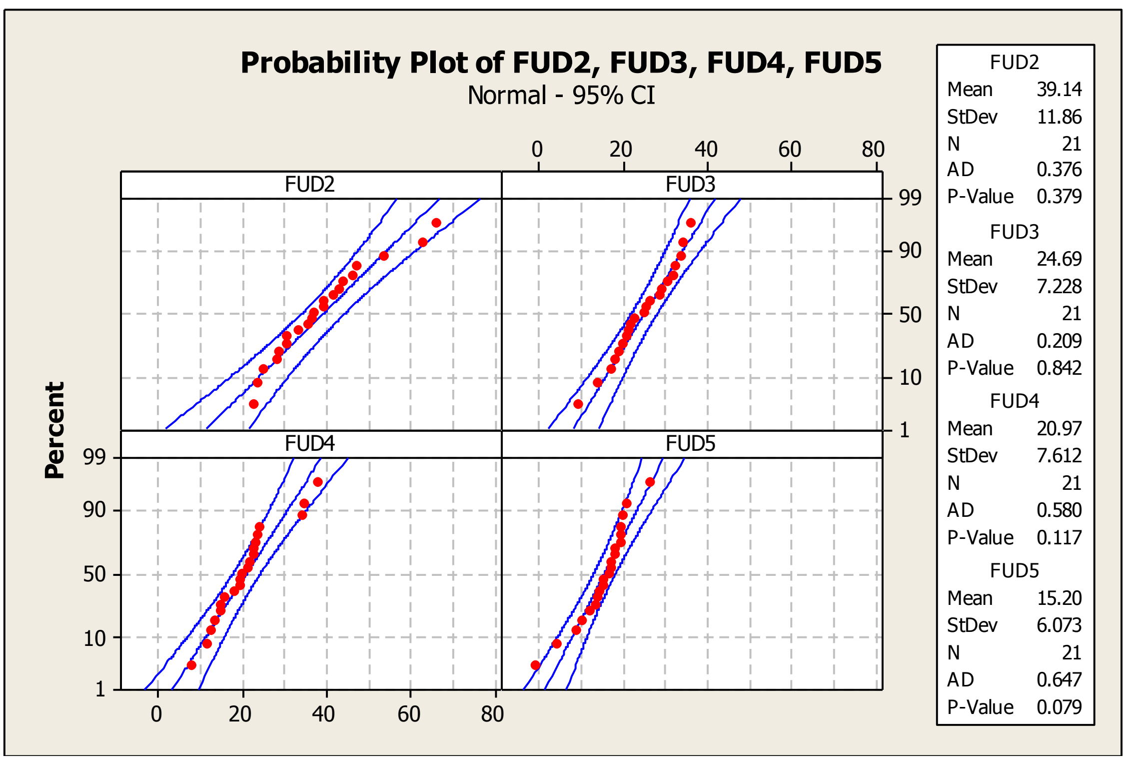


Figure H.10: *The probability plot of the females' fingers, in ulnar deviation of the wrist.*

D. The data also investigated through Box-Plots for outliers and extreme values. The graphs' labelling is according the previous rules.

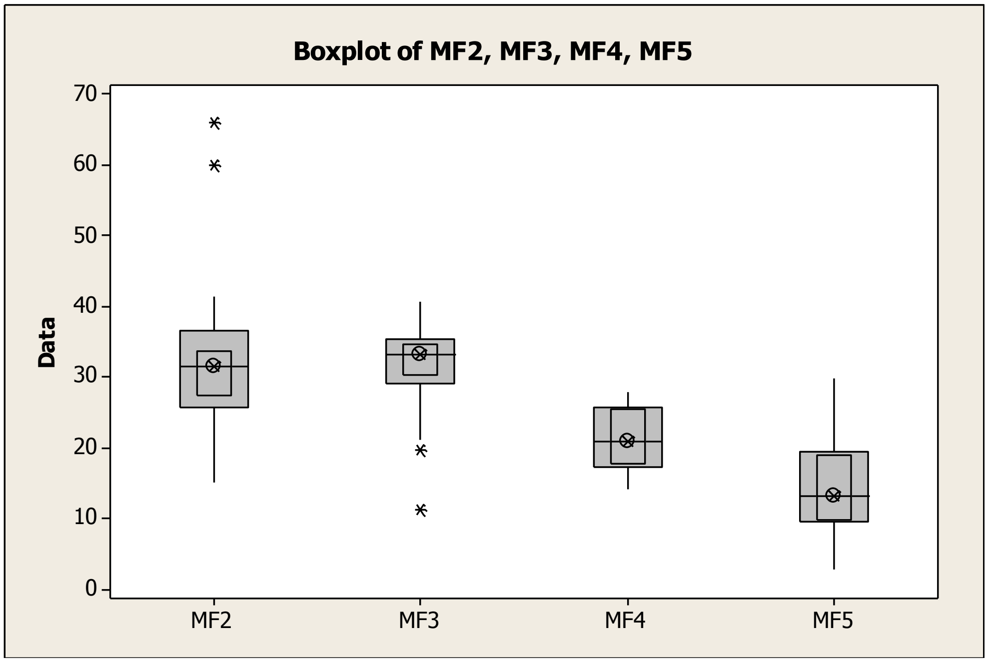


Figure H.11: *The boxplot of the males' fingers, in flexion of the wrist.*

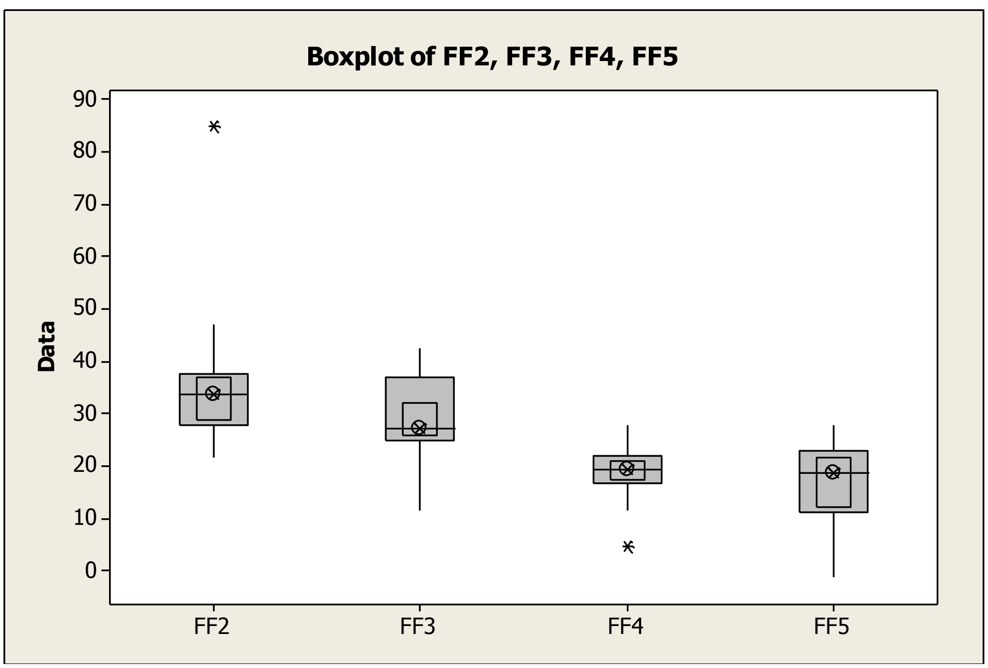


Figure H.12: *The boxplot of the females' fingers, in flexion of the wrist.*

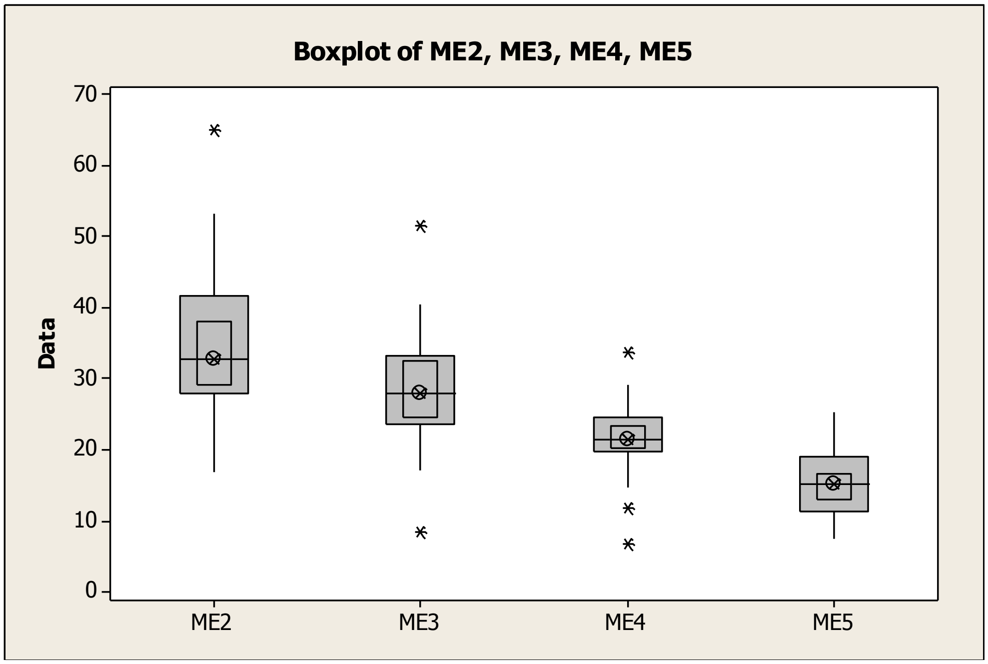


Figure H.13: *The boxplot of the males' fingers, in extension of the wrist.*

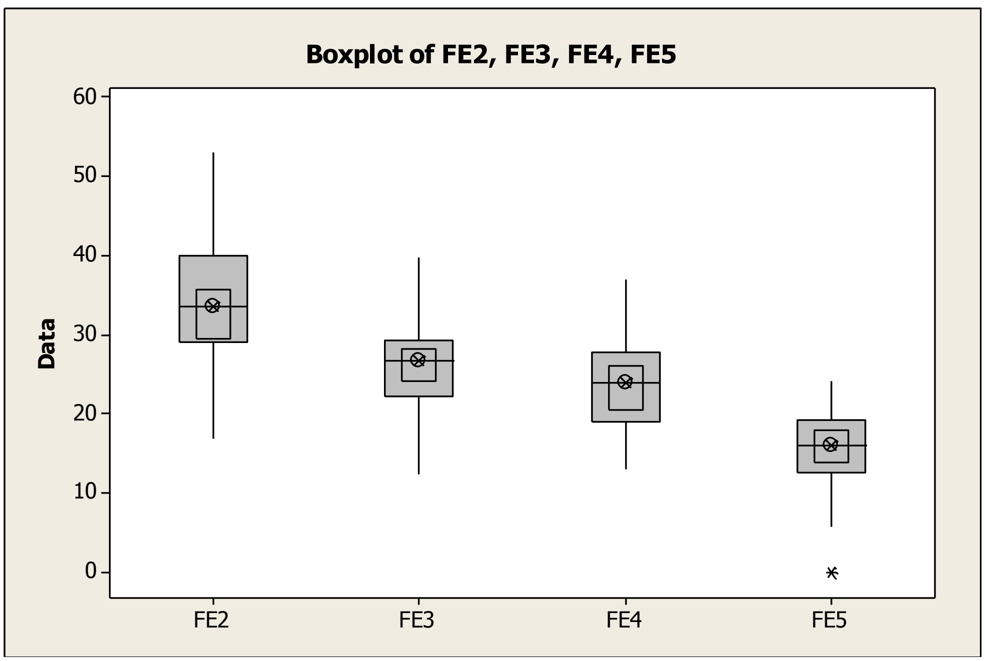


Figure H.14: *The boxplot of the females' fingers, in extension of the wrist.*

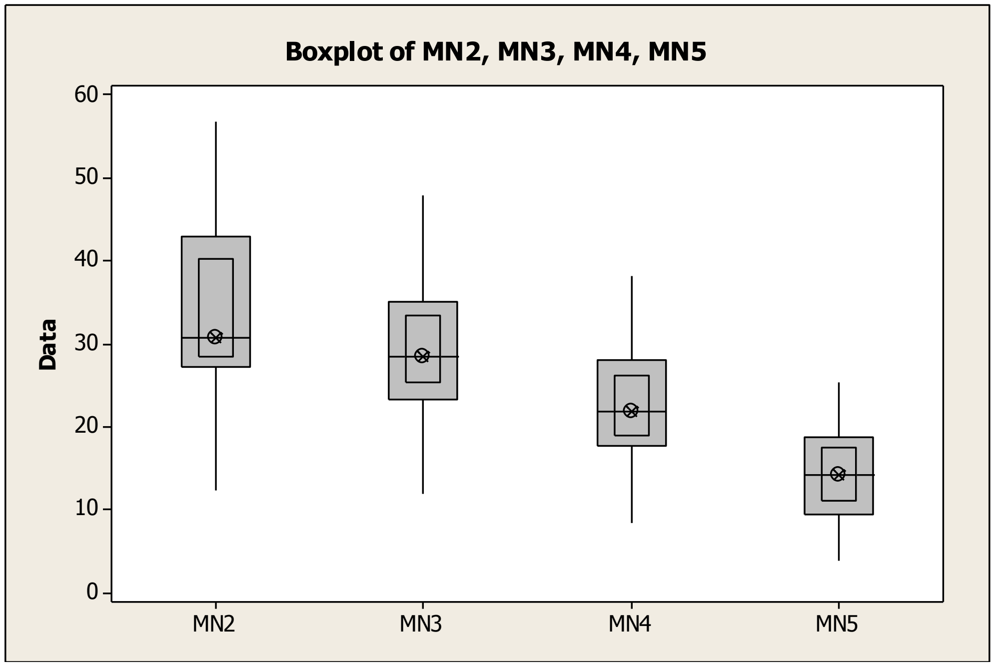


Figure H.15: *The boxplot of the males' fingers, in neutral wrist position.*

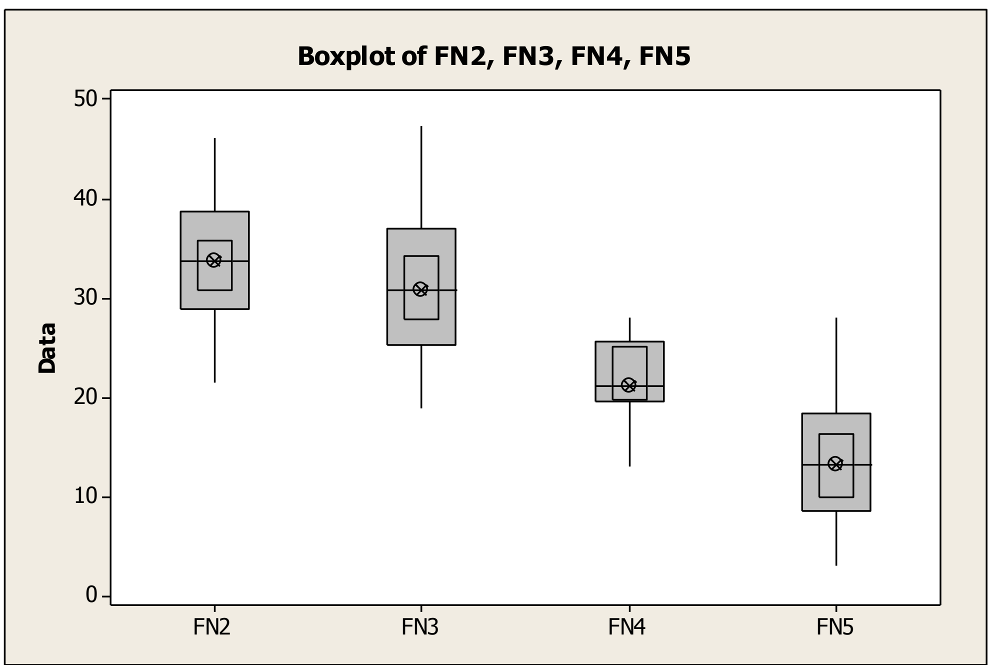


Figure H.16: *The boxplot of the females' fingers, in neutral wrist position.*

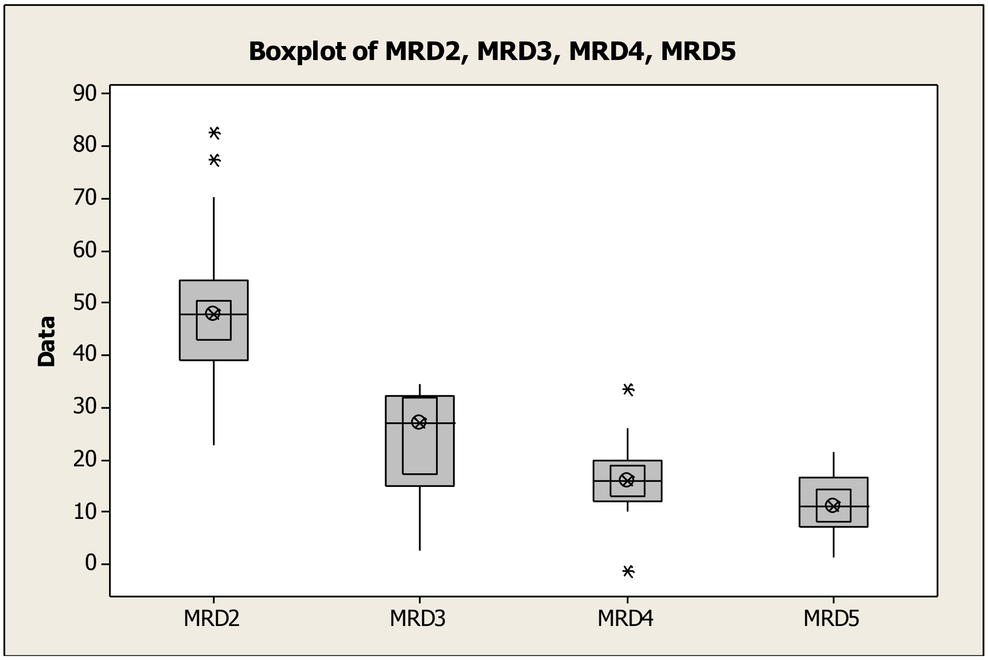


Figure H.17: *The boxplot of the males' fingers, in radial deviation of the wrist.*

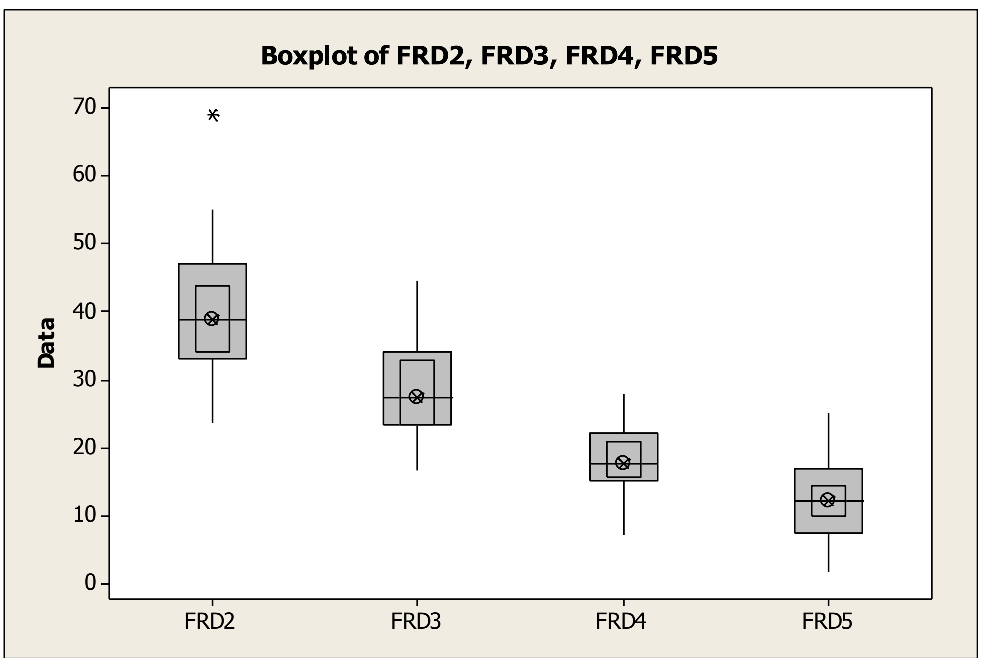


Figure H.18: *The boxplot of the females' fingers, in radial deviation of the wrist.*

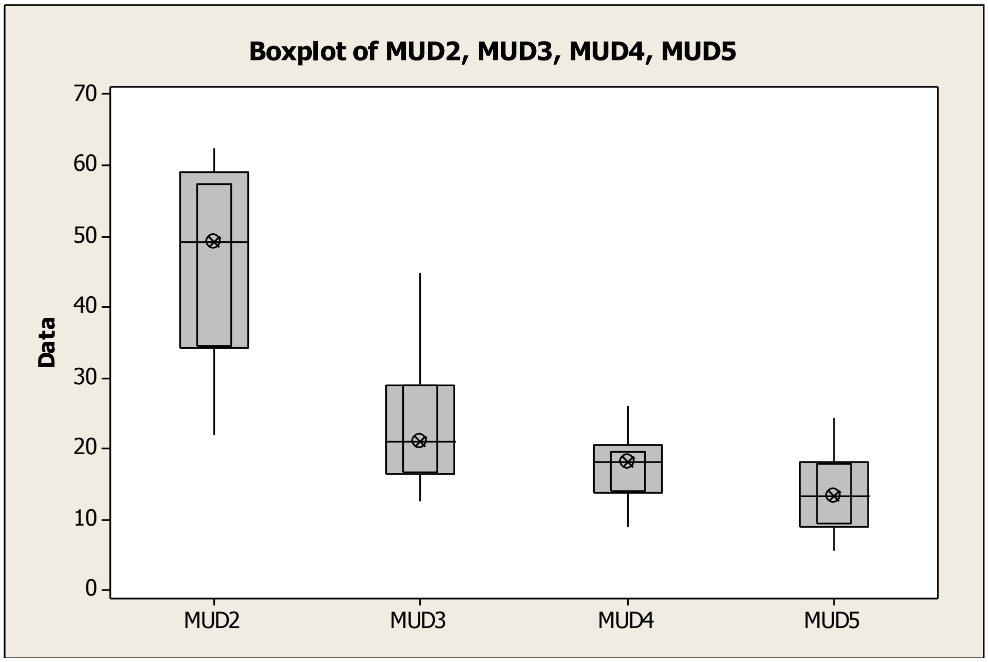


Figure H.19: *The boxplot of the males' fingers, in ulnar deviation of the wrist.*

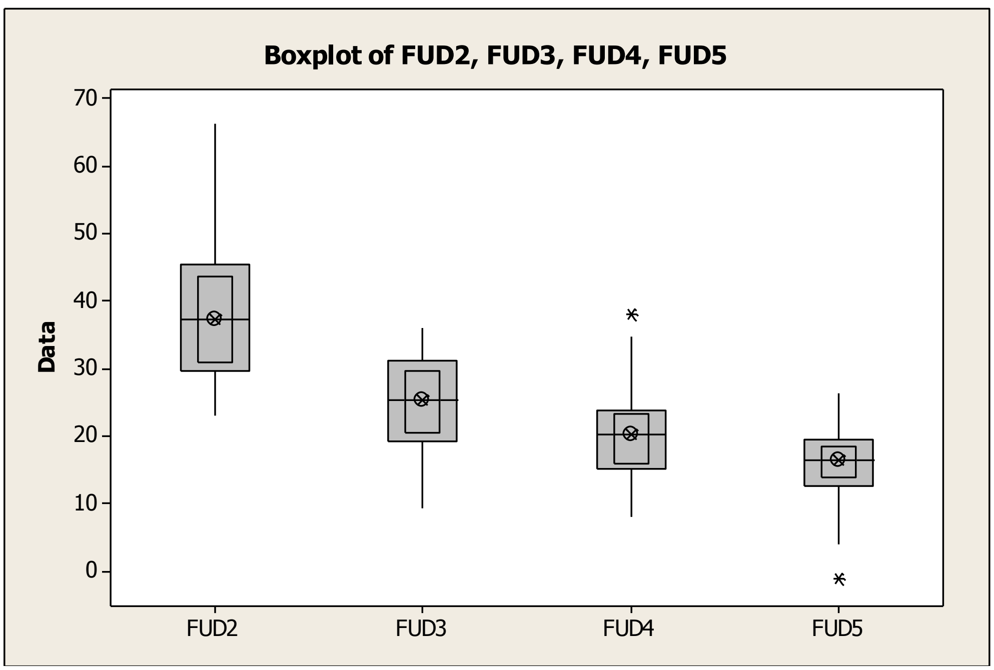


Figure H.20: *The boxplot of the females' fingers, in ulnar deviation of the wrist.*

H3: Statistical examination of any differences between the genders

In five (MF2, MF3, MF4, FF2 and MRD3) out of the twenty cases there was an indication of non-normal distribution of the values. Additionally, boxplots showed outliers in some data sets, and in some cases extremes. The deduction of the outliers and extremes did not solve the problem with the probability of these data sets and therefore, a non-parametric statistical tool was chosen to test if there are any differences in the percentage distribution of the FzT across the fingers between the genders. The null hypothesis for the Mann-Whitney test was: Ho= no difference. The non-parametric tests results follow.

Mann-Whitney Test and CI: MF2, FF2

	N	Median
MF2	22	31.53
FF2	23	33.67

Point estimate for ETA1-ETA2 is -1.98
95.0 Percent CI for ETA1-ETA2 is (-6.54,3.16)
W = 474.0
Test of ETA1 = ETA2 vs ETA1 not = ETA2 **is significant at 0.4745**

Mann-Whitney Test and CI: MF3, FF3

	N	Median
MF3	22	33.230
FF3	23	27.190

Point estimate for ETA1-ETA2 is 3.343
95.0 Percent CI for ETA1-ETA2 is (-2.091,7.530)
W = 564.0
Test of ETA1 = ETA2 vs ETA1 not = ETA2 **is significant at 0.1917**

Mann-Whitney Test and CI: MF4, FF4

	N	Median
MF4	22	21.008
FF4	23	19.520

Point estimate for ETA1-ETA2 is 2.023
95.0 Percent CI for ETA1-ETA2 is (-1.250,5.297)
W = 558.0
Test of ETA1 = ETA2 vs ETA1 not = ETA2 **is significant at 0.2**

Mann-Whitney Test and CI: MF5, FF5

	N	Median
MF5	22	13.097
FF5	23	18.658

Point estimate for ETA1-ETA2 is -2.911
95.0 Percent CI for ETA1-ETA2 is (-7.674,1.065)
W = 438.0
Test of ETA1 = ETA2 vs ETA1 not = ETA2 **is significant at 0.1254**

Mann-Whitney Test and CI: ME2, FE2

	N	Median
ME2	25	32.804
FE2	24	33.649

Point estimate for ETA1-ETA2 is 0.082
95.1 Percent CI for ETA1-ETA2 is (-4.947,5.524)
W = 629.0
Test of ETA1 = ETA2 vs ETA1 not = ETA2 **is significant at 0.9442**

Mann-Whitney Test and CI: ME3, FE3

	N	Median
ME3	25	27.956
FE3	24	26.691

Point estimate for ETA1-ETA2 is 1.772
95.1 Percent CI for ETA1-ETA2 is (-2.708,5.937)
W = 663.0
Test of ETA1 = ETA2 vs ETA1 not = ETA2 **is significant at 0.4533**

Mann-Whitney Test and CI: ME4, FE4

	N	Median
ME4	25	21.538
FE4	24	23.954

Point estimate for ETA1-ETA2 is -1.970
95.1 Percent CI for ETA1-ETA2 is (-4.988,1.306)
W = 569.0
Test of ETA1 = ETA2 vs ETA1 not = ETA2 **is significant at 0.2670**

Mann-Whitney Test and CI: ME5, FE5

	N	Median
ME5	25	15.325
FE5	24	16.048

Point estimate for ETA1-ETA2 is -0.931
95.1 Percent CI for ETA1-ETA2 is (-3.438,2.346)
W = 595.0
Test of ETA1 = ETA2 vs ETA1 not = ETA2 **is significant at 0.5552**

Mann-Whitney Test and CI: MN2, FN2

	N	Median
MN2	25	30.761
FN2	25	33.696

Point estimate for ETA1-ETA2 is -0.308
95.2 Percent CI for ETA1-ETA2 is (-4.966,4.790)
W = 629.0
Test of ETA1 = ETA2 vs ETA1 not = ETA2 **is significant at 0.8766**

Mann-Whitney Test and CI: MN3, FN3

	N	Median
MN3	25	28.537
FN3	25	30.843

Point estimate for ETA1-ETA2 is -2.022
95.2 Percent CI for ETA1-ETA2 is (-6.057,2.756)
W = 602.0
Test of ETA1 = ETA2 vs ETA1 not = ETA2 **is significant at 0.4971**

Mann-Whitney Test and CI: MN4, FN4

	N	Median
MN4	25	21.867
FN4	25	21.186

Point estimate for ETA1-ETA2 is 0.418
95.2 Percent CI for ETA1-ETA2 is (-3.531,3.191)
W = 657.0
Test of ETA1 = ETA2 vs ETA1 not = ETA2 **is significant at 0.7124**

Mann-Whitney Test and CI: MN5, FN5

	N	Median
MN5	25	14.109
FN5	25	13.199

Point estimate for ETA1-ETA2 is 0.770
95.2 Percent CI for ETA1-ETA2 is (-2.855,4.427)
W = 659.0
Test of ETA1 = ETA2 vs ETA1 not = ETA2 **is significant at 0.6837**

Mann-Whitney Test and CI: MRD2, FRD2

	N	Median
MRD2	23	47.92
FRD2	20	38.84

Point estimate for ETA1-ETA2 is 7.49
95.0 Percent CI for ETA1-ETA2 is (0.19,14.16)
W = 590.0
Test of ETA1 = ETA2 vs ETA1 not = ETA2 **is significant at 0.042**

Mann-Whitney Test and CI: MRD3, FRD3

	N	Median
MRD3	23	27.088
FRD3	20	27.553

Point estimate for ETA1-ETA2 is -3.615
95.0 Percent CI for ETA1-ETA2 is (-10.065,2.641)
W = 457.0
Test of ETA1 = ETA2 vs ETA1 not = ETA2 **is significant at 0.2376**

Mann-Whitney Test and CI: MRD4, FRD4

	N	Median
MRD4	23	16.152
FRD4	20	17.828

Point estimate for ETA1-ETA2 is -2.334
95.0 Percent CI for ETA1-ETA2 is (-5.478,1.084)
W = 441.0
Test of ETA1 = ETA2 vs ETA1 not = ETA2 **is significant at 0.1163**

Mann-Whitney Test and CI: MRD5, FRD5

	N	Median
MRD5	23	11.108
FRD5	20	12.366

Point estimate for ETA1-ETA2 is -1.066
95.0 Percent CI for ETA1-ETA2 is (-4.654,2.529)
W = 476.0
Test of ETA1 = ETA2 vs ETA1 not = ETA2 **is significant at 0.4726**

Mann-Whitney Test and CI: MUD2, FUD2

	N	Median
MUD2	16	49.31
FUD2	21	37.31

Point estimate for ETA1-ETA2 is 7.70
95.2 Percent CI for ETA1-ETA2 is (-3.20,17.28)
W = 349.0
Test of ETA1 = ETA2 vs ETA1 not = ETA2 **is significant at 0.1725**

Mann-Whitney Test and CI: MUD3, FUD3

	N	Median
MUD3	16	21.11
FUD3	21	25.25

Point estimate for ETA1-ETA2 is -2.65
95.2 Percent CI for ETA1-ETA2 is (-7.16,3.40)
W = 272.0
Test of ETA1 = ETA2 vs ETA1 not = ETA2 **is significant at 0.3342**

Mann-Whitney Test and CI: MUD4, FUD4

	N	Median
MUD4	16	18.034
FUD4	21	20.230

Point estimate for ETA1-ETA2 is -2.903
95.2 Percent CI for ETA1-ETA2 is (-6.458,1.214)
W = 258.0
Test of ETA1 = ETA2 vs ETA1 not = ETA2 **is significant at 0.1630**

Mann-Whitney Test and CI: MUD5, FUD5

	N	Median
MUD5	16	13.436
FUD5	21	16.592

Point estimate for ETA1-ETA2 is -1.912
95.2 Percent CI for ETA1-ETA2 is (-6.461,1.657)
W = 269.0
Test of ETA1 = ETA2 vs ETA1 not = ETA2 **is significant at 0.2902**

In only one case (MRD2-FRD2) the Mann-Whitney test showed statistical difference between the genders as regards the percentage distribution of the ΣFzT across the fingers. Therefore, the null hypothesis was accepted, which estimates that the trend is that there is no statistical difference between the genders. Thus, the datasets of both male and female subjects were accumulated, and after the deduction of the extremes (of the Fz) were as follows.

H4: The final sample size after the deduction of the extreme values

	Wrist Position				
Cases	**Flexion**	**Extension**	**Radial**	**Ulnar**	**Neutral**
N	41	43	41	29	46

H5: The F_zT, for each finger, in every wrist orientation

The accumulated data sets of the F_zT, for every finger in each wrist orientation follow.

		Flexion		
No	Index (N)	Middle (N)	Ring (N)	Little (N)
1	-14.7	-16.0	-9.2	-5.3
2	-13.4	-15.5	-10.4	-4.7
3	-21.9	-26.9	-21.0	-7.6
4	-19.6	-15.0	-11.3	-12.3
5	-16.7	-8.2	-8.0	-11.4
6	-12.1	-22.5	-9.7	-11.1
7	-11.2	-20.1	-10.2	-7.8
8	-19.3	-25.0	-19.8	-13.7
9	-16.2	-14.3	-7.2	-2.9
10	-10.6	-7.6	-4.4	-3.4
11	-11.7	-25.8	-20.8	-19.3
12	-19.3	-20.6	-15.8	-5.9
13	-19.5	-19.2	-11.7	-7.5
14	-13.0	-12.6	-9.2	-11.9
15	-11.3	-10.3	-9.3	-8.7
16	-30.4	-16.5	-19.0	-18.0
17	-19.0	-17.4	-11.9	-14.5
18	-10.2	-15.7	-8.8	-6.8
19	-23.8	-9.0	-13.6	-4.2
20	-9.7	-12.7	-11.7	-7.9
21	-21.3	-31.9	-21.1	-7.8
22	-16.3	-11.4	-6.5	-5.2
23	-33.2	-5.7	-7.2	-4.3
24	-18.6	-11.3	-8.7	-11.6
25	-13.7	-8.0	-9.3	-7.1
26	-12.9	-14.4	-4.0	-4.0
27	-18.7	-11.6	-8.4	-4.3
28	-17.1	-12.9	-7.4	-10.0
29	-14.9	-14.7	-13.6	-5.4
30	-11.5	-22.8	-10.9	-8.2
31	-9.1	-11.5	-8.5	-4.1
32	-13.3	-9.8	-7.0	-9.1
33	-11.6	-11.0	-4.2	-3.0
34	-12.2	-1.6	-0.7	0.2
35	-24.3	-26.7	-11.6	-9.5
36	-10.9	-11.4	-9.8	-12.3
37	-25.0	-26.6	-18.2	-13.8
38	-12.7	-17.6	-11.8	-5.6

39	-12.3	-12.3	-5.3	-7.9
40	-11.8	-12.7	-8.1	-7.6
41	-21.3	-19.7	-10.5	-12.4

		Extension		
No	Index (N)	Middle (N)	Ring (N)	Little (N)
1	-23.8	-17.4	-6.1	-4.6
2	-16.4	-15.5	-11.6	-6.5
3	-25.4	-10.6	-12.2	-13.1
4	-22.5	-12.3	-11.3	-8.6
5	-15.3	-18.8	-17.9	-11.2
6	-23.3	-16.5	-13.3	-14.2
7	-13.0	-27.6	-23.8	-12.0
8	-25.9	-24.5	-18.3	-6.0
9	-19.5	-22.3	-13.7	-9.4
10	-20.7	-14.7	-14.4	-9.7
11	-39.0	-24.2	-22.3	-19.2
12	-42.0	-5.5	-10.9	-6.1
13	-18.2	-19.2	-11.6	-7.0
14	-28.5	-39.8	-28.3	-18.8
15	-22.5	-5.3	-7.9	-6.7
16	-20.2	-25.7	-19.5	-11.9
17	-23.5	-37.2	-23.2	-9.7
18	-18.7	-12.3	-14.8	-11.4
19	-20.9	-8.5	-12.5	-6.9
20	-16.9	-14.2	-15.6	-7.4
21	-31.5	-35.0	-26.1	-18.7
22	-23.6	-16.3	-9.3	-4.0
23	-21.4	-12.0	-10.2	-3.7
24	-14.3	-16.8	-12.5	-9.0
25	-14.2	-6.5	-12.5	-7.9
26	-18.5	-15.6	-15.1	-10.2
27	-15.5	-14.7	-4.9	-2.2
28	-17.9	-9.4	-6.2	-3.9
29	-13.7	-13.1	-8.8	-11.4
30	-29.3	-13.2	-15.9	-11.8
31	-19.2	-16.7	-18.2	-10.6
32	-16.7	-14.8	-14.1	-6.7
33	-12.0	-8.0	-7.0	-4.5
34	-23.3	-14.9	-13.6	-15.2
35	-11.3	-8.9	-5.0	-6.0
36	-11.1	-6.8	-4.0	-2.1

37	-34.8	-19.8	-19.3	-18.4
38	-9.2	-8.1	-14.5	-8.5
39	-15.4	-13.3	-12.4	-11.8
40	-15.7	-12.2	-10.1	-7.1
41	-20.2	-15.4	-20.9	0.0
42	-13.5	-13.7	-14.2	-7.5
43	-33.5	-34.7	-21.7	-17.4

		Neutral		
No	Index (N)	Middle (N)	Ring (N)	Little (N)
1	-21.7	-14.4	-7.2	-7.1
2	-18.8	-29.1	-21.5	-9.6
3	-31.9	-23.9	-18.5	-17.8
4	-22.5	-15.8	-13.9	-11.7
5	-18.9	-15.0	-18.2	-20.4
6	-22.7	-17.3	-16.9	-19.3
7	-14.4	-19.9	-18.2	-14.5
8	-19.9	-24.8	-14.1	-6.2
9	-22.9	-26.8	-16.5	-8.3
10	-26.9	-11.4	-16.8	-5.0
11	-33.7	-31.1	-21.5	-12.0
12	-44.9	-19.1	-7.7	-20.3
13	-21.8	-24.0	-18.6	-11.3
14	-40.7	-48.5	-30.7	-19.8
15	-14.1	-10.6	-8.2	-8.6
16	-27.6	-33.1	-28.4	-9.4
17	-40.4	-22.2	-17.3	-13.1
18	-28.1	-18.6	-11.6	-2.8
19	-30.0	-24.7	-22.7	-11.6
20	-22.8	-19.8	-21.6	-14.6
21	-28.3	-26.6	-22.4	-8.4
22	-17.5	-14.9	-19.2	-14.8
23	-39.0	-40.9	-25.3	-22.7
24	-44.3	-17.1	-11.9	-4.7
25	-40.0	-22.3	-19.3	-6.3
26	-22.0	-13.9	-7.1	-11.2
27	-23.0	-12.7	-13.1	-16.3
28	-16.5	-26.5	-13.9	-9.6
29	-19.0	-18.5	-15.5	-7.1
30	-20.8	-31.6	-11.1	-3.3
31	-24.2	-20.8	-11.9	-3.7
32	-17.9	-27.1	-14.7	-9.7

33	-38.4	-24.5	-15.8	-7.6
34	-17.9	-17.0	-10.6	-4.4
35	-23.7	-19.5	-8.5	-6.3
36	-10.5	-14.8	-12.2	-3.1
37	-24.6	-20.8	-16.0	-12.3
38	-15.3	-21.4	-11.6	-7.5
39	-13.7	-15.7	-7.7	-2.4
40	-48.3	-31.5	-14.8	-18.7
41	-34.1	-30.4	-11.1	-2.5
42	-41.3	-36.9	-19.5	-15.6
43	-20.9	-24.1	-14.1	-9.0
44	-15.6	-11.6	-5.3	-7.8
45	-22.5	-13.5	-15.4	-6.8
46	-25.5	-7.9	-25.4	-7.6

		Radial Deviation		
No	Index (N)	Middle (N)	Ring (N)	Little (N)
1	-19.4	-21.0	-12.1	-8.3
2	-26.4	-16.1	-10.9	-4.0
3	-21.0	-10.4	-10.9	-6.1
4	-23.2	-8.9	-9.3	-11.8
5	-26.1	-23.3	-10.7	-7.5
6	-29.7	-18.3	-14.5	-7.5
7	-17.0	-16.2	-13.2	-4.2
8	-25.5	-11.3	-9.6	-6.4
9	-27.7	-25.9	-15.9	-9.4
10	-41.0	-14.5	-10.5	-16.0
11	-45.7	-11.2	-12.0	-5.2
12	-45.5	-3.5	-7.9	-7.8
13	-23.2	-11.9	-6.0	-2.3
14	-31.7	-21.1	-10.1	-2.8
15	-19.2	-9.9	-5.2	-3.6
16	-48.1	-7.8	0.7	-6.8
17	-43.4	-13.7	-8.1	-14.1
18	-19.7	-17.9	-18.0	-8.9
19	-19.4	-13.1	-11.7	-11.8
20	-29.3	-7.3	-11.2	-13.0
21	-18.2	-15.6	-9.9	-5.5
22	-29.1	-19.2	-12.0	-3.7
23	-30.5	-23.8	-9.3	-5.5
24	-34.6	-1.2	-5.5	-0.6
25	-14.8	-16.2	-7.3	-6.6

26	-19.4	-17.2	-8.8	-5.7
27	-32.0	-8.6	-3.3	-2.5
28	-23.7	-11.7	-6.8	-0.8
29	-21.9	-13.0	-12.5	-7.0
30	-11.2	-17.1	-7.2	-11.9
31	-13.4	-2.8	-5.0	-5.2
32	-35.5	-22.8	-8.4	-7.4
33	-23.1	-16.4	-12.5	-7.2
34	-11.9	-10.2	-6.6	-6.1
35	-8.7	-13.8	-6.4	-2.0
36	-34.4	-30.4	-13.2	-9.8
37	-11.0	-13.0	-10.4	-7.7
38	-34.0	-26.4	-12.9	-4.7
39	-14.6	-11.9	-4.4	-2.3
40	-30.9	-10.7	-7.0	-8.4
41	-36.8	-16.7	-8.4	-12.8

		Ulnar Deviation		
No	Index (N)	Middle (N)	Ring (N)	Little (N)
1	-24.6	-11.5	-3.9	-3.8
2	-17.4	-12.4	-9.3	-9.6
3	-28.2	-11.6	-8.0	-10.5
4	-18.7	-12.8	-22.6	-10.8
5	-25.5	-17.5	-13.5	-11.8
6	-21.6	-18.4	-15.2	-8.2
7	-27.7	-16.1	-7.7	-12.3
8	-36.0	-10.5	-9.9	-3.4
9	-22.3	-11.5	-14.0	-12.7
10	-42.1	-13.0	-13.5	-15.1
11	-30.6	-25.2	-17.0	-7.7
12	-32.3	-8.2	-4.0	-4.2
13	-13.1	-16.6	-9.9	-6.5
14	-30.7	-6.5	-23.8	-8.4
15	-24.9	-20.7	-12.6	-13.5
16	-27.5	-28.1	-15.6	-13.0
17	-34.9	-7.0	-8.0	-5.9
18	-14.5	-18.6	-13.7	-10.4
19	-15.6	-13.4	-11.4	-9.8
20	-20.0	-5.9	-8.4	-8.6
21	-19.5	-8.9	-5.6	-7.2
22	-18.4	-16.7	-11.0	-8.3
23	-29.9	-10.1	-13.1	-2.2

24	-13.7	-7.1	-4.5	-9.1
25	-14.4	-10.0	-5.1	-4.9
26	-13.8	-19.6	-14.1	-10.6
27	-23.6	-13.5	-13.1	-9.0
28	-13.9	-15.6	-6.9	-8.8
29	-33.9	-11.2	-9.0	-11.8

H6: The percentage distribution of the $\Sigma F_z T$ on the fingers

The percentage distribution of the $\Sigma F_z T$ on the fingers for every wrist orientation follows.

		Flexion		
No	Index (%)	Middle (%)	Ring (%)	Little (%)
1	32.5	35.5	20.3	11.8
2	30.5	35.1	23.6	10.7
3	28.3	34.7	27.1	9.9
4	33.7	25.8	19.4	21.1
5	37.6	18.5	18.2	25.7
6	21.9	40.6	17.5	20.1
7	22.7	40.7	20.7	15.9
8	24.8	32.1	25.5	17.6
9	39.8	35.2	17.8	7.2
10	40.8	29.4	16.8	13.0
11	15.0	33.3	26.8	24.9
12	31.3	33.5	25.6	9.6
13	33.6	33.2	20.2	13.0
14	27.8	27.0	19.8	25.5
15	28.6	26.0	23.4	22.0
16	36.2	19.7	22.6	21.5
17	30.2	27.7	18.9	23.1
18	24.6	37.8	21.2	16.5
19	47.1	17.7	26.8	8.3
20	23.0	30.2	27.9	18.9
21	25.9	38.9	25.7	9.5
22	41.3	28.9	16.6	13.3
23	65.8	11.3	14.2	8.6
24	37.1	22.6	17.3	23.0
25	36.0	21.0	24.3	18.7
26	36.5	40.7	11.4	11.4
27	43.4	27.0	19.5	10.1
28	36.2	27.2	15.6	21.1
29	30.6	30.3	28.0	11.1

30	21.5	42.7	20.5	15.3
31	27.3	34.6	25.6	12.5
32	33.9	24.9	17.9	23.3
33	38.8	36.9	14.2	10.1
34	84.9	11.4	4.9	-1.2
35	33.7	37.0	16.1	13.2
36	24.5	25.8	22.0	27.8
37	29.9	31.8	21.8	16.5
38	26.7	36.9	24.8	11.6
39	32.5	32.6	14.1	20.9
40	29.3	31.5	20.2	19.0
41	33.4	30.9	16.4	19.4

		Extension		
No	Index (%)	Middle (%)	Ring (%)	Little (%)
1	45.8	33.5	11.8	8.9
2	32.8	31.0	23.2	13.0
3	41.5	17.2	19.9	21.4
4	41.2	22.4	20.7	15.7
5	24.3	29.7	28.3	17.8
6	34.6	24.5	19.8	21.1
7	17.0	36.2	31.1	15.7
8	34.7	32.8	24.5	8.0
9	30.0	34.3	21.1	14.5
10	34.8	24.7	24.2	16.3
11	37.3	23.2	21.3	18.3
12	65.1	8.5	16.9	9.4
13	32.4	34.3	20.7	12.5
14	24.7	34.5	24.6	16.3
15	53.1	12.6	18.7	15.7
16	26.2	33.2	25.2	15.4
17	25.1	39.8	24.8	10.3
18	32.7	21.4	25.9	19.9
19	42.8	17.4	25.7	14.1
20	31.3	26.2	28.8	13.7
21	28.3	31.5	23.5	16.8
22	44.3	30.6	17.5	7.6
23	45.3	25.4	21.5	7.8
24	27.2	32.0	23.7	17.1
25	34.6	15.7	30.4	19.3
26	31.1	26.3	25.4	17.1
27	41.7	39.4	13.2	5.8

28	47.8	25.2	16.6	10.5
29	29.2	27.8	18.7	24.3
30	41.7	18.8	22.7	16.8
31	29.7	25.9	28.2	16.3
32	31.9	28.3	26.9	12.9
33	38.1	25.3	22.3	14.3
34	34.7	22.3	20.2	22.8
35	36.2	28.5	16.1	19.2
36	46.4	28.2	16.8	8.6
37	37.7	21.5	20.9	19.9
38	22.8	20.1	36.1	21.1
39	29.1	25.1	23.4	22.3
40	34.8	27.0	22.4	15.8
41	35.7	27.2	37.1	0.0
42	27.6	28.0	29.1	15.3
43	31.2	32.3	20.2	16.2

		Neutral		
No	Index (%)	Middle (%)	Ring (%)	Little (%)
1	43.1	28.5	14.2	14.1
2	23.7	36.8	27.2	12.2
3	34.6	26.0	20.1	19.3
4	35.2	24.7	21.8	18.3
5	26.0	20.7	25.2	28.1
6	29.8	22.7	22.2	25.3
7	21.6	29.7	27.1	21.6
8	30.7	38.1	21.6	9.6
9	30.8	35.9	22.2	11.1
10	44.8	19.0	28.0	8.3
11	34.3	31.6	21.9	12.2
12	48.8	20.8	8.3	22.1
13	28.9	31.7	24.6	14.9
14	29.1	34.7	22.0	14.2
15	34.0	25.4	19.7	20.8
16	28.1	33.6	28.8	9.5
17	43.4	23.8	18.6	14.1
18	46.0	30.5	19.0	4.5
19	33.7	27.8	25.5	13.0
20	28.9	25.2	27.4	18.5
21	33.0	31.0	26.2	9.8
22	26.4	22.5	28.9	22.3
23	30.5	32.0	19.8	17.8

24	56.8	21.9	15.3	6.0
25	45.5	25.4	22.0	7.1
26	40.6	25.6	13.1	20.7
27	35.4	19.6	20.1	25.0
28	24.8	39.8	20.9	14.5
29	31.6	30.8	25.7	11.9
30	31.1	47.3	16.6	5.0
31	40.0	34.3	19.6	6.0
32	25.7	39.0	21.2	14.0
33	44.4	28.4	18.3	8.8
34	35.9	34.0	21.2	8.9
35	40.8	33.6	14.6	10.9
36	26.0	36.5	30.0	7.5
37	33.4	28.3	21.7	16.6
38	27.4	38.4	20.8	13.4
39	34.7	39.7	19.5	6.1
40	42.6	27.8	13.1	16.5
41	43.7	39.0	14.2	3.1
42	36.4	32.6	17.2	13.8
43	30.7	35.4	20.7	13.2
44	38.8	28.8	13.1	19.3
45	38.6	23.1	26.5	11.7
46	38.4	11.9	38.2	11.5

		Radial Deviation		
No	Index (%)	Middle (%)	Ring (%)	Little (%)
1	31.9	34.5	19.9	13.6
2	46.0	28.1	19.0	6.9
3	43.4	21.6	22.5	12.5
4	43.7	16.8	17.4	22.1
5	38.6	34.4	15.8	11.1
6	42.4	26.1	20.8	10.7
7	33.6	32.1	26.0	8.3
8	48.2	21.4	18.2	12.2
9	35.1	32.8	20.1	12.0
10	50.0	17.7	12.8	19.5
11	61.7	15.1	16.2	7.1
12	70.3	5.4	12.2	12.1
13	53.5	27.4	13.7	5.3
14	48.3	32.1	15.4	4.2
15	50.8	26.0	13.6	9.6
16	77.5	12.6	-1.1	11.0
17	54.8	17.2	10.2	17.8
18	30.5	27.8	27.9	13.9

19	34.6	23.4	20.9	21.1
20	48.2	11.9	18.4	21.4
21	36.9	31.8	20.0	11.2
22	45.5	30.0	18.8	5.7
23	44.2	34.4	13.5	7.9
24	82.6	2.8	13.1	1.5
25	32.9	36.1	16.2	14.8
26	37.9	33.7	17.3	11.2
27	68.9	18.6	7.2	5.3
28	55.1	27.2	15.9	1.9
29	40.2	23.9	23.0	12.9
30	23.6	36.1	15.1	25.2
31	50.7	10.7	18.9	19.7
32	47.9	30.8	11.3	10.0
33	39.0	27.7	21.1	12.2
34	34.1	29.4	18.9	17.7
35	28.1	44.7	20.8	6.4
36	39.2	34.6	15.1	11.1
37	26.1	30.9	24.7	18.3
38	43.5	33.8	16.5	6.1
39	44.0	35.9	13.3	6.8
40	54.3	18.8	12.2	14.7
41	49.3	22.4	11.3	17.1

		Ulnar Deviation		
No	Index (%)	Middle (%)	Ring (%)	Little (%)
1	56.1	26.3	9.0	8.7
2	35.7	25.5	19.1	19.7
3	48.3	19.9	13.8	17.9
4	28.9	19.7	34.8	16.6
5	37.3	25.6	19.8	17.3
6	34.1	29.1	24.0	12.8
7	43.4	25.2	12.1	19.3
8	60.2	17.5	16.6	5.7
9	36.8	19.0	23.1	21.0
10	50.3	15.6	16.1	18.1
11	38.0	31.3	21.1	9.6
12	66.3	16.9	8.2	8.6
13	28.4	35.9	21.5	14.2
14	44.3	9.3	34.3	12.1
15	34.7	28.8	17.6	18.9
16	32.7	33.4	18.5	15.4

17	62.5	12.6	14.3	10.6
18	25.4	32.5	23.9	18.2
19	31.1	26.6	22.8	19.5
20	46.6	13.8	19.7	20.0
21	47.4	21.5	13.7	17.4
22	33.8	30.7	20.2	15.2
23	54.0	18.3	23.6	4.0
24	39.9	20.8	13.1	26.3
25	41.8	29.1	15.0	14.1
26	23.7	33.7	24.3	18.3
27	39.8	22.9	22.1	15.1
28	30.7	34.4	15.3	19.5
29	51.5	16.9	13.7	17.9

The above percentage distributions of the ΣFzT across the fingers were used for the final results presented in chapter four.

APPENDIX (I): **Kinetics: Fingers Statistics**

I1: The sample size

A. The sample size of the accumulated percentage distribution of the ΣFzT across the fingers presented on the Appendix H (H.4) demonstrates different sample size for each finger in the different wrist position. But in order to perform statistical tests for dependent variables (every finger in the different wrist orientations) the sample sizes must be the same. Therefore, only the data from the subjects provided validate processed results for all the wrist orientations were chosen for these statistical tests, which is shown in the following tables.

		Flexion		
No	Index (N)	Middle (N)	Ring (N)	Little (N)
1	-13.4	-15.8	-10.4	-4.7
2	-21.9	-26.9	-21.0	-7.6
3	-12.1	-22.5	-9.7	-11.1
4	-19.3	-25.0	-19.8	-13.7
5	-11.7	-25.8	-20.8	-19.3
6	-19.3	-20.6	-15.8	-5.9
7	-19.5	-19.2	-11.7	-7.5
8	-40.6	-25.9	-19.1	-22.6
9	-9.7	-12.7	-11.7	-7.9
10	-21.3	-31.9	-21.1	-7.8
11	-33.2	-5.7	-7.2	-4.3
12	-21.3	-19.7	-10.5	-12.4
13	-19.6	-15.0	-11.3	-12.3
14	-16.7	-8.2	-8.0	-11.4
15	-11.2	-20.1	-10.2	-7.8
16	-10.6	-7.6	-4.4	-3.4
17	-13.0	-12.6	-9.2	-11.9
18	-19.0	-17.4	-11.9	-14.5
19	-10.2	-15.7	-8.8	-6.8
20	-23.8	-9.0	-13.6	-4.2
21	-18.6	-11.3	-8.7	-11.6
22	-12.9	-14.4	-4.0	-4.0
23	-18.7	-11.6	-8.4	-4.3
24	-14.9	-14.7	-13.6	-5.4
25	-11.5	-22.8	-10.9	-8.2

26	-11.6	-11.0	-4.2	-3.0
27	-12.2	-1.6	-0.7	0.2
28	-10.9	-11.4	-9.8	-12.3
29	-12.3	-12.3	-5.3	-7.9

		Extension		
No	Index (N)	Middle (N)	Ring (N)	Little (N)
1	-16.4	-15.5	-11.6	-6.5
2	-25.4	-10.6	-12.2	-13.1
3	-23.3	-16.5	-13.3	-14.2
4	-25.9	-24.5	-18.3	-6.0
5	-31.8	-49.9	-28.7	-12.9
6	-39.0	-24.2	-22.3	-19.2
7	-42.0	-5.5	-10.9	-6.1
8	-28.5	-39.8	-28.3	-18.8
9	-16.9	-14.2	-15.6	-7.4
10	-31.5	-35.0	-26.1	-18.7
11	-21.4	-12.0	-10.2	-3.7
12	-13.5	-13.7	-14.2	-7.5
13	-22.5	-12.3	-11.3	-8.6
14	-15.3	-18.8	-17.9	-11.2
15	-13.0	-27.6	-23.8	-12.0
16	-20.7	-14.7	-14.4	-9.7
17	-18.2	-19.2	-11.6	-7.0
18	-23.5	-37.2	-23.2	-9.7
19	-18.7	-12.3	-14.8	-11.4
20	-20.9	-8.5	-12.5	-6.9
21	-14.3	-16.8	-12.5	-9.0
22	-15.5	-14.7	-4.9	-2.2
23	-17.9	-9.4	-6.2	-3.9
24	-19.2	-16.7	-18.2	-10.6
25	-16.7	-14.8	-14.1	-6.7
26	-11.3	-8.9	-5.0	-6.0
27	-11.1	-6.8	-4.0	-2.1
28	-9.2	-8.1	-14.5	-8.5
29	-15.7	-12.2	-10.1	-7.1

		Neutral		
No	Index (N)	Middle (N)	Ring (N)	Little (N)
1	-18.8	-29.1	-21.5	-9.6

2	-31.9	-23.9	-18.5	-17.8
3	-22.7	-17.3	-16.9	-19.3
4	-19.9	-24.8	-14.1	-6.2
5	-31.3	-52.8	-22.0	-4.2
6	-33.7	-31.1	-21.5	-12.0
7	-40.7	-48.5	-30.7	-19.8
8	-17.5	-14.9	-19.2	-14.8
9	-39.0	-40.9	-25.3	-22.7
10	-22.0	-13.9	-7.1	-11.2
11	-25.5	-7.9	-25.4	-7.6
12	-22.5	-15.8	-13.9	-11.7
13	-18.9	-15.0	-18.2	-20.4
14	-14.4	-19.9	-18.2	-14.5
15	-26.9	-11.4	-16.8	-5.0
16	-21.8	-24.0	-18.6	-11.3
17	-28.1	-18.6	-11.6	-2.8
18	-30.0	-24.7	-22.7	-11.6
19	-22.8	-19.8	-21.6	-14.6
20	-28.3	-26.6	-22.4	-8.4
21	-23.0	-12.7	-13.1	-16.3
22	-20.8	-31.6	-11.1	-3.3
23	-24.2	-20.8	-11.9	-3.7
24	-17.9	-17.0	-10.6	-4.4
25	-23.7	-19.5	-8.5	-6.3
26	-15.3	-21.4	-11.6	-7.5
27	-13.7	-15.7	-7.7	-2.4
28	-34.1	-30.4	-11.1	-2.5
29	-15.6	-11.6	-5.3	-7.8

		Radial Deviation		
No	Index (N)	Middle (N)	Ring (N)	Little (N)
1	-19.4	-21.0	-12.1	-8.3
2	-26.4	-16.1	-10.9	-4.0
3	-16.7	-19.9	-24.6	-12.2
4	-29.7	-18.3	-14.5	-7.5
5	-27.7	-25.9	-15.9	-9.4
6	-45.7	-11.2	-12.0	-5.2
7	-45.5	-3.5	-7.9	-7.8
8	-31.7	-21.1	-10.1	-2.8
9	-48.1	-7.8	0.7	-6.8
10	-29.3	-7.3	-11.2	-13.0
11	-18.2	-15.6	-9.9	-5.5

12	-34.6	-1.2	-5.5	-0.6
13	-30.9	-10.7	-7.0	-8.4
14	-21.0	-10.4	-10.9	-6.1
15	-23.2	-8.9	-9.3	-11.8
16	-26.1	-23.3	-10.7	-7.5
17	-25.5	-11.3	-9.6	-6.4
18	-23.2	-11.9	-6.0	-2.3
19	-19.7	-17.9	-18.0	-8.9
20	-19.4	-13.1	-11.7	-11.8
21	-33.0	-21.0	-24.2	-11.3
22	-14.8	-16.2	-7.3	-6.6
23	-32.0	-8.6	-3.3	-2.5
24	-23.7	-11.7	-6.8	-0.8
25	-21.9	-13.0	-12.5	-7.0
26	-11.2	-17.1	-7.2	-11.9
27	-11.9	-10.2	-6.6	-6.1
28	-8.7	-13.8	-6.4	-2.0
29	-11.0	-13.0	-10.4	-7.7

		Ulnar Deviation		
No	Index (N)	Middle (N)	Ring (N)	Little (N)
1	-17.4	-12.4	-9.3	-9.6
2	-28.2	-11.6	-8.0	-10.5
3	-21.8	-17.8	-20.9	-19.4
4	-21.6	-18.4	-15.2	-8.2
5	-17.3	-35.3	-17.2	-8.9
6	-67.9	-22.4	-22.3	-7.0
7	-36.0	-10.5	-9.9	-3.4
8	-42.1	-13.0	-13.5	-15.1
9	-30.6	-25.2	-17.0	-7.7
10	-24.9	-20.7	-12.6	-13.5
11	-27.5	-28.1	-15.6	-13.0
12	-34.9	-7.0	-8.0	-5.9
13	-33.9	-11.2	-9.0	-11.8
14	-18.7	-12.8	-22.6	-10.8
15	-25.5	-17.5	-13.5	-11.8
16	-18.3	-23.0	-30.4	-8.1
17	-27.7	-16.1	-7.7	-12.3
18	-22.3	-11.5	-14.0	-12.7
19	-13.1	-16.6	-9.9	-6.5
20	18.6	16.4	9.6	7.0
21	-30.7	-6.5	-23.8	-8.4

22	-14.5	-18.6	-13.7	-10.4
23	-20.0	-5.9	-8.4	-8.6
24	-19.5	-8.9	-5.6	-7.2
25	-18.4	-16.7	-11.0	-8.3
26	-29.9	-10.1	-13.1	-2.2
27	-13.7	-7.1	-4.5	-9.1
28	-14.4	-10.0	-5.1	-4.9
29	-13.8	-19.6	-14.1	-10.6

B. The percentage distributions of the aforementioned loads on the fingers follow.

		Flexion		
No	Index (%)	Middle (%)	Ring (%)	Little (%)
1	30.2	35.6	23.4	10.7
2	28.3	34.7	27.1	9.9
3	21.9	40.6	17.5	20.1
4	24.8	32.1	25.5	17.6
5	15.0	33.3	26.8	24.9
6	31.3	33.5	25.6	9.6
7	33.6	33.2	20.2	13.0
8	37.5	23.9	17.7	20.9
9	23.0	30.2	27.9	18.9
10	25.9	38.9	25.7	9.5
11	65.8	11.3	14.2	8.6
12	33.4	30.9	16.4	19.4
13	33.7	25.8	19.4	21.1
14	37.6	18.5	18.2	25.7
15	22.7	40.7	20.7	15.9
16	40.8	29.4	16.8	13.0
17	27.8	27.0	19.8	25.5
18	30.2	27.7	18.9	23.1
19	24.6	37.8	21.2	16.5
20	47.1	17.7	26.8	8.3
21	37.1	22.6	17.3	23.0
22	36.5	40.7	11.4	11.4
23	43.4	27.0	19.5	10.1
24	30.6	30.3	28.0	11.1
25	21.5	42.7	20.5	15.3
26	38.8	36.9	14.2	10.1
27	84.9	11.4	4.9	-1.2
28	24.5	25.8	22.0	27.8
29	32.5	32.6	14.1	20.9

		Extension		
No	Index (%)	Middle (%)	Ring (%)	Little (%)
1	32.8	31.0	23.2	13.0
2	41.5	17.2	19.9	21.4
3	34.6	24.5	19.8	21.1
4	34.7	32.8	24.5	8.0
5	25.8	40.5	23.3	10.5
6	37.3	23.2	21.3	18.3
7	65.1	8.5	16.9	9.4
8	24.7	34.5	24.6	16.3
9	31.3	26.2	28.8	13.7
10	28.3	31.5	23.5	16.8
11	45.3	25.4	21.5	7.8
12	27.6	28.0	29.1	15.3
13	41.2	22.4	20.7	15.7
14	24.3	29.7	28.3	17.8
15	17.0	36.2	31.1	15.7
16	34.8	24.7	24.2	16.3
17	32.4	34.3	20.7	12.5
18	25.1	39.8	24.8	10.3
19	32.7	21.4	25.9	19.9
20	42.8	17.4	25.7	14.1
21	27.2	32.0	23.7	17.1
22	41.7	39.4	13.2	5.8
23	47.8	25.2	16.6	10.5
24	29.7	25.9	28.2	16.3
25	31.9	28.3	26.9	12.9
26	36.2	28.5	16.1	19.2
27	46.4	28.2	16.8	8.6
28	22.8	20.1	36.1	21.1
29	34.8	27.0	22.4	15.8

		Neutral		
No	Index (%)	Middle (%)	Ring (%)	Little (%)
1	23.7	36.8	27.2	12.2
2	34.6	26.0	20.1	19.3
3	29.8	22.7	22.2	25.3
4	30.7	38.1	21.6	9.6
5	28.4	47.9	19.9	3.8
6	34.3	31.6	21.9	12.2
7	29.1	34.7	22.0	14.2
8	26.4	22.5	28.9	22.3
9	30.5	32.0	19.8	17.8

10	40.6	25.6	13.1	20.7
11	38.4	11.9	38.2	11.5
12	35.2	24.7	21.8	18.3
13	26.0	20.7	25.2	28.1
14	21.6	29.7	27.1	21.6
15	44.8	19.0	28.0	8.3
16	28.9	31.7	24.6	14.9
17	46.0	30.5	19.0	4.5
18	33.7	27.8	25.5	13.0
19	28.9	25.2	27.4	18.5
20	33.0	31.0	26.2	9.8
21	35.4	19.6	20.1	25.0
22	31.1	47.3	16.6	5.0
23	40.0	34.3	19.6	6.0
24	35.9	34.0	21.2	8.9
25	40.8	33.6	14.6	10.9
26	27.4	38.4	20.8	13.4
27	34.7	39.7	19.5	6.1
28	43.7	39.0	14.2	3.1
29	38.8	28.8	13.1	19.3

		Radial Deviation		
No	Index (%)	Middle (%)	Ring (%)	Little (%)
1	31.9	34.5	19.9	13.6
2	46.0	28.1	19.0	6.9
3	22.8	27.1	33.4	16.7
4	42.4	26.1	20.8	10.7
5	35.1	32.8	20.1	12.0
6	61.7	15.1	16.2	7.1
7	70.3	5.4	12.2	12.1
8	48.3	32.1	15.4	4.2
9	77.5	12.6	-1.1	11.0
10	48.2	11.9	18.4	21.4
11	36.9	31.8	20.0	11.2
12	82.6	2.8	13.1	1.5
13	54.3	18.8	12.2	14.7
14	43.4	21.6	22.5	12.5
15	43.7	16.8	17.4	22.1
16	38.6	34.4	15.8	11.1
17	48.2	21.4	18.2	12.2
18	53.5	27.4	13.7	5.3
19	30.5	27.8	27.9	13.9
20	34.6	23.4	20.9	21.1

21	36.8	23.5	27.1	12.7
22	32.9	36.1	16.2	14.8
23	68.9	18.6	7.2	5.3
24	55.1	27.2	15.9	1.9
25	40.2	23.9	23.0	12.9
26	23.6	36.1	15.1	25.2
27	34.1	29.4	18.9	17.7
28	28.1	44.7	20.8	6.4
29	26.1	30.9	24.7	18.3

		Ulnar Deviation		
No	Index (%)	Middle (%)	Ring (%)	Little (%)
1	35.7	25.5	19.1	19.7
2	48.3	19.9	13.8	17.9
3	27.3	22.3	26.1	24.3
4	34.1	29.1	24.0	12.8
5	22.0	44.9	21.8	11.4
6	56.8	18.7	18.6	5.8
7	60.2	17.5	16.6	5.7
8	50.3	15.6	16.1	18.1
9	38.0	31.3	21.1	9.6
10	34.7	28.8	17.6	18.9
11	32.7	33.4	18.5	15.4
12	62.5	12.6	14.3	10.6
13	51.5	16.9	13.7	17.9
14	28.9	19.7	34.8	16.6
15	37.3	25.6	19.8	17.3
16	23.0	28.8	38.1	10.1
17	43.4	25.2	12.1	19.3
18	36.8	19.0	23.1	21.0
19	28.4	35.9	21.5	14.2
20	36.1	31.9	18.6	13.5
21	44.3	9.3	34.3	12.1
22	25.4	32.5	23.9	18.2
23	46.6	13.8	19.7	20.0
24	47.4	21.5	13.7	17.4
25	33.8	30.7	20.2	15.2
26	54.0	18.3	23.6	4.0
27	39.9	20.8	13.1	26.3
28	41.8	29.1	15.0	14.1
29	23.7	33.7	24.3	18.3

I2: Normality test of the percentage distribution of the $\Sigma F_z T$ across the fingers

The sample size for the accumulated percentage distribution of the $\Sigma F_z T$ across the fingers was that of Appendix H (H.4). The Probability plots of the percentage distribution of the $\Sigma F_z T$ across the fingers follows. On the graph titles, the letter indicates the wrist position (F=Flexion, E=Extension, N=Neutral, RD=Radial Deviation, and UD=Ulnar Deviation) and the number indicates the finger (2=Index, 3=Middle, 4=Ring and 5=Little). Inside the box on the right of each graph, is the Anderson-Darling normality test (AD) value as well as its p.

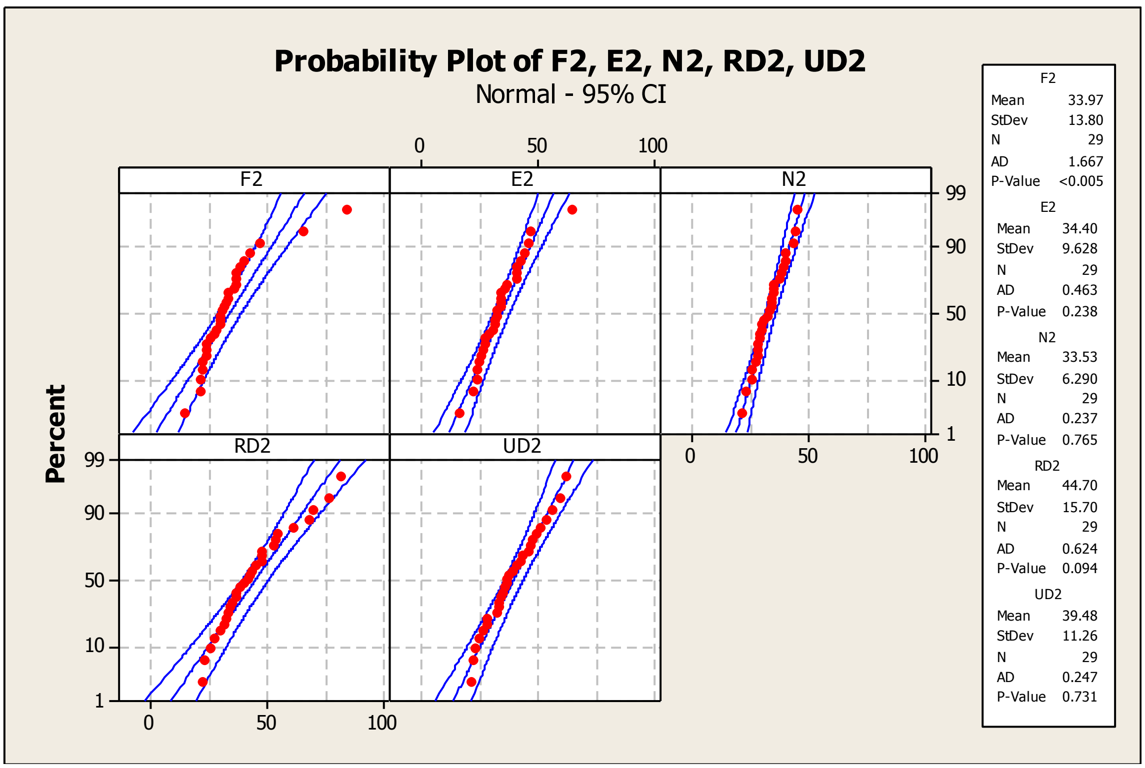


Figure I.1: *The Probability plot of the Index finger in each wrist orientation.*

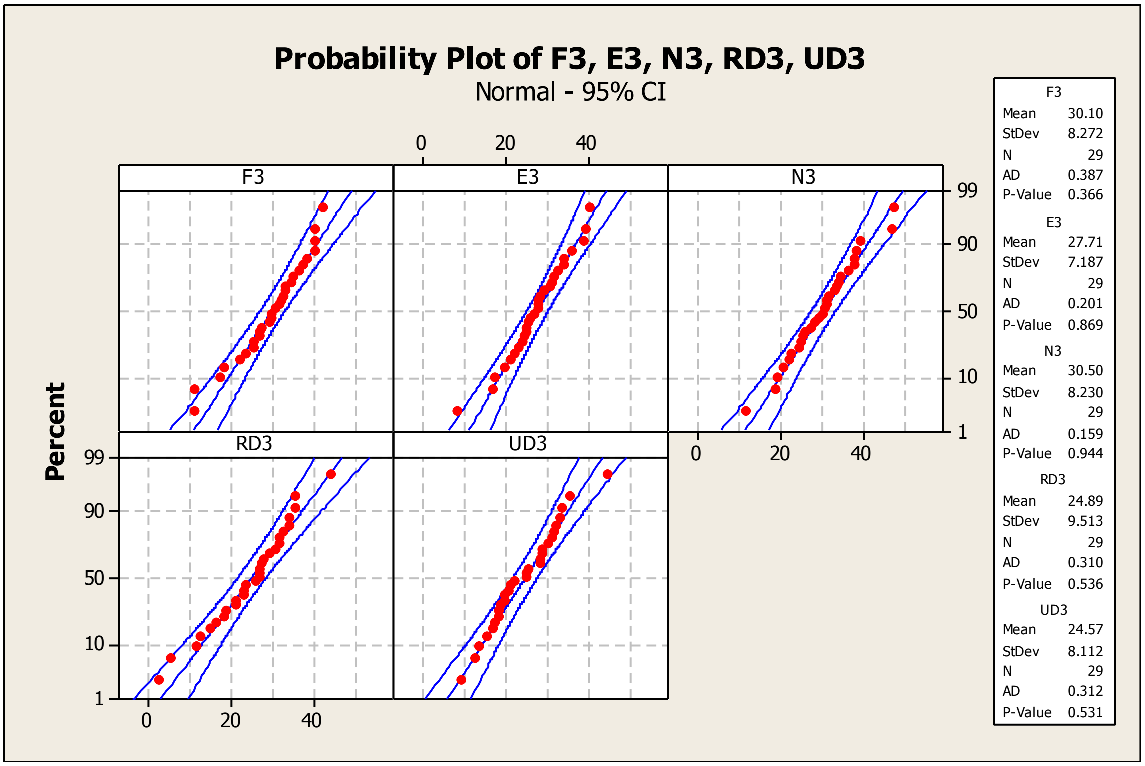


Figure I.2: *The Probability plot of the Middle finger in each wrist orientation.*

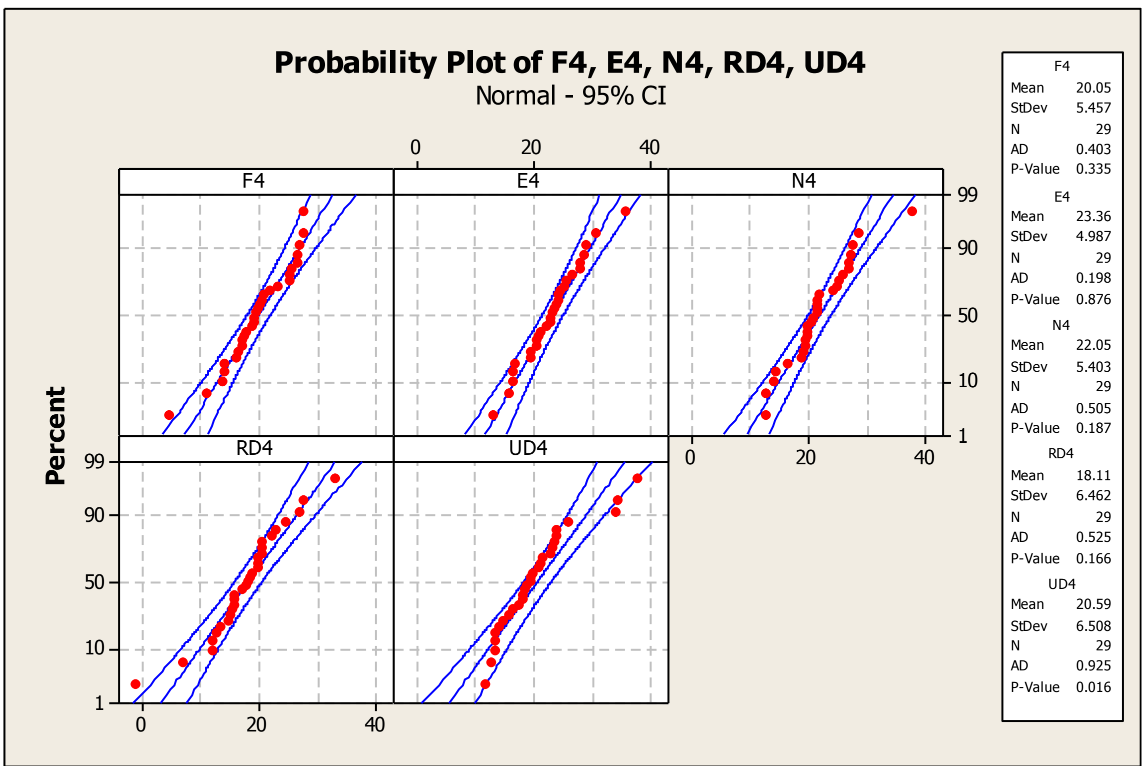


Figure I.3: *The Probability plot of the Ring finger in each wrist orientation.*

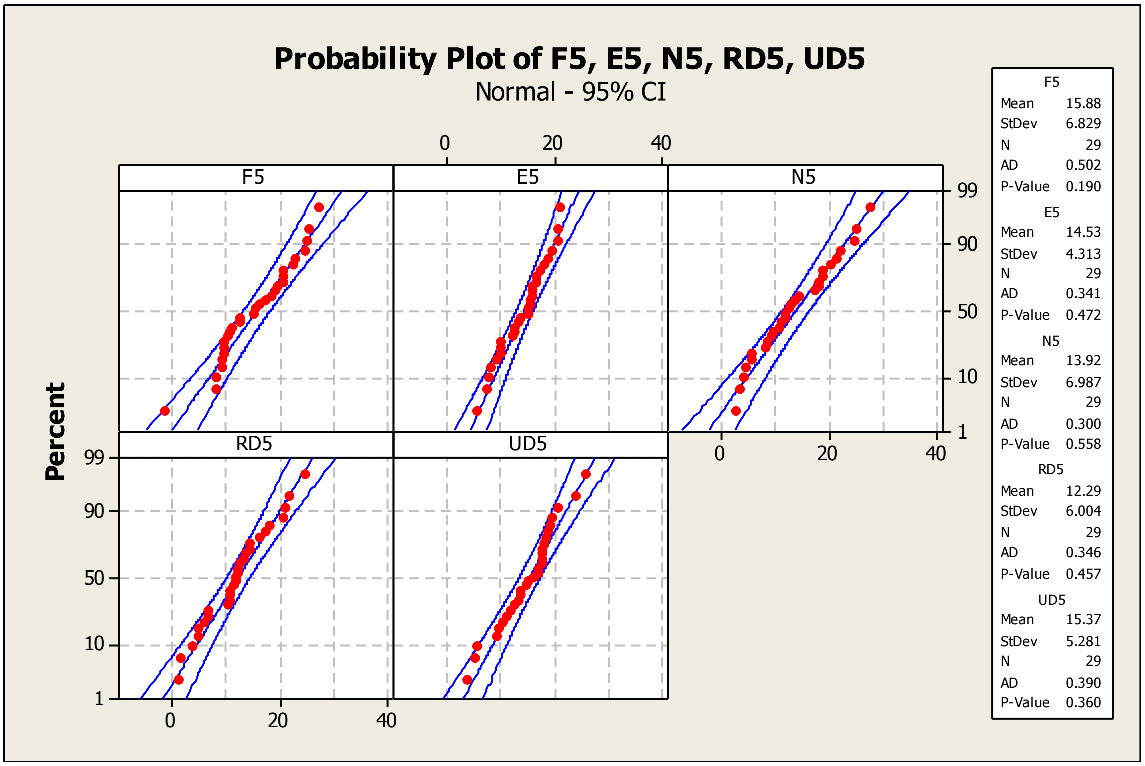


Figure I.4: *The Probability plot of the Little finger in each wrist orientation.*

In some cases, there is a strong statistical indication of non-normal distribution. As in these data sets the extremes values of the F_z were deducted, further deduction on extreme values are in general prohibited. Thus, the non-parametric Wilcoxon matched paired test used to test the hypothesis of equality or not, as regards the percentage distribution of the $\Sigma F_z T$ across each finger in the five wrist orientations. The null hypothesis was Ho= no difference in the percentage distribution of the $\Sigma F_z T$ across the finger, and the Confidence Intervals were set at 95%.

I3: Statistical test results

Table I.1: *The results of the Wilcoxon test for the fingers.*

	W+	W-	P
		Index	
Flexion-Extension	190.5	244.5	p <= 0.5666
Flexion-Neutral	204	231	p <= 0.7786
Flexion-Radial Dev.	94.5	340.5	p <= 0.008077
Flexion-Ulnar Dev.	121.5	313.5	p <= 0.03892
Extension-Neutral	242	193	p <= 0.6038

Extension-Radial Dev.	92	343	p <= 0.006874
Extension-Ulnar Dev.	134	301	p <= 0.0727
Neutral-Radial Dev.	70	365	p <= 0.00148
Neutral-Ulnar Dev.	120.5	314.5	p <= 0.03692
Radial Dev.-Ulnar Dev.	334.5	100.5	p <= 0.01177
		Middle	
Flexion-Extension	273	162	p <= 0.2343
Flexion-Neutral	205	230	p <= 0.7953
Flexion-Radial Dev.	315.5	119.5	p <= 0.03501
Flexion-Ulnar Dev.	337	98	p <= 0.01008
Extension-Neutral	139.5	266.5	p <= 0.1514
Extension-Radial Dev.	289	146	p <= 0.1247
Extension-Ulnar Dev.	293	142	p <= 0.1049
Neutral-Radial Dev.	334	101	p <= 0.01213
Neutral-Ulnar Dev.	356	79	p <= 0.002845
Radial Dev.-Ulnar Dev.	226	209	p <= 0.8627

	W+	**W-**	**P**
		Ring	
Flexion-Extension	97.5	337.5	p <= 0.009767
Flexion-Neutral	169.5	265.5	p <= 0.3044
Flexion-Radial Dev.	273.5	161.5	p <= 0.2301
Flexion-Ulnar Dev.	218	217	p <= 1
Extension-Neutral	244.5	190.5	p <= 0.5666
Extension-Radial Dev.	376	59	p <= 0.0006345
Extension-Ulnar Dev.	301	134	p <= 0.0727
Neutral-Radial Dev.	330.5	104.5	p <= 0.01499
Neutral-Ulnar Dev.	264.5	170.5	p <= 0.3147
Radial Dev.-Ulnar Dev.	158.5	276.5	p <= 0.2059
		Little	
Flexion-Extension	262	173	p <= 0.3414
Flexion-Neutral	242	193	p <= 0.6038
Flexion-Radial Dev.	306.5	128.5	p <= 0.05566
Flexion-Ulnar Dev.	245	190	p <= 0.5593
Extension-Neutral	236	199	p <= 0.6971
Extension-Radial Dev.	260	146	p <= 0.1982
Extension-Ulnar Dev.	190	245	p <= 0.5593
Neutral-Radial Dev.	261	174	p <= 0.3525
Neutral-Ulnar Dev.	188	247	p <= 0.5306
Radial Dev.-Ulnar Dev.	105.5	300.5	p <= 0.02719

APPENDIX (J): **Kinetics: Loads on the metacarpophalangeal Joints**

J1: The sample size

A. The sample size of the loads for each wrist position is presented in the Table below:

	Wrist Position				
Cases	**Flexion**	**Extension**	**Radial**	**Ulnar**	**Neutral**
N	45	49	43	37	50

The processed loads for every digit, in each wrist orientation, in the metacarpal axis system are given in the Tables below:

A1. For the **Flexion** of the wrist:

			Thumb			
No	F_x (N)	F_y (N)	F_z (N)	M_x (Nm)	M_y (Nm)	M_z (Nm)
1	-10.2	15.7	38.0	-1.86	0.27	-0.58
2	-37.3	17.8	22.9	-0.83	-0.20	-1.07
3	-37.7	36.0	18.3	-0.84	0.17	-1.93
4	28.3	-2.0	-39.9	1.67	-1.37	1.04
5	-34.2	18.7	14.6	-0.69	0.21	-1.39
6	-15.8	21.7	45.1	-3.26	-1.10	0.40
7	-20.1	12.8	36.1	-1.99	-1.38	-0.13
8	-50.7	19.6	42.0	-1.27	0.14	-1.55
9	-27.4	11.9	24.0	-1.13	-0.35	-0.79
10	-6.2	10.5	21.1	-0.91	0.10	-0.21
11	-45.4	22.0	-3.6	0.12	-0.12	-2.24
12	-36.4	23.9	34.0	-1.54	-0.16	-1.42
13	-32.7	16.0	42.2	-2.65	0.69	-1.83
14	-26.9	13.4	31.5	-1.68	-0.03	-0.96
15	-67.9	54.9	34.5	-1.28	0.40	-3.18
16	-25.5	20.9	14.3	-0.88	-0.31	-1.10
17	-57.2	14.6	47.4	-2.17	-1.49	-2.05
18	-10.3	18.9	52.5	-2.10	-0.85	0.13
19	-12.1	17.1	32.9	-1.54	-0.39	0.18

20	-39.3	27.3	16.7	-0.93	-0.29	-1.67
21	-28.4	14.3	20.3	-1.11	-0.02	-1.12
22	-43.6	22.0	56.4	-2.46	-0.79	-1.17
23	-33.0	18.7	10.1	-0.43	-0.04	-1.26
24	-29.8	-64.2	-1.4	-3.88	1.73	1.21
25	-33.9	18.6	11.1	-0.13	0.53	-1.25
26	-37.8	26.3	12.8	-0.64	-0.24	-1.43
27	-29.2	15.0	18.1	-0.94	-0.48	-1.08
28	-29.0	19.2	4.6	-0.33	-0.26	-1.19
29	-35.9	12.2	11.1	-0.55	-0.15	-1.70
30	-33.7	25.1	18.1	-0.54	1.73	-3.45
31	-52.7	36.8	50.0	-2.28	-0.88	-1.79
32	-45.1	15.9	5.4	-0.54	-0.79	-1.82
33	-39.1	29.8	3.8	-0.29	-0.09	-2.09
34	-23.6	20.6	-4.0	-0.55	-0.78	-0.80
35	-33.2	-4.5	-11.4	0.43	-1.00	-1.02
36	-24.7	18.3	0.7	-0.21	-0.24	-1.29
37	-11.7	4.2	6.1	-0.35	-0.37	-0.42
38	-26.1	35.3	54.5	-2.85	-0.20	-1.23
39	-32.3	25.2	5.0	-0.73	-0.61	-1.42
40	-57.5	39.1	11.0	-1.08	-1.17	-1.56
41	-10.7	-41.8	-19.6	-1.21	0.85	-1.14
42	-29.0	19.6	10.6	-0.72	-0.45	-1.08
43	-34.4	7.6	4.5	-0.30	-0.51	-1.19
44	-43.1	23.4	19.6	-0.59	0.33	-1.67
45	-75.3	46.1	27.0	-1.03	-0.83	-1.32

			Index			
No	F_x (N)	F_y (N)	F_z (N)	M_x (Nm)	M_y (Nm)	M_z (Nm)
1	-7.7	-9.6	-8.4	0.53	0.32	-0.84
2	-0.9	-10.3	-9.7	0.86	0.26	-0.37
3	-3.7	-16.8	-15.4	1.17	0.51	-0.85
4	-8.7	-18.4	3.2	0.52	-0.47	-1.34
5	-3.2	-15.6	-6.1	0.86	-0.09	-0.25
6	-4.6	-11.0	-2.8	0.45	0.07	-0.97
7	-2.1	-9.0	-6.4	0.64	0.15	-0.42
8	-1.9	-18.1	-7.2	0.73	0.26	-0.86
9	-6.2	-13.3	-7.2	0.63	0.10	-0.73
10	-4.1	-9.2	-3.5	0.54	-0.01	-0.59
11	-1.8	-11.3	-5.5	0.29	0.37	-0.84
12	-8.0	-17.4	-4.7	0.59	0.02	-1.07
13	-4.0	-17.9	-7.2	0.84	0.30	-1.19
14	-5.4	-9.6	-7.0	0.54	0.13	-0.60
15	-16.5	-13.4	-36.9	1.20	1.64	-1.19

16	-8.9	-0.4	7.3	0.24	-0.35	0.27
17	-10.4	-26.9	-10.3	1.00	0.35	-1.99
18	-8.6	-15.9	-7.2	0.60	0.16	-1.10
19	-0.3	-9.1	-4.8	0.54	0.10	-0.26
20	-1.2	-17.2	-17.2	1.07	0.57	-0.74
21	0.4	-9.5	-2.9	0.45	0.14	-0.43
22	-11.5	-19.0	-6.2	1.00	-0.21	-1.22
23	-4.2	-12.8	-9.4	0.79	0.17	-0.57
24	-8.6	-32.6	-25.9	1.10	1.45	-2.26
25	6.4	-32.5	-7.2	0.98	0.29	-0.95
26	-1.8	-14.2	-12.3	0.91	0.24	-0.43
27	-4.4	-11.5	-6.2	0.62	0.16	-0.73
28	-2.0	-10.9	-7.4	0.66	0.18	-0.45
29	-4.8	-17.3	-7.3	0.93	0.07	-0.78
30	1.3	-17.0	-3.6	0.84	0.27	-0.95
31	-7.9	-23.4	-10.9	0.96	0.57	-1.91
32	-2.9	-11.9	-8.6	0.74	0.36	-0.74
33	-9.9	-10.1	-2.8	0.23	0.02	-0.90
34	-1.7	-8.7	-2.0	0.12	0.11	-0.64
35	-2.9	-11.7	-5.8	0.37	0.27	-0.70
36	-3.2	-9.7	-5.4	0.45	0.14	-0.54
37	-3.6	-10.6	-5.3	-1.17	1.47	-2.15
38	-5.6	-22.2	-8.4	1.05	0.24	-1.36
39	-0.2	-10.3	-3.6	0.73	0.05	-0.20
40	-5.6	-22.8	-9.5	0.24	0.59	-1.57
41	-2.5	-11.6	-4.9	0.54	0.12	-0.57
42	-3.8	-8.3	-9.3	0.59	0.46	-0.65
43	-3.7	-9.9	-6.0	0.45	0.22	-0.63
44	-5.7	-19.3	-7.6	0.78	0.19	-1.04
45	-15.9	-22.1	-10.4	0.44	0.46	-1.76

			Middle			
No	F_x (N)	F_y (N)	F_z (N)	M_x (Nm)	M_y (Nm)	M_z (Nm)
1	-4.0	-16.5	-1.9	0.45	0.01	-1.19
2	-0.4	-15.6	-4.3	0.14	0.23	-0.83
3	4.1	-26.9	-6.6	0.02	0.27	-1.11
4	-5.3	-15.0	3.3	-0.06	-0.18	-0.93
5	-2.5	-8.1	-0.4	0.10	-0.01	-0.44
6	-9.9	-20.7	-0.9	0.75	-0.28	-1.78
7	-4.8	-18.1	-7.8	0.97	0.18	-1.02
8	-2.7	-23.7	-8.3	0.04	0.45	-1.31
9	-5.9	-13.6	0.0	0.15	-0.06	-0.88
10	2.1	-6.8	-3.9	-0.03	0.29	-0.51
11	3.9	-24.3	-8.2	0.82	0.60	-1.37

12	-4.1	-20.5	-1.2	-0.05	0.08	-1.10
13	3.6	-21.3	-3.7	0.59	0.36	-1.58
14	-3.0	-13.2	-2.1	0.18	0.08	-0.75
15	-1.4	-25.7	-6.4	0.17	0.40	-1.67
16	-2.4	-9.2	-4.9	-0.20	0.19	-0.28
17	-11.3	5.8	-11.8	0.44	-1.00	-0.94
18	-8.0	-15.8	1.5	-0.20	-0.01	-1.03
19	2.1	-16.3	-2.0	0.68	0.17	-0.71
20	-0.6	-8.9	-2.2	0.11	0.11	-0.44
21	-0.4	-12.3	-5.3	0.32	0.26	-0.67
22	-6.1	-32.3	-0.6	0.60	-0.07	-1.73
23	-3.0	-10.9	-3.6	0.27	0.15	-0.66
24	-7.3	-8.0	-10.7	0.67	0.49	-0.82
25	0.5	-4.0	-4.4	-0.06	0.16	-0.16
26	-2.3	-10.0	-5.3	0.12	0.22	-0.47
27	-0.7	-8.5	-2.3	0.28	0.09	-0.42
28	-1.4	-14.5	-2.3	0.30	0.06	-0.62
29	-4.8	-10.0	-3.5	0.35	0.05	-0.63
30	-5.3	-11.1	-5.0	1.41	-0.39	-0.63
31	-3.2	-27.2	-6.2	0.14	0.35	-1.62
32	-2.9	-13.8	-5.3	0.36	0.31	-1.02
33	-1.4	-22.6	-3.2	0.02	-0.03	0.03
34	0.4	-11.8	-1.8	0.28	0.12	-0.78
35	-0.7	-8.8	-4.3	0.36	0.16	-0.38
36	-2.7	-11.0	-1.7	0.08	0.08	-0.63
37	0.3	-1.5	0.7	-0.05	-0.05	-0.08
38	-9.4	-25.4	-2.5	0.47	-0.01	-1.80
39	-1.9	-11.8	0.1	0.25	-0.06	-0.70
40	-6.0	-27.0	-1.3	0.31	-0.01	-1.49
41	-6.6	-15.6	-5.3	0.63	0.02	-0.94
42	-2.5	-12.2	-3.5	0.21	0.15	-0.68
43	0.6	-13.2	-1.7	0.46	0.08	-0.53
44	-4.7	-19.1	-4.6	0.21	0.22	-1.09
45	0.1	-31.6	-8.4	1.07	0.45	-1.71

			Ring			
No	F_x (N)	F_y (N)	F_z (N)	M_x (Nm)	M_y (Nm)	M_z (Nm)
1	-4.4	-7.9	-2.1	-0.13	0.25	-0.67
2	-0.9	-8.1	-7.6	0.00	0.40	-0.42
3	1.7	-20.6	-6.3	0.27	0.23	-0.65
4	-3.5	-11.2	1.8	-0.17	-0.04	-0.64
5	-3.3	-7.4	-2.0	0.14	0.06	-0.43
6	-3.0	-9.1	-2.1	0.43	0.02	-0.68
7	-0.9	-10.3	-3.1	0.33	0.15	-0.58

8	-4.3	-17.7	-9.0	0.21	0.44	-0.96
9	-3.1	-6.5	-1.1	0.03	0.06	-0.45
10	-1.3	-4.0	-1.0	0.16	-0.01	-0.17
11	6.1	-18.6	-7.2	0.81	0.56	-0.75
12	-6.1	-14.6	-1.9	-0.04	0.09	-0.53
13	2.7	-11.5	-5.3	0.86	0.51	-0.67
14	-2.5	-9.2	-2.4	0.34	0.05	-0.52
15	-7.2	-16.5	6.8	-1.20	0.16	-0.87
16	-2.0	-8.5	-4.4	0.40	0.10	-0.37
17	-8.2	-16.9	5.1	-1.00	0.34	-0.48
18	-7.5	-8.8	-4.5	0.20	0.18	-0.70
19	-1.2	-8.4	-4.1	0.04	0.22	-0.46
20	-1.3	-11.7	-6.9	0.19	0.32	-0.58
21	-3.4	10.7	-4.1	0.23	-0.24	-0.79
22	-4.7	-21.1	-3.3	0.02	0.18	-1.08
23	-2.6	-6.1	-1.8	0.17	0.04	-0.39
24	-2.9	-11.2	-3.6	-0.14	0.30	-0.83
25	4.8	-5.8	-2.7	0.07	0.12	-0.14
26	-1.7	-8.0	-3.5	0.10	0.13	-0.34
27	-3.7	-8.4	-2.2	0.23	0.05	-0.51
28	-1.5	-3.6	-1.5	0.07	0.06	-0.21
29	-4.6	-7.0	-2.6	0.14	0.08	-0.46
30	-3.2	-6.2	-3.4	1.06	-0.31	-0.43
31	-2.8	-21.2	-5.0	0.69	0.06	-0.71
32	-5.6	-12.7	-1.8	0.08	0.12	-1.03
33	0.6	-10.7	-2.6	0.38	0.10	-0.31
34	-0.5	-8.4	-2.2	0.32	0.11	-0.45
35	-3.2	-5.9	-2.6	0.11	0.09	-0.33
36	-1.0	-4.0	-1.9	0.12	0.07	-0.20
37	0.0	-0.7	-0.6	0.02	0.02	-0.03
38	-3.2	-11.0	-4.4	0.35	0.18	-0.69
39	-3.9	-7.9	-4.9	0.37	0.17	-0.56
40	-4.9	-17.4	-2.8	0.06	0.17	-1.04
41	-2.8	-11.1	4.5	-0.57	-0.04	-0.44
42	-1.3	-5.3	-1.7	0.00	0.09	-0.27
43	-2.6	-7.7	1.0	-0.12	-0.02	-0.41
44	-4.4	-9.7	-1.6	0.07	0.07	-0.58
45	0.6	-19.6	-6.7	0.53	0.31	-0.85

			Little			
No	F_x (N)	F_y (N)	F_z (N)	M_x (Nm)	M_y (Nm)	M_z (Nm)
1	-3.6	-3.6	2.3	-0.28	0.07	-0.33
2	-1.4	-3.6	2.8	-0.08	-0.03	-0.08
3	-1.4	-7.0	3.2	-0.47	0.18	0.12

4	-7.3	-9.5	2.7	0.04	-0.22	-0.75
5	8.9	-8.0	-1.7	-0.68	-0.62	-0.59
6	-2.4	-8.9	6.4	-0.49	-0.32	-0.62
7	-3.2	-5.9	5.0	-0.26	0.11	-0.03
8	-1.4	-14.0	-0.7	-0.77	0.09	0.35
9	-0.4	-2.9	-0.7	0.03	0.04	-0.16
10	0.0	0.9	3.3	0.08	0.12	-0.04
11	2.5	-14.6	-12.7	0.08	0.57	-0.64
12	-0.8	-5.8	2.8	-0.03	-0.05	-0.14
13	1.1	-8.7	2.9	-0.68	-0.22	-0.40
14	-3.1	-9.5	6.8	-0.89	0.05	-0.34
15	20.6	-9.9	-0.1	-0.78	-1.61	-1.38
16	-5.2	-6.8	2.7	-0.34	0.12	-0.37
17	-2.4	-17.5	-4.5	0.90	-0.25	0.64
18	1.7	-14.6	2.4	0.74	0.06	-0.28
19	-3.7	5.7	3.3	0.12	0.35	-0.50
20	-1.3	-4.0	-0.9	-0.16	0.09	-0.15
21	0.0	-8.5	0.6	-0.42	-0.01	-0.27
22	-3.9	-6.5	2.7	-0.12	0.01	-0.22
23	-5.0	-1.9	0.1	0.00	0.00	-0.40
24	4.0	0.0	1.9	-0.16	-0.17	0.34
25	0.0	-4.6	2.5	-0.19	-0.03	-0.04
26	-3.5	-10.6	4.7	-0.48	0.15	0.00
27	1.4	-7.1	-2.4	0.66	0.00	0.37
28	-0.8	-4.0	-0.4	-0.16	0.05	-0.11
29	-0.3	-3.9	2.1	-0.31	0.00	-0.05
30	-6.2	-6.8	4.2	-0.11	-0.62	-1.19
31	-0.5	-6.4	3.6	-0.29	-0.07	-0.16
32	-3.7	-4.0	-0.1	-0.10	0.11	-0.51
33	-4.2	-7.1	0.5	-0.20	0.10	-0.34
34	-0.2	-4.3	0.9	-0.11	-0.04	-0.21
35	-0.6	-9.3	-0.3	-0.41	0.05	-0.35
36	1.6	-2.4	1.5	-0.20	-0.02	0.18
37	1.0	-0.2	0.4	-0.03	-0.03	0.06
38	-3.0	-8.9	2.0	-0.20	-0.06	-0.67
39	-3.1	-11.7	2.7	-0.77	0.15	-0.39
40	2.8	-14.4	0.4	-0.50	-0.08	-0.53
41	-2.8	-4.8	0.7	-0.22	0.08	-0.35
42	-2.0	-7.7	-0.5	-0.22	0.09	-0.48
43	1.0	-7.8	3.0	-0.44	-0.09	-0.15
44	-4.8	-10.6	4.6	-0.57	0.07	-0.46
45	-7.5	-31.9	8.3	-0.41	-0.13	-0.89

A2. For the **Extension** of the wrist:

			Thumb			
No	F_x (N)	F_y (N)	F_z (N)	M_x (Nm)	M_y (Nm)	M_z (Nm)
1	-19.0	27.2	37.9	-1.87	0.55	-1.27
2	-42.1	9.0	17.9	-0.49	-0.14	-1.19
3	-44.3	15.5	28.0	-1.31	0.29	-2.16
4	43.3	2.0	-23.5	1.02	-0.69	1.63
5	-50.9	6.8	25.7	-1.57	-0.33	-2.22
6	-15.0	34.4	50.8	-3.78	-0.80	0.34
7	-41.0	4.7	57.1	-2.76	-2.46	-0.82
8	-68.5	12.6	7.0	0.08	1.32	-2.40
9	-40.3	-0.4	45.9	-2.34	-0.70	-0.88
10	-46.1	-15.1	29.1	-1.17	-0.61	-1.84
11	-111.0	11.5	37.9	-1.92	-0.32	-4.75
12	-89.3	-9.5	44.8	-2.12	-1.68	-3.38
13	-96.0	-12.0	-19.3	0.79	0.07	-3.90
14	-27.7	16.6	53.0	-3.80	0.87	-2.20
15	-24.2	18.7	42.8	-2.00	-0.09	-0.55
16	-80.6	45.4	36.5	-1.35	0.46	-3.98
17	-31.6	16.1	17.8	-0.98	-0.03	-1.73
18	-43.2	-12.6	46.6	8.16	6.34	9.63
19	-78.6	-19.0	26.0	-1.10	-1.04	-4.15
20	9.2	21.4	76.2	-3.63	-1.02	1.50
21	-18.4	17.9	48.3	-2.38	-0.21	-0.08
22	-33.3	8.3	32.8	-2.01	-0.30	-1.74
23	-29.4	3.9	42.7	-2.94	-0.32	-1.02
24	-78.1	-6.5	58.3	-2.17	-1.15	-2.44
25	-50.8	19.2	-1.6	0.28	0.29	-2.19
26	-79.8	13.8	53.3	-2.33	-1.54	-3.15
27	-36.3	26.6	23.3	-0.76	0.21	-1.37
28	-36.2	17.2	31.0	-1.65	-0.43	-1.78
29	-35.7	8.0	14.5	-0.65	-0.62	-1.32
30	-39.6	6.0	40.2	-1.74	-1.05	-1.57
31	-25.2	17.8	21.2	-1.01	-0.28	-0.92
32	-28.1	12.4	20.1	-0.83	0.17	-1.23
33	-32.9	18.4	23.6	-1.23	1.89	-3.19
34	-34.3	8.6	58.7	-2.09	-1.35	-1.05
35	-60.3	-6.1	-13.9	0.74	-0.67	-2.84
36	-43.8	8.8	19.3	-0.94	0.08	-2.23
37	-31.0	4.3	-2.2	0.07	-0.72	-1.86
38	-127.3	24.5	47.3	-2.39	-2.51	-5.43
39	-42.8	-18.0	-38.2	1.59	-0.56	-1.40
40	-23.0	13.5	14.7	-0.80	-0.15	-1.06
41	-18.4	3.2	9.7	-0.46	-0.51	-0.70

42	-48.4	13.6	67.0	-3.00	-0.59	-2.16
43	-34.8	-8.6	-9.3	0.61	-0.92	-1.30
44	-89.4	3.1	19.6	-0.80	-2.20	-3.56
45	-2.8	-41.6	-28.4	-2.41	1.18	-1.38
46	-38.9	8.1	18.6	-0.90	-0.58	-1.68
47	-49.7	1.9	-14.8	0.80	-0.66	-2.42
48	-35.6	0.2	26.2	-1.14	0.09	-1.56
49	-77.7	21.5	42.2	-2.26	-0.91	-3.83

			Index			
No	F_x (N)	F_y (N)	F_z (N)	M_x (Nm)	M_y (Nm)	M_z (Nm)
1	-7.7	-18.2	-13.9	0.93	0.66	-1.41
2	-0.4	-13.5	-10.1	0.82	0.31	-0.47
3	-2.1	-14.3	-21.0	1.53	0.63	-0.59
4	-5.3	-22.6	-0.5	0.64	-0.11	-1.40
5	-0.8	-12.1	-10.1	0.98	0.18	-0.28
6	-9.8	-21.5	0.4	0.74	-0.35	-1.63
7	-0.9	-10.5	-7.6	0.75	0.25	-0.43
8	-1.8	-24.6	-13.7	0.76	0.46	-0.94
9	-7.8	-12.2	-13.2	0.76	0.26	-0.67
10	-7.8	-10.2	-16.6	0.92	0.39	-0.68
11	-15.0	-24.9	-14.6	1.00	0.52	-1.92
12	-5.7	-10.2	-16.2	1.12	0.80	-0.92
13	-7.8	-16.7	-35.7	1.54	0.86	-0.84
14	-16.2	-38.5	-9.5	1.43	0.12	-3.17
15	-5.9	-15.6	-7.8	0.61	0.19	-0.84
16	-13.4	-5.3	-26.0	1.10	1.23	-0.85
17	-15.0	-4.0	16.6	0.47	-0.39	0.37
18	-12.4	-13.0	-9.8	-1.37	-1.49	3.72
19	-6.3	-33.3	-34.5	0.89	2.17	-2.27
20	-5.8	-23.1	-7.1	0.69	0.34	-1.60
21	-3.3	-14.7	-11.3	1.01	0.17	-0.53
22	-10.8	-13.2	-13.0	0.98	0.25	-1.11
23	-3.1	-15.3	-8.4	1.00	0.28	-0.89
24	-10.0	-18.7	-24.4	1.56	0.52	-1.03
25	-7.3	-15.0	-17.0	0.90	0.38	-0.73
26	-4.0	-16.5	-21.3	1.53	0.85	-0.97
27	-5.5	-19.0	-10.9	0.83	0.23	-0.81
28	-4.0	-8.5	-10.8	0.87	0.20	-0.48
29	-3.5	-9.3	-10.1	0.68	0.41	-0.64
30	-10.0	-16.8	-0.6	-0.13	0.14	-1.42
31	-0.5	-14.5	-6.4	0.65	0.30	-0.70
32	-8.6	-14.2	-7.0	0.75	-0.07	-0.74
33	-0.9	-12.4	-6.0	0.67	0.39	-0.88

34	-16.0	-23.7	-9.1	0.39	0.45	-1.82
35	-5.5	-8.8	-16.7	0.56	0.90	-0.66
36	-11.4	-12.5	-3.1	0.34	0.02	-1.24
37	-7.3	-7.8	-6.1	0.22	0.34	-0.71
38	-16.7	-11.5	-21.4	1.33	0.60	-1.45
39	-6.6	-15.3	-17.5	0.78	0.76	-0.94
40	-6.2	-8.7	-4.4	0.38	0.05	-0.63
41	-5.1	-8.8	-4.9	-0.64	1.52	-2.04
42	-13.2	-23.7	-23.8	1.37	0.88	-1.68
43	2.6	-3.0	-8.5	0.43	0.39	-0.01
44	-15.6	-23.9	-15.2	-0.12	1.19	-1.75
45	-5.5	-10.8	-9.7	0.78	0.12	-0.57
46	-6.0	-11.0	-9.7	0.57	0.43	-0.83
47	-4.9	-11.9	-15.5	0.65	0.77	-0.82
48	-6.5	-9.4	-7.3	0.55	0.20	-0.73
49	-13.8	-29.9	-13.2	0.52	0.91	-2.58

			Middle			
No	F_x (N)	F_y (N)	F_z (N)	M_x (Nm)	M_y (Nm)	M_z (Nm)
1	1.3	-16.7	-6.4	0.60	0.45	-1.06
2	0.3	-16.2	-8.2	-0.09	0.46	-0.91
3	-0.3	-10.0	-4.4	0.18	0.26	-0.60
4	-4.6	-11.2	2.1	-0.60	0.14	-0.58
5	-6.1	-18.0	-5.1	0.32	0.27	-1.34
6	-4.9	-15.9	1.7	0.70	-0.31	-0.87
7	-4.5	-23.9	-14.2	0.75	0.84	-1.65
8	9.6	-18.5	-13.9	0.46	0.79	-0.75
9	-12.1	-19.5	-3.9	0.45	-0.02	-1.29
10	-2.3	-7.6	-12.5	0.44	0.59	-0.44
11	-10.1	-40.9	-27.6	1.86	1.34	-2.69
12	-15.9	-27.2	-8.1	-0.78	1.19	-2.49
13	-6.9	-17.9	-15.7	-0.07	0.91	-1.01
14	-0.2	-6.1	0.1	0.24	-0.02	-0.53
15	-2.8	-19.7	-5.1	0.28	0.21	-0.96
16	0.5	-40.1	-10.2	0.65	0.62	-2.43
17	-0.8	-4.4	-3.2	-0.12	0.13	-0.15
18	-10.1	-24.2	-10.2	0.00	-1.38	3.26
19	-2.6	-11.8	-12.0	0.20	0.85	-0.90
20	-10.5	-36.6	7.5	-0.50	-0.35	-2.33
21	3.5	-14.2	-1.5	0.74	0.23	-0.39
22	-2.8	-7.6	-3.6	0.25	0.15	-0.51
23	-3.4	-13.8	-5.4	0.35	0.31	-1.06
24	-18.4	-27.3	-14.7	0.69	0.39	-1.59
25	-4.7	-13.2	-9.2	0.39	0.35	-0.71

26	-16.5	-37.7	-25.9	0.75	1.68	-2.95
27	-3.9	-13.2	-1.2	-0.24	0.14	-0.71
28	-6.2	-15.9	-5.7	0.38	0.23	-1.05
29	-1.0	-7.6	-1.5	0.14	0.06	-0.44
30	-8.8	-13.2	-0.9	-0.21	0.22	-1.17
31	-3.5	-14.3	-5.1	0.27	0.23	-0.82
32	-4.3	-8.7	-0.9	0.14	-0.01	-0.43
33	-5.1	-12.6	-3.0	1.06	-0.26	-0.71
34	-6.8	-12.0	-0.9	-0.18	0.15	-0.74
35	-1.2	-12.1	-13.5	0.37	0.84	-0.78
36	-7.4	-13.1	2.2	-0.31	0.29	0.67
37	-2.8	-5.3	-5.5	0.24	0.31	-0.43
38	-16.1	-51.9	-21.0	0.88	1.31	-3.98
39	-2.9	-10.1	-10.9	0.25	0.58	-0.61
40	-4.7	-8.4	0.8	-0.05	-0.02	-0.57
41	-4.4	-4.9	2.3	-0.22	0.02	-0.37
42	-11.6	-14.9	-8.0	0.35	0.36	-1.17
43	-2.1	-3.9	-7.1	0.25	0.37	-0.27
44	-18.5	-18.3	-7.8	0.29	0.25	-1.28
45	-6.0	-10.9	-5.8	0.43	0.12	-0.67
46	-6.8	-9.2	-5.6	0.30	0.17	-0.64
47	-1.5	-11.3	-10.7	0.37	0.62	-0.74
48	-6.5	-9.8	-7.0	0.40	0.23	-0.69
49	-3.4	-31.4	-16.2	1.20	1.07	-2.31

			Ring			
No	F_x (N)	F_y (N)	F_z (N)	M_x (Nm)	M_y (Nm)	M_z (Nm)
1	-1.8	-5.9	-1.1	0.05	0.08	-0.46
2	-2.1	-10.8	-7.1	0.16	0.42	-0.68
3	-4.0	-9.3	-7.5	0.19	0.39	-0.58
4	-5.1	-10.0	-2.4	0.46	-0.09	-0.60
5	-5.4	-15.8	-7.3	0.41	0.36	-1.08
6	-5.2	-12.1	2.1	0.35	-0.30	-0.96
7	-3.5	-23.1	-5.8	0.89	0.21	-1.35
8	5.3	-14.1	-11.4	0.10	0.65	-0.76
9	-8.1	-11.0	-3.3	0.08	0.19	-0.83
10	-5.0	-7.0	-11.9	0.02	0.70	-0.42
11	-1.4	-23.7	-17.4	1.12	1.15	-1.66
12	-17.6	-35.5	-10.3	-0.13	1.03	-3.35
13	-10.8	-15.1	-13.1	0.00	0.77	-0.87
14	-1.9	-11.1	-4.0	0.50	0.34	-1.16
15	-0.7	-12.4	-2.5	0.48	0.06	-0.43
16	-6.4	-28.0	3.4	-1.63	0.23	-1.20
17	-1.2	-6.3	-4.8	0.35	0.17	-0.32

18	-10.9	-18.2	-3.1	1.19	-1.15	2.54
19	-7.3	-9.5	-5.5	0.09	0.49	-0.94
20	-9.6	-21.9	-2.9	0.00	0.22	-1.54
21	-4.8	-14.9	-2.9	-0.04	0.16	-0.76
22	-6.0	-9.5	-5.8	0.23	0.29	-0.70
23	-6.6	13.1	-8.0	0.29	-0.67	-1.38
24	-10.5	-20.4	-13.6	0.11	0.73	-1.17
25	-2.4	-8.6	-4.1	0.18	0.14	-0.40
26	-2.8	-5.8	-0.9	-0.10	0.12	-0.43
27	-5.9	-8.5	-1.3	-0.05	0.11	-0.49
28	-7.7	-9.6	-2.9	0.09	0.17	-0.76
29	-5.4	-11.2	-3.6	0.32	0.11	-0.74
30	0.4	-12.2	-9.0	1.01	0.25	-0.29
31	-2.3	-4.4	-1.2	0.06	0.05	-0.27
32	-4.0	-5.0	-0.5	0.04	0.00	-0.29
33	-4.4	-6.9	-3.8	1.07	-0.49	-0.34
34	-8.0	-10.6	-8.8	0.51	0.12	-0.61
35	-7.3	-15.2	-9.2	0.30	0.57	-1.19
36	-6.0	-11.1	-6.5	0.57	-0.08	-0.39
37	-2.4	-5.3	-4.3	0.31	0.16	-0.37
38	-16.8	-45.7	-11.5	-0.25	0.97	-3.54
39	-5.1	-10.2	-7.8	0.27	0.32	-0.60
40	-2.7	-4.9	-0.7	0.07	0.01	-0.31
41	-2.8	-2.5	-1.8	0.07	0.10	-0.26
42	-9.4	-12.6	-11.4	0.64	0.32	-0.87
43	-4.0	-5.4	-13.0	0.27	0.76	-0.40
44	-10.0	-14.5	-13.9	0.33	0.74	-1.02
45	-8.3	-9.4	3.1	-0.33	0.05	-0.75
46	-7.1	-6.9	-3.5	0.04	0.22	-0.52
47	-6.8	-19.1	-7.4	-0.37	0.62	-1.19
48	-9.4	-10.3	-3.4	0.22	0.06	-0.77
49	0.1	-18.3	-13.0	0.58	0.92	-1.29

			Little			
No	F_x (N)	F_y (N)	F_z (N)	M_x (Nm)	M_y (Nm)	M_z (Nm)
1	0.8	-4.6	-0.1	0.46	0.08	-0.04
2	2.2	-8.0	-1.9	-0.26	0.02	-0.39
3	-11.2	-6.4	-2.4	0.20	-0.11	-0.67
4	-3.8	-7.5	3.0	0.00	-0.19	-0.49
5	-2.3	-10.8	2.1	-0.24	-0.09	-0.66
6	-3.8	-10.6	8.8	-0.60	-0.47	-0.79
7	-8.0	-9.3	1.3	-0.13	0.00	-0.80
8	8.1	-6.2	-3.3	-0.26	-0.29	-0.14
9	-5.8	-6.7	-3.5	0.19	0.04	-0.39

10	-7.0	-6.5	-2.1	-0.20	0.30	-0.31
11	-7.9	-9.3	-4.8	-0.17	0.63	-0.93
12	-18.1	-18.2	-1.5	-0.29	0.43	-1.83
13	-7.4	-17.5	-5.8	-0.29	0.52	-1.21
14	4.2	-6.3	3.4	-0.54	-0.47	-0.21
15	-5.0	-5.2	2.6	-0.12	-0.04	-0.31
16	-6.2	-16.0	8.4	-0.92	-0.09	-0.85
17	-5.0	-4.7	2.3	-0.22	0.07	-0.36
18	-3.2	-9.9	7.7	2.75	-0.37	0.69
19	-2.6	-13.5	0.7	-0.78	0.10	-1.01
20	-4.3	-6.5	7.4	-0.52	-0.10	-0.39
21	-6.7	-9.2	1.8	-0.18	0.05	-0.37
22	-4.8	-5.3	2.4	-0.19	0.04	-0.29
23	-4.4	-5.9	1.1	-0.07	-0.05	-0.59
24	-18.5	-8.6	-4.3	0.06	0.08	-0.38
25	-2.2	-3.5	-0.6	0.08	-0.03	-0.15
26	-3.8	-12.0	4.7	-0.42	-0.29	-1.06
27	-3.6	-1.4	0.6	-0.04	0.05	-0.13
28	-6.2	-4.3	5.5	-0.31	-0.05	-0.40
29	-4.7	-6.2	-1.8	-0.05	0.15	-0.39
30	-4.5	-7.2	6.4	-0.50	-0.13	-0.50
31	-1.2	-1.5	1.1	-0.09	0.01	-0.09
32	-2.9	-2.3	1.5	-0.08	-0.02	-0.22
33	-5.6	-6.9	8.0	-0.87	-0.51	-1.06
34	-7.0	-9.0	5.4	-0.52	0.09	-0.52
35	-7.1	-6.2	-5.0	-0.01	0.44	-0.52
36	-4.8	-4.9	1.4	-0.03	-0.06	-0.30
37	-3.4	-3.2	0.0	-0.07	0.07	-0.28
38	-29.6	-17.0	6.1	-0.92	1.12	-1.34
39	-8.8	-11.3	-6.1	-0.02	0.29	-0.51
40	-0.6	1.5	6.0	-0.36	0.04	-0.04
41	-1.1	-1.6	1.3	-0.16	0.00	-0.13
42	-15.3	-11.5	-0.4	-0.05	0.08	-0.60
43	-7.9	-3.0	-1.2	-0.19	0.56	-0.21
44	-18.3	-19.7	3.6	-0.55	0.39	-0.72
45	-7.1	-9.6	2.2	0.04	-0.22	-0.80
46	-5.2	-5.2	1.5	-0.14	0.06	-0.30
47	0.0	0.0	0.0	0.00	0.00	0.00
48	-5.5	-4.6	2.6	-0.08	-0.09	-0.33
49	-8.4	-13.5	9.8	-0.59	-0.29	-0.90

A3. For the **Neutral** wrist position:

No			**Thumb**			
	F_x (N)	F_y (N)	F_z (N)	M_x (Nm)	M_y (Nm)	M_z (Nm)
1	-21.7	20.3	40.6	-1.99	0.55	-1.31
2	-80.4	11.7	18.2	-0.67	-0.76	-2.88
3	-60.7	54.0	12.9	-0.39	0.35	-3.12
4	48.6	-10.6	-34.8	1.85	-1.33	2.34
5	-63.0	11.9	3.1	-0.51	-0.24	-2.59
6	-59.4	17.1	32.2	-2.65	-2.16	-2.46
7	-45.3	-4.6	41.0	-2.45	-2.10	-2.37
8	-49.3	-8.5	35.1	-1.85	0.67	-2.44
9	-54.8	14.8	40.6	-2.07	-0.98	-1.48
10	-46.3	10.0	31.4	-1.22	-0.48	-1.49
11	-81.8	68.7	8.0	-0.14	0.23	-3.32
12	-98.0	11.9	13.7	-0.39	-1.68	-3.27
13	-87.4	15.4	-12.0	0.58	-0.04	-3.97
14	-79.9	32.2	14.9	-1.15	-0.16	-4.88
15	-53.0	24.0	39.8	-1.98	-0.71	-1.70
16	-90.6	60.9	31.8	-1.19	0.11	-4.56
17	-30.9	16.0	18.8	-1.11	-0.29	-1.63
18	-74.8	-12.7	47.5	7.54	9.10	14.61
19	-73.9	-17.9	37.3	-1.61	-1.88	-4.02
20	-49.4	-9.6	24.3	-0.85	-0.86	-2.11
21	-13.6	21.4	74.5	-3.31	-0.62	0.24
22	-53.0	25.2	39.4	-2.18	-1.17	-1.55
23	-53.0	18.1	61.3	-3.25	-1.25	-1.42
24	-41.9	1.7	44.3	-2.98	0.00	-1.83
25	-107.2	26.6	30.7	-1.38	-1.65	-4.16
26	-71.2	24.6	1.7	0.04	-0.25	-3.10
27	-51.8	29.4	60.1	-2.86	-0.57	-2.14
28	-43.2	6.4	31.5	-1.51	0.19	-2.09
29	-56.0	16.5	20.3	-1.04	-0.63	-2.56
30	-61.1	13.9	12.6	-0.63	-0.98	-2.19
31	-55.8	10.1	10.3	-0.52	-0.61	-2.44
32	-55.0	24.2	19.2	-0.84	-0.62	-1.84
33	-52.8	20.5	17.6	-0.84	-0.16	-2.48
34	-52.8	25.5	23.5	-1.37	1.86	-5.13
35	-57.4	31.8	54.0	-2.59	-1.39	-1.89
36	-45.7	10.6	-9.3	0.45	-0.25	-2.51
37	-41.6	32.6	18.6	-0.76	0.21	-2.08
38	-31.1	22.0	0.2	-0.64	-0.94	-1.85
39	-126.7	17.9	29.8	-1.61	-2.07	-5.82
40	-51.0	-18.0	-43.1	1.79	-0.71	-1.79
41	51.5	-18.7	-1.9	0.63	1.79	1.00

42	-33.9	5.7	10.9	-0.49	-0.65	-1.18
43	-66.1	37.6	70.4	-3.23	-0.34	-2.93
44	-63.9	44.3	4.8	-1.17	-1.60	-2.71
45	-91.5	9.0	-16.9	0.54	-1.21	-3.77
46	-16.7	-47.9	-41.6	-2.89	2.29	-1.35
47	-33.7	12.4	6.8	-0.51	-0.48	-1.72
48	-46.9	5.6	-19.0	0.96	-0.67	-2.48
49	-58.8	8.5	19.6	-0.77	0.10	-2.41
50	-92.0	48.1	65.5	-1.90	-1.22	-2.00

			Index			
No	F_x (N)	F_y (N)	F_z (N)	M_x (Nm)	M_y (Nm)	M_z (Nm)
1	-8.7	-16.3	-11.5	0.76	0.55	-1.39
2	5.3	-13.2	-12.9	1.15	0.50	-0.09
3	-2.8	-28.2	-15.0	1.35	0.61	-1.42
4	-5.4	-20.5	-7.8	0.80	0.28	-1.26
5	4.0	-14.0	-12.0	1.06	0.33	-0.06
6	-2.6	-16.2	-15.7	1.16	0.74	-0.96
7	1.3	-9.8	-10.5	1.02	0.38	-0.23
8	-8.1	-14.2	-13.4	0.88	0.43	-1.06
9	-3.0	-17.4	-14.8	1.00	0.44	-0.72
10	0.6	-22.7	-15.3	1.17	0.56	-0.78
11	-4.0	-27.9	-13.6	1.27	0.63	-1.66
12	-2.5	-10.6	-9.9	0.60	0.48	-0.66
13	-10.1	-28.1	-20.3	1.04	0.65	-1.46
14	0.6	-27.0	-36.4	1.85	2.25	-1.60
15	-5.7	-21.6	-8.6	0.80	0.25	-1.12
16	-11.5	-13.8	-38.3	1.06	1.84	-0.99
17	-10.0	-1.8	10.4	0.34	-0.25	0.30
18	-8.1	-24.4	-12.2	-1.91	-1.37	4.03
19	-5.3	-28.7	-28.8	1.34	1.60	-1.87
20	0.8	-25.4	-13.0	1.11	0.66	-1.18
21	-6.7	-28.6	-11.2	0.90	0.48	-1.67
22	1.7	-16.6	-16.0	1.28	0.42	-0.34
23	-3.2	-22.0	-18.6	0.87	0.71	-1.06
24	-0.6	-14.0	-10.8	1.18	0.38	-0.55
25	-4.1	-29.9	-27.1	1.93	1.05	-1.47
26	1.5	-38.7	-23.7	1.67	1.14	-1.75
27	-19.9	-37.0	-11.7	1.58	0.00	-2.64
28	-8.6	-12.6	-16.0	1.18	0.17	-0.77
29	-2.6	-13.7	-18.5	1.27	0.46	-0.52
30	-4.3	-11.3	-11.6	0.72	0.49	-0.75
31	-5.1	-13.6	-12.8	0.29	0.72	-0.90
32	5.1	-17.9	-9.3	0.95	0.61	-0.62

33	-9.3	-21.5	-8.4	0.95	0.04	-1.15
34	-0.3	-16.6	-7.0	0.79	0.60	-1.46
35	-6.2	-36.1	-12.8	0.99	0.79	-2.70
36	-1.5	-12.4	-12.9	0.78	0.61	-0.67
37	-10.7	-23.3	1.4	0.13	-0.13	-1.46
38	-2.0	-9.4	-4.4	0.32	0.29	-0.76
39	-15.1	-17.6	-24.2	1.46	0.72	-1.53
40	-4.6	-18.1	-17.2	0.75	0.87	-1.11
41	-4.6	-13.3	-7.2	0.52	0.22	-0.75
42	-4.7	-11.1	-6.9	-0.52	1.87	-2.63
43	-4.5	-47.1	-19.7	1.84	0.95	-2.72
44	6.6	-34.4	-6.6	1.92	0.62	-1.23
45	-16.7	-30.5	-27.5	-0.28	1.97	-2.13
46	0.4	-16.6	-13.3	1.03	0.65	-0.77
47	-2.7	-11.4	-10.6	0.58	0.62	-0.81
48	-1.7	-13.6	-17.9	0.71	1.02	-0.86
49	-4.5	-17.5	-18.1	1.12	0.69	-0.92
50	-8.5	-33.5	-13.6	0.33	0.94	-2.48

			Middle			
No	F_x (N)	F_y (N)	F_z (N)	M_x (Nm)	M_y (Nm)	M_z (Nm)
1	-2.4	-13.6	-4.7	0.49	0.28	-2.4
2	-6.8	-24.2	-15.9	-0.64	1.34	-6.8
3	3.3	-25.1	-3.6	0.30	0.23	3.3
4	-4.2	-14.9	-5.9	0.05	0.41	-4.2
5	-4.5	-12.4	-7.3	0.42	0.35	-4.5
6	-1.9	-15.0	-9.6	0.68	0.71	-1.9
7	-2.6	-15.2	-12.7	1.16	0.58	-2.6
8	3.7	-21.8	-17.8	0.52	1.08	3.7
9	-8.5	-24.9	-7.4	0.67	0.25	-8.5
10	2.9	-9.4	-6.4	0.46	0.37	2.9
11	-15.1	-50.4	-10.8	1.55	0.20	-15.1
12	-26.7	-32.6	-9.7	-0.44	1.23	-26.7
13	-6.0	-28.0	-13.4	0.04	0.83	-6.0
14	9.3	-14.3	-10.3	0.70	1.21	9.3
15	-3.5	-22.5	-8.5	0.37	0.49	-3.5
16	5.7	-48.5	-12.0	0.08	0.86	5.7
17	-2.7	-6.9	-7.5	-0.26	0.27	-2.7
18	-4.9	-33.1	-12.8	-0.40	-1.50	-4.9
19	-4.2	-13.9	-17.9	0.21	1.51	-4.2
20	-0.4	19.0	3.4	0.29	-0.20	-0.4
21	-6.9	-24.3	-1.7	-0.12	0.14	-6.9
22	8.3	-19.6	-4.7	1.08	0.63	8.3
23	-1.8	-24.3	-12.5	0.60	0.73	-1.8

24	-0.9	-15.7	-6.0	0.61	0.27	-0.9
25	-7.9	-39.4	-13.1	0.74	0.75	-7.9
26	-0.8	-14.6	-9.2	0.64	0.56	-0.8
27	-9.6	-19.7	-5.7	-0.14	0.52	-9.6
28	-10.9	-8.5	-1.6	-0.19	0.37	-10.9
29	-3.9	-9.8	-7.9	0.20	0.43	-3.9
30	2.4	-25.5	-12.3	0.85	0.76	2.4
31	-5.5	-12.4	-12.7	0.42	0.82	-5.5
32	0.3	-30.6	-9.8	1.02	0.52	0.3
33	-5.5	-20.0	-4.8	0.38	0.17	-5.5
34	-5.2	-27.0	-6.8	<u>2.51</u>	-0.14	-5.2
35	-0.7	-23.2	-9.3	0.53	0.62	-0.7
36	0.7	-15.4	-8.9	0.56	0.58	0.7
37	-0.9	-20.2	-0.8	0.81	-0.11	-0.9
38	-0.5	-13.7	-5.7	0.80	0.41	-0.5
39	-10.8	<u>-50.5</u>	-21.3	0.90	1.49	-10.8
40	2.0	-15.9	-13.7	0.65	0.78	2.0
41	-4.0	-21.6	-4.9	0.12	0.31	-4.0
42	-9.6	-11.9	4.3	-0.49	0.14	-9.6
43	-11.1	-26.9	-12.3	0.26	0.84	-11.1
44	-2.9	-29.1	-9.1	0.74	0.60	-2.9
45	1.4	-36.7	-20.4	0.27	1.53	1.4
46	-9.6	-18.3	-12.5	0.43	0.75	-9.6
47	-3.2	-10.3	-5.6	0.31	0.29	-3.2
48	-1.0	-9.8	-9.2	0.37	0.62	-1.0
49	-0.8	-6.2	-5.1	0.24	0.30	-0.8
50	7.1	-29.3	-6.1	<u>1.61</u>	0.77	7.1

			Ring			
No	F_x (N)	F_y (N)	F_z (N)	M_x (Nm)	M_y (Nm)	M_z (Nm)
1	-1.4	-7.3	-1.2	-0.12	0.11	-0.55
2	-1.5	-19.2	-11.8	0.04	0.87	-1.40
3	0.3	-18.4	-6.0	0.20	0.33	-0.98
4	-6.2	-12.7	-3.4	0.20	0.16	-0.95
5	-3.5	-16.6	-7.4	0.51	0.38	-1.07
6	-4.3	-16.6	-3.6	0.29	0.26	-1.52
7	-0.1	-16.6	-7.9	0.82	0.49	-1.05
8	-3.2	-12.2	-7.5	0.14	0.51	-0.94
9	-7.6	-14.3	-4.9	0.11	0.31	-1.05
10	0.2	-14.5	-8.8	0.43	0.48	-0.75
11	0.3	-21.4	-7.6	0.83	0.38	-1.02
12	<u>-15.1</u>	<u>-41.1</u>	-9.7	-0.37	0.89	<u>-3.18</u>
13	-4.5	-19.2	-9.6	0.31	0.54	-1.25
14	2.8	-6.7	-3.1	0.12	0.35	-0.67

15	-1.4	-17.5	-6.8	0.52	0.37	-1.05
16	-8.1	-29.7	3.3	-2.08	0.43	-1.30
17	-3.2	-6.7	-3.6	0.34	0.07	-0.43
18	-12.6	-26.8	-6.1	0.79	-1.27	3.95
19	-7.6	-14.8	-5.1	-0.03	0.48	-1.36
20	-3.3	-10.3	-5.4	0.07	0.28	-0.58
21	-9.1	-20.5	-6.1	0.18	0.31	-1.29
22	-6.5	-19.0	-8.1	-0.16	0.61	-1.31
23	-1.8	-20.6	-11.1	0.24	0.70	-1.38
24	-9.1	17.2	-4.7	-0.05	-0.45	-1.65
25	-6.0	-21.6	-11.9	0.22	0.81	-1.59
26	-4.0	-10.1	-5.4	0.13	0.40	-0.83
27	-5.9	-19.5	-2.7	-0.48	0.35	-1.46
28	-5.1	-5.0	-0.9	-0.02	0.09	-0.36
29	-5.3	-11.6	-4.3	0.03	0.26	-0.77
30	-6.1	-10.6	-6.8	0.39	0.34	-0.89
31	7.4	-11.2	-7.8	0.88	0.75	-0.25
32	0.6	-11.1	-4.1	0.16	0.23	-0.59
33	-5.8	-10.2	-3.7	0.15	0.14	-0.60
34	-6.2	-12.0	-6.0	1.81	-0.50	-0.88
35	-3.5	-13.9	-7.3	0.43	0.30	-0.77
36	-2.5	-10.0	-3.7	0.20	0.21	-0.73
37	-0.9	-8.4	-2.8	0.35	0.05	-0.26
38	-1.4	-12.5	-1.3	0.24	0.06	-0.96
39	-14.7	-44.1	-7.6	-0.81	0.88	-3.65
40	-4.1	-13.9	-7.9	0.35	0.35	-0.79
41	-5.3	-8.5	-7.5	0.19	0.49	-0.68
42	-4.4	-5.1	-4.3	0.15	0.24	-0.43
43	-3.9	-12.2	-7.8	0.57	0.33	-0.80
44	-4.6	-8.0	-7.8	0.24	0.54	-0.70
45	-5.1	-18.3	-8.7	0.21	0.62	-1.42
46	-6.6	-12.7	1.3	-0.61	0.23	-0.87
47	-1.8	-4.0	-3.4	0.06	0.23	-0.30
48	-5.3	-13.8	-5.1	-0.35	0.50	-0.99
49	-11.0	-21.8	-7.8	0.46	0.33	-1.57
50	3.0	-49.7	-13.6	1.48	0.96	-3.29

			Little			
No	F_x (N)	F_y (N)	F_z (N)	M_x (Nm)	M_y (Nm)	M_z (Nm)
1	-4.4	-5.5	1.4	-0.30	0.13	-0.44
2	-3.1	-9.7	-0.2	-0.21	0.08	-0.67
3	-9.1	-13.2	8.3	-0.29	-0.22	-0.73
4	-4.9	-9.7	5.9	-0.08	-0.35	-0.65
5	-10.6	-16.9	5.3	-0.20	-0.28	-1.28

6	-12.9	-14.8	3.0	-0.54	0.16	-1.57
7	-8.1	-12.3	0.0	-0.27	0.18	-1.03
8	-0.8	-6.3	2.7	-0.44	-0.08	-0.31
9	-2.9	-7.8	-0.6	-0.05	0.06	-0.54
10	-0.6	-5.1	-0.7	-0.09	0.06	-0.29
11	-2.0	-4.0	0.7	-0.07	0.00	-0.23
12	-5.3	-16.2	-0.2	-0.03	0.03	-1.31
13	-4.5	-12.6	1.6	-0.17	-0.06	-0.97
14	-3.8	-21.1	0.1	-0.49	0.07	-1.96
15	-6.9	-9.3	3.8	-0.20	-0.13	-0.70
16	-10.0	-17.2	3.9	-0.68	0.14	-1.15
17	-5.7	-7.0	2.2	-0.23	0.03	-0.50
18	-8.9	-3.7	4.2	1.17	-0.62	1.93
19	-5.9	-12.5	2.0	-0.58	0.12	-0.99
20	-0.5	-2.7	0.9	-0.11	-0.03	-0.14
21	-5.3	-8.8	7.2	-0.55	-0.14	-0.60
22	-7.8	-12.6	1.3	-0.48	0.21	-0.77
23	-5.6	-6.6	-0.9	-0.19	0.24	-0.60
24	-4.0	-13.3	6.9	-0.31	-0.38	-0.91
25	-10.3	-20.2	-4.0	0.18	0.21	-1.52
26	-1.1	-4.6	0.4	0.09	-0.05	-0.35
27	-1.4	-6.6	1.7	-0.11	-0.13	-0.59
28	-9.6	-5.8	1.8	-0.16	0.08	-0.52
29	-9.6	-12.1	6.5	-0.56	0.03	-0.76
30	-4.9	-9.0	-0.4	-0.06	0.06	-0.66
31	-2.3	-6.9	-1.0	-0.24	0.15	-0.48
32	-0.3	-3.4	0.3	-0.11	0.00	-0.16
33	0.8	-3.5	1.9	-0.20	-0.08	-0.07
34	-4.8	-8.4	3.8	0.22	-0.57	-0.97
35	-1.3	-7.7	3.0	-0.40	-0.08	-0.40
36	-1.8	-4.3	0.0	0.04	-0.02	-0.33
37	-3.1	-5.1	2.5	-0.20	-0.05	-0.34
38	-1.2	-2.8	1.0	-0.15	-0.02	-0.21
39	-29.6	-20.9	3.9	-1.22	1.31	-2.20
40	-4.8	-11.3	-2.6	-0.03	0.15	-0.63
41	1.4	-2.6	8.5	-0.65	0.39	0.22
42	-0.9	-2.1	1.8	-0.22	-0.02	-0.13
43	-5.7	-18.7	4.2	-0.11	-0.28	-1.39
44	1.1	-3.2	1.6	-0.26	-0.18	-0.17
45	-3.9	-13.6	-7.0	-0.54	0.47	-0.63
46	-2.9	-8.8	-0.1	-0.02	0.01	-0.71
47	-3.1	-7.5	0.7	-0.15	0.01	-0.66
48	-4.0	-5.3	-2.3	-0.14	0.32	-0.50
49	-4.8	-5.9	1.6	-0.17	0.00	-0.49
50	-7.2	-24.4	3.9	-0.91	-0.02	-1.73

A4. For the **Radial Deviation** of the wrist:

			Thumb			
No	F_x (N)	F_y (N)	F_z (N)	M_x (Nm)	M_y (Nm)	M_z (Nm)
1	-59.5	28.1	25.4	-0.99	-0.56	-1.74
2	-38.8	32.4	26.7	-1.19	0.03	-1.67
3	37.1	13.2	-18.6	0.57	-0.31	0.98
4	-47.2	27.9	-5.0	0.00	-0.20	-1.98
5	-49.2	36.2	35.2	-3.04	-1.84	-1.43
6	-39.6	29.7	44.9	-2.50	-1.37	-0.93
7	-68.5	16.6	10.4	-0.11	0.60	-2.06
8	-38.3	17.2	29.1	-1.25	-0.84	-0.66
9	-44.5	3.5	33.6	-0.57	-0.62	-0.72
10	-59.4	44.9	25.6	-1.06	0.25	-2.30
11	-72.8	37.3	17.0	-0.66	-0.19	-2.70
12	-65.7	29.4	-14.0	0.63	0.20	-2.50
13	-57.5	21.2	28.8	-1.95	-0.19	-3.57
14	-36.8	30.0	6.2	-0.25	0.06	-1.69
15	-58.4	37.0	13.1	-0.30	0.37	-2.62
16	-31.1	20.7	17.4	-0.96	-0.22	-1.38
17	-35.2	-32.2	-50.0	3.63	13.17	-11.03
18	-81.4	-4.4	-3.6	0.15	-2.02	-2.63
19	-40.0	24.9	47.2	-2.17	-0.59	-1.40
20	-38.2	25.5	30.2	-1.76	-0.67	-1.22
21	-68.6	15.0	53.7	-2.61	-1.45	-1.95
22	-63.1	16.7	6.9	-0.18	-0.26	-1.82
23	-33.4	20.6	36.0	-1.62	-0.28	-1.34
24	-62.1	24.8	2.5	-0.01	-0.09	-2.51
25	-58.9	23.6	35.5	-1.59	0.23	-2.73
26	-42.0	22.0	-7.0	0.12	0.19	-1.20
27	-19.2	42.9	-12.5	1.40	-0.18	-2.57
28	-40.0	23.2	25.5	-1.39	-0.71	-1.64
29	-51.0	-7.5	-8.7	0.29	-1.63	-0.20
30	-46.5	16.0	10.7	-0.51	-0.30	-1.83
31	-51.6	5.8	21.9	-1.04	-0.10	-2.29
32	-35.8	22.7	-4.8	-0.06	-0.41	-1.53
33	-21.3	21.0	3.2	-0.76	-0.69	-0.43
34	-46.0	-41.4	-46.1	1.73	-4.58	2.44
35	-49.2	-4.2	-39.2	1.38	-0.63	-1.63
36	-31.7	16.1	12.3	-0.84	-0.33	-1.66
37	-29.0	3.1	12.0	-0.52	-0.89	-1.01
38	-34.5	50.7	63.3	-3.10	-0.43	-1.34
39	-32.7	28.1	15.2	-1.15	-0.87	-1.04
40	-70.3	39.4	2.8	-0.48	-0.79	-2.70
41	-28.9	19.6	8.9	-0.61	-0.23	-1.44

42	-54.8	21.2	-1.1	0.03	0.28	-1.29
43	-73.5	16.3	10.2	-0.36	-1.10	-1.37

			Index			
No	F_x (N)	F_y (N)	F_z (N)	M_x (Nm)	M_y (Nm)	M_z (Nm)
1	5.4	-12.7	-14.0	1.04	0.53	-0.09
2	-1.3	-21.7	-15.3	1.21	0.76	-1.17
3	1.2	-20.3	-6.8	0.75	0.37	-0.99
4	8.5	-17.3	-13.3	1.14	0.49	0.05
5	-0.4	-14.1	-9.4	1.00	0.46	-0.72
6	2.0	-25.3	-7.7	1.34	0.35	-0.77
7	7.5	-19.3	-21.5	1.17	0.91	-0.44
8	-0.3	-14.0	-9.8	0.77	0.27	-0.42
9	-4.3	-19.2	-16.4	1.27	0.11	-0.49
10	-6.1	-22.7	-15.5	1.27	0.69	-1.40
11	5.7	-24.8	-32.8	1.23	1.73	-1.13
12	1.0	-32.5	-32.2	1.75	0.84	-0.84
13	1.9	-25.0	-39.1	1.48	2.63	-1.69
14	6.6	-17.8	-13.7	0.86	0.58	-0.38
15	1.8	-5.3	-31.6	1.19	0.80	-0.06
16	-6.3	-3.6	17.8	0.50	0.03	0.21
17	19.6	31.4	-32.8	8.26	-1.26	3.80
18	2.8	-22.7	-37.7	1.06	2.26	-1.28
19	-1.6	-12.6	-15.1	1.10	0.52	-0.54
20	3.6	-14.5	-12.6	1.13	0.37	-0.12
21	1.3	-23.0	-24.1	0.95	0.71	-0.78
22	11.6	-16.5	-22.3	1.14	0.93	-0.08
23	3.8	-17.0	-7.7	1.28	0.40	-0.26
24	3.8	-21.7	-19.6	1.26	0.68	-0.49
25	-2.6	-19.7	-23.7	1.90	0.82	-0.89
26	13.8	-19.5	-25.6	1.00	1.40	-0.54
27	-1.2	-12.3	-8.3	0.88	0.12	-0.29
28	-1.9	-17.6	-8.0	0.36	0.48	-1.16
29	23.9	-9.7	-19.7	0.26	1.45	-0.50
30	0.5	-17.0	-17.4	1.02	0.58	-0.56
31	3.8	-6.0	20.7	2.37	-0.38	-0.53
32	-6.0	-10.3	-4.8	0.36	0.23	-0.94
33	-0.3	-12.4	-6.1	0.20	0.38	-0.81
34	10.6	8.3	-33.1	-1.82	2.69	0.07
35	-1.0	-18.4	-14.4	0.97	0.61	-0.84
36	-2.0	-9.1	-7.4	0.63	0.24	-0.44
37	-0.2	-4.7	-7.5	0.12	1.62	-1.01
38	1.2	-31.7	-13.6	1.79	0.71	-1.57
39	1.0	-11.3	-1.4	0.70	0.08	-0.18

40	-0.9	-26.1	-21.8	0.40	1.29	-1.56
41	-0.1	-11.2	-9.4	0.64	0.53	-0.62
42	4.8	-20.0	-23.3	1.29	0.85	-0.46
43	-7.9	-27.6	-23.1	0.83	1.04	-1.49

			Middle			
No	F_x (N)	F_y (N)	F_z (N)	M_x (Nm)	M_y (Nm)	M_z (Nm)
1	-2.8	-21.3	-5.6	<u>-1.21</u>	0.51	-1.34
2	-2.5	-16.2	-5.2	0.11	0.34	-1.12
3	-2.3	-10.2	-4.9	0.10	0.28	-0.63
4	-1.7	-7.8	-4.6	0.16	0.23	-0.46
5	-2.4	-19.4	-5.3	0.86	0.26	-1.33
6	-2.2	-21.6	-8.5	1.01	0.31	-1.04
7	-3.0	-13.0	-13.2	0.04	0.79	-0.79
8	-6.2	-15.0	-2.9	0.13	0.14	-0.97
9	1.3	-7.9	-8.5	0.39	0.27	-0.20
10	1.8	-22.9	-14.1	0.93	1.00	-1.50
11	-3.3	-12.4	-8.0	0.48	0.56	-1.06
12	-1.5	-7.0	-9.8	0.30	0.48	-0.39
13	3.0	-3.2	-1.7	0.18	0.26	-0.22
14	0.3	-9.9	-7.3	0.41	0.36	-0.49
15	-0.3	-19.3	-12.1	0.41	0.70	-1.13
16	1.3	-6.7	-7.4	-0.27	0.34	-0.35
17	1.7	4.0	-6.9	1.29	-0.11	0.26
18	2.0	-8.5	-13.9	0.13	0.98	-0.58
19	-9.1	-15.0	-4.4	-0.02	0.32	-1.08
20	5.9	-11.6	-5.3	0.76	0.54	-0.34
21	0.5	-19.8	-10.4	0.49	0.62	-1.14
22	0.0	-4.3	-6.6	0.19	0.33	-0.23
23	-3.9	-15.2	-4.5	0.75	0.05	-0.86
24	-0.2	-14.9	-13.2	0.75	0.71	-0.81
25	-8.8	-19.4	-13.1	-0.06	0.98	-1.41
26	0.6	-0.4	-1.3	-0.03	0.06	-0.03
27	-3.8	-16.1	-4.4	0.25	0.20	-0.94
28	-1.3	-14.3	-10.3	0.57	0.79	-1.18
29	5.9	-2.1	-6.1	-0.18	0.54	-0.35
30	-1.3	-11.0	-5.5	0.25	0.24	-0.57
31	-1.3	-10.9	-7.9	0.63	0.36	-0.60
32	2.2	-13.3	-11.4	<u>1.74</u>	<u>-0.47</u>	<u>0.88</u>
33	1.8	-3.0	-1.3	0.09	0.12	-0.15
34	8.0	<u>10.9</u>	-20.9	<u>-2.31</u>	<u>2.36</u>	0.34
35	1.6	-10.2	-14.3	0.64	0.64	-0.39
36	-4.4	-9.0	-2.3	0.17	0.09	-0.68
37	-9.6	-9.9	-1.8	-0.19	0.32	-0.77

38	-5.9	-27.2	-12.9	1.51	0.46	-1.64
39	-3.8	-12.7	-0.9	0.46	-0.08	-0.84
40	-0.3	-21.7	-16.0	0.49	0.89	-1.25
41	-2.5	-10.0	-6.8	0.41	0.29	-0.58
42	1.9	-8.6	-6.8	0.19	0.34	-0.38
43	4.4	-11.7	-12.5	0.66	0.72	-0.43

			Ring			
No	F_x (N)	F_y (N)	F_z (N)	M_x (Nm)	M_y (Nm)	M_z (Nm)
1	1.1	-12.6	-2.0	0.62	0.20	-0.87
2	-1.9	-10.7	-6.3	0.03	0.42	-0.73
3	-1.8	-10.8	-4.1	0.64	0.01	-0.32
4	-3.4	-8.2	-3.2	0.10	0.17	-0.53
5	-7.5	-23.2	-4.4	0.81	0.06	-1.64
6	-1.5	-10.5	-3.3	0.30	0.14	-0.58
7	1.7	-10.1	-11.5	0.24	0.71	-0.58
8	-4.5	-12.3	-3.7	0.04	0.22	-0.77
9	-3.2	-6.7	-6.5	0.18	0.19	-0.29
10	6.0	-14.3	-7.4	0.68	0.68	-0.74
11	-4.6	-9.3	-4.3	0.20	0.35	-0.97
12	0.8	-9.6	-7.2	0.19	0.34	-0.44
13	-4.4	-6.1	-4.2	0.09	0.38	-0.65
14	-0.5	-5.3	-3.4	0.22	0.13	-0.23
15	-5.9	-10.0	-0.9	-0.44	0.31	-0.51
16	0.0	-3.8	-3.9	0.26	0.16	-0.16
17	-0.3	0.1	0.7	-0.17	0.02	-0.08
18	-3.1	-6.4	-4.9	0.07	0.36	-0.51
19	-9.9	-13.2	-8.8	0.34	0.38	-0.97
20	-4.9	-9.5	-5.4	-0.02	0.41	-0.70
21	0.6	-20.3	-16.1	0.30	1.14	-1.43
22	-6.2	5.5	-8.9	0.30	-0.60	-0.57
23	-2.0	-10.5	-2.3	0.23	0.09	-0.58
24	-3.5	-9.1	-8.2	0.32	0.45	-0.63
25	-2.5	-9.3	-1.0	-0.27	0.13	-0.57
26	1.2	-1.7	-6.1	-0.10	0.31	-0.13
27	-3.7	-6.2	-2.6	0.12	0.12	-0.45
28	4.1	-7.4	-4.1	0.75	0.43	-0.02
29	0.5	-1.1	-3.6	-0.08	0.27	-0.10
30	-3.9	-4.7	-3.9	0.11	0.17	-0.33
31	-4.3	-10.9	-5.5	0.51	0.16	-0.71
32	3.0	-6.0	-2.7	0.32	0.21	-0.12
33	0.4	-5.4	-1.4	0.15	0.10	-0.34
34	-0.4	4.2	-9.0	-0.90	1.07	0.54
35	-3.9	-9.4	-9.0	0.41	0.32	-0.51

36	-3.8	-4.8	-2.9	0.19	0.09	-0.40
37	-2.8	-3.2	-5.4	0.22	0.34	-0.31
38	-4.1	-11.5	-6.2	0.54	0.20	-0.71
39	-2.3	-9.5	-5.9	0.33	0.30	-0.59
40	-1.0	-10.5	-8.5	0.19	0.51	-0.66
41	-2.4	-3.2	-2.6	0.06	0.15	-0.24
42	0.2	-1.8	-7.0	0.09	0.29	-0.07
43	2.2	-6.6	-5.5	0.32	0.30	-0.23

			Little			
No	F_x (N)	F_y (N)	F_z (N)	M_x (Nm)	M_y (Nm)	M_z (Nm)
1	-5.4	-6.1	2.2	-0.37	0.12	-0.59
2	-2.4	-2.4	2.5	-0.25	0.03	-0.21
3	-0.4	-4.8	5.4	-0.17	-0.21	-0.21
4	-2.4	-10.5	6.3	-0.84	-0.06	-0.40
5	-5.0	-10.5	4.9	-0.37	-0.13	-0.63
6	-1.5	-6.6	4.6	-0.44	-0.10	-0.28
7	3.2	-8.7	0.4	-0.51	-0.20	-0.15
8	-1.9	-3.7	0.0	0.00	0.01	-0.27
9	-2.0	-6.4	0.5	-0.10	0.01	-0.23
10	1.2	-10.4	-0.3	-0.20	0.00	-0.51
11	-4.9	-12.2	10.6	-0.44	-0.54	-0.82
12	0.6	-5.9	0.5	-0.08	-0.02	-0.20
13	-5.9	-7.5	-0.4	-0.54	0.48	-0.71
14	0.3	-2.4	1.9	-0.08	-0.07	-0.07
15	2.2	-3.6	1.5	-0.19	-0.08	0.10
16	-2.4	-3.2	1.4	-0.19	0.04	-0.22
17	1.8	-0.9	-7.1	1.59	-0.27	0.45
18	-0.9	-14.6	0.0	-0.74	0.05	-0.85
19	-3.8	-8.7	2.3	-0.28	0.00	-0.47
20	-4.8	-11.5	0.9	-0.32	0.08	-0.56
21	-2.7	-11.9	-0.6	-0.30	0.11	-1.07
22	1.8	-14.0	2.1	-0.27	-0.14	-0.77
23	-2.2	-4.2	4.3	-0.30	-0.07	-0.22
24	-2.2	-3.2	0.3	0.00	-0.03	-0.24
25	-0.9	-6.3	4.6	-0.29	-0.20	-0.33
26	-0.1	-0.9	0.3	-0.04	0.00	0.00
27	-3.2	-4.4	4.1	-0.41	-0.02	-0.35
28	-0.6	-5.7	2.6	-0.23	-0.21	-0.50
29	1.1	-2.9	-1.2	-0.28	0.01	-0.26
30	0.6	-1.2	-0.3	-0.09	-0.06	0.03
31	-4.6	-6.0	0.8	-0.03	-0.05	-0.64
32	-3.3	-11.3	-3.4	0.08	0.12	-0.51
33	-0.9	-5.0	1.8	-0.18	-0.06	-0.31

34	-2.0	-4.7	-7.6	-0.68	1.05	-0.47
35	-2.8	-7.3	0.5	0.33	-0.14	-0.12
36	-0.2	-0.7	6.3	-0.45	0.07	0.00
37	-0.3	-2.3	0.3	-0.13	-0.01	-0.18
38	-1.9	-9.4	5.0	-0.19	-0.21	-0.48
39	-3.5	-6.0	4.0	-0.39	-0.11	-0.50
40	-0.2	-5.3	1.5	-0.16	-0.04	-0.16
41	0.4	-2.4	1.1	-0.23	0.00	0.10
42	-3.0	-8.0	1.4	-0.21	0.05	-0.12
43	-3.3	-12.4	-0.7	-0.10	0.04	-0.29

A5. For the **Ulnar Deviation** of the wrist:

			Thumb			
No	F_x (N)	F_y (N)	F_z (N)	M_x (Nm)	M_y (Nm)	M_z (Nm)
1	-15.1	6.4	42.5	-2.23	0.39	-0.84
2	-43.0	10.8	30.8	-1.57	-0.07	-2.14
3	-43.6	35.1	2.9	-0.21	-0.14	-2.03
4	31.6	37.5	6.6	0.07	0.17	-1.12
5	-63.0	4.5	0.0	-0.26	-0.34	-2.54
6	-59.5	25.9	17.9	-1.97	-1.91	-2.46
7	-51.7	10.8	50.1	-3.13	-2.49	-1.38
8	-56.8	14.1	0.0	0.14	0.55	-1.77
9	-52.3	-2.2	29.5	-1.04	-0.83	-1.58
10	-64.1	22.6	-14.9	0.52	0.04	-2.04
11	-91.9	29.7	-46.7	1.17	0.22	-2.14
12	-57.1	4.6	21.1	-1.28	-0.50	-3.01
13	-50.2	19.9	3.7	-0.26	-0.31	-2.13
14	-68.3	37.7	0.9	0.10	0.15	-2.72
15	-67.0	27.4	-8.8	4.47	14.27	8.63
16	-37.4	-1.7	24.6	-1.03	-0.68	-1.65
17	-22.1	15.9	32.3	-1.88	-0.18	-0.79
18	43.7	-12.5	6.6	-0.96	-5.51	-4.66
19	-56.9	3.4	25.0	-1.33	-0.73	-2.46
20	-62.5	21.1	14.1	-0.75	-0.44	-2.14
21	-69.4	11.5	29.6	-1.66	-0.84	-2.80
22	-47.9	17.8	22.1	-1.25	0.17	-2.63
23	-33.3	37.1	15.1	-0.87	-0.20	-1.73
24	-42.7	15.0	10.6	-0.63	-0.50	-1.78
25	-31.5	18.6	7.1	-0.59	-0.54	-1.48
26	-35.3	14.2	8.2	-0.45	-0.05	-1.63
27	-84.7	-10.9	17.2	-0.55	-1.74	-4.28
28	45.4	0.8	20.3	2.08	4.14	-4.84
29	-13.5	42.0	-25.2	-1.00	2.24	4.29
30	16.6	-68.8	-106.9	7.90	-10.87	8.19

31	-28.7	12.3	-1.4	-0.06	-0.33	-1.44
32	-31.1	-1.9	8.7	-0.32	-0.87	-1.42
33	-49.5	0.7	-15.7	0.59	-1.37	-1.91
34	-15.4	-34.5	-38.5	-2.43	2.08	-0.83
35	-30.4	17.9	2.1	-0.29	-0.34	-1.37
36	-63.1	-8.1	-28.5	0.96	-0.34	-1.91
37	-58.6	15.1	-11.6	0.47	0.35	-1.94

			Index			
No	F_x (N)	F_y (N)	F_z (N)	M_x (Nm)	M_y (Nm)	M_z (Nm)
1	-12.0	-13.8	-16.8	0.92	0.50	-1.07
2	1.0	-13.4	-11.6	1.48	0.19	-0.12
3	6.6	-17.0	-22.0	1.51	0.75	-0.14
4	2.4	-16.9	-8.9	0.59	0.33	-0.47
5	11.1	-10.0	-21.3	1.04	0.84	0.14
6	-3.3	-14.4	-16.1	0.99	0.63	-0.76
7	-0.9	-14.5	-12.2	0.93	0.35	-0.48
8	2.3	-11.7	-18.2	0.79	0.52	-0.25
9	2.9	-14.7	-23.4	1.33	0.91	-0.40
10	-3.0	-8.5	-15.2	0.61	0.69	-0.51
11	16.5	-40.5	-52.9	1.96	1.61	-0.75
12	1.1	-12.1	-34.3	1.16	1.74	-0.55
13	0.3	-13.2	-18.3	0.98	0.38	-0.26
14	2.3	-0.4	-42.1	1.62	0.75	0.03
15	7.3	-20.8	-21.5	-1.67	-4.46	3.78
16	-0.3	-28.8	-15.7	1.20	0.76	-1.42
17	-3.9	-5.6	-11.3	0.74	0.43	-0.45
18	-10.4	12.6	-9.8	-2.10	-0.53	1.54
19	1.7	-9.7	-29.3	1.22	1.14	-0.31
20	8.8	-13.1	-19.7	1.00	1.02	-0.28
21	3.8	-14.1	-23.6	1.51	0.95	-0.31
22	-3.1	-19.9	-29.2	1.81	0.98	-0.83
23	-1.1	-13.0	-7.2	0.84	0.10	-0.30
24	-4.9	-11.1	-9.9	0.77	0.31	-0.71
25	5.2	-13.0	-14.4	0.93	0.70	-0.28
26	-6.5	-11.7	-14.4	0.93	0.20	-0.59
27	-12.7	-11.2	-54.6	0.90	3.92	-1.01
28	-8.0	0.7	16.6	2.54	-0.23	1.23
29	16.9	-22.3	-12.1	-2.03	-1.73	0.32
30	39.5	58.8	-35.0	-7.39	6.64	2.59
31	-3.4	-8.5	-10.3	0.64	0.21	-0.37
32	-4.2	-6.6	-12.2	0.18	2.89	-1.65
33	5.1	-3.2	-12.6	0.62	0.61	0.08
34	2.3	-12.4	-20.2	1.02	0.91	-0.44

35	-6.2	-9.3	-9.8	0.61	0.33	-0.71
36	7.6	-20.4	-39.7	1.22	1.78	-0.72
37	4.9	-16.8	-29.2	1.49	0.60	-0.10

			Middle			
No	F_x (N)	F_y (N)	F_z (N)	M_x (Nm)	M_y (Nm)	M_z (Nm)
1	-1.4	-12.4	-5.9	0.54	0.30	-0.74
2	-5.0	-11.5	-2.6	0.22	0.11	-0.91
3	2.1	-10.9	-6.2	0.29	0.36	-0.55
4	3.8	-11.2	-6.5	0.04	0.25	-0.42
5	-1.5	-8.6	-16.7	0.54	0.81	-0.48
6	2.8	-16.4	-8.3	1.04	0.55	-0.73
7	2.2	-18.5	-14.7	1.08	0.68	-0.68
8	1.9	-11.8	-15.2	0.31	0.64	-0.50
9	5.8	-6.9	-14.2	0.57	0.85	-0.19
10	8.1	-21.8	-26.9	1.71	1.35	-0.60
11	4.1	-16.3	-15.4	-0.04	0.77	-0.82
12	2.2	-7.1	-8.5	0.34	0.70	-0.50
13	3.1	-6.0	-10.1	0.42	0.51	-0.17
14	4.7	-10.0	-8.7	0.33	0.56	-0.47
15	7.0	-17.3	-18.4	0.18	-3.16	3.06
16	-4.5	6.7	3.6	0.04	-0.25	0.52
17	-6.0	-12.0	-10.1	0.40	0.44	-0.76
18	9.2	-13.0	-6.2	0.11	-1.16	2.57
19	-0.2	-2.7	-5.9	0.10	0.37	-0.16
20	2.0	-14.7	-15.1	0.55	0.85	-0.75
21	-4.7	-19.7	-20.1	0.78	1.03	-1.18
22	-2.5	-5.4	-6.3	0.02	0.40	-0.36
23	-0.9	-18.9	-7.8	0.77	0.28	-0.75
24	-1.4	-12.3	-6.7	0.46	0.30	-0.66
25	-0.9	-2.0	-5.6	0.05	0.37	-0.15
26	0.8	-8.1	-5.0	0.45	0.12	-0.14
27	-0.9	-3.9	-12.1	-0.09	0.96	-0.31
28	-12.2	-10.9	5.1	1.38	-1.58	-0.08
29	2.7	-8.0	-6.5	0.63	0.67	-0.54
30	9.7	16.4	-9.5	-2.97	2.67	1.58
31	-1.5	-6.3	-3.9	0.19	0.17	-0.33
32	-6.8	-7.0	-2.8	0.02	0.21	-0.60
33	-0.4	-12.1	-16.3	0.46	1.02	-0.77
34	-1.7	-8.4	-10.5	0.49	0.55	-0.53
35	-3.4	-14.7	-5.8	0.43	0.17	-0.70
36	2.8	-11.1	-10.5	0.16	0.62	-0.61
37	-0.1	-4.5	-10.8	-0.36	0.48	-0.20

			Ring			
No	F_x (N)	F_y (N)	F_z (N)	M_x (Nm)	M_y (Nm)	M_z (Nm)
1	-1.6	-4.8	-1.4	-0.05	0.12	-0.35
2	-2.9	-9.3	-0.8	0.35	-0.06	-0.62
3	3.8	-6.3	-4.3	0.24	0.42	-0.42
4	-10.3	-12.6	-16.2	-0.58	-1.07	1.17
5	-6.2	-9.8	-6.9	0.05	0.41	-0.64
6	-6.7	-19.0	-6.4	0.19	0.53	-1.77
7	-1.9	-24.7	-18.7	0.84	1.07	-1.49
8	-5.1	-6.9	-13.4	0.33	0.73	-0.51
9	-0.1	-5.3	-5.7	0.11	0.33	-0.30
10	5.1	-13.0	-10.7	0.49	0.77	-0.71
11	0.4	-16.6	-15.0	-0.09	0.74	-0.82
12	2.5	-6.2	-9.1	-0.03	0.93	-0.65
13	-2.3	-11.3	-8.2	0.46	0.43	-0.72
14	-7.6	-10.9	3.5	-0.89	0.54	-0.23
15	-14.1	-9.2	-3.0	1.64	-2.94	1.33
16	-3.5	-2.5	-1.3	-0.09	0.18	-0.13
17	-3.7	-3.6	-8.6	0.21	0.45	-0.27
18	5.9	6.1	5.1	1.65	0.03	-1.92
19	-3.2	-13.7	-19.4	0.31	1.17	-0.88
20	-5.4	9.1	-7.0	0.35	-0.43	-0.83
21	-2.2	-11.9	-10.4	0.11	0.66	-0.76
22	-2.5	-7.6	-2.9	-0.06	0.21	-0.51
23	-5.7	-12.3	-2.4	0.12	0.11	-0.87
24	-5.2	-8.4	-6.0	0.37	0.27	-0.67
25	-3.4	-7.3	-3.2	0.13	0.17	-0.51
26	-4.8	-3.4	0.3	-0.18	0.21	-0.20
27	2.7	-3.7	-8.1	0.08	0.66	-0.26
28	-3.0	6.6	8.4	1.45	-0.72	1.09
29	2.2	-11.6	-7.2	-0.83	-0.40	0.40
30	10.4	18.8	-13.1	-3.26	3.58	2.57
31	-0.8	-3.8	-3.1	0.15	0.13	-0.21
32	-1.6	-2.1	-4.9	0.21	0.28	-0.19
33	-7.1	-7.2	-10.3	0.29	0.17	-0.34
34	-7.8	-10.6	0.7	-0.58	0.37	-0.69
35	-2.6	-5.3	-3.7	0.09	0.17	-0.32
36	-4.3	-7.2	-8.5	-0.27	0.61	-0.38
37	0.2	-6.3	-6.9	0.25	0.36	-0.32

			Little			
No	F_x (N)	F_y (N)	F_z (N)	M_x (Nm)	M_y (Nm)	M_z (Nm)
1	-1.5	-4.3	2.7	-0.40	0.00	-0.23
2	-2.7	-8.1	7.8	-0.63	-0.13	-0.36

3	6.4	-8.5	-4.3	-0.47	0.05	-0.80
4	-0.4	-11.3	2.2	-0.13	-0.06	-0.34
5	-7.3	-9.3	3.2	-0.45	0.27	-0.17
6	-11.1	-16.3	0.0	-0.67	0.46	-1.34
7	-5.0	-5.4	-3.6	0.20	0.00	-0.26
8	-1.3	-9.0	1.1	-0.57	0.05	-0.11
9	-6.5	-10.9	-1.0	-0.41	0.27	-0.38
10	-1.5	-6.3	-6.2	-0.20	0.25	-0.21
11	-1.7	-7.1	-1.1	-0.20	0.08	-0.27
12	-3.0	-2.9	1.2	-0.18	0.07	-0.13
13	-6.1	-10.7	-4.2	-0.11	0.24	-0.47
14	-8.7	-11.0	8.4	-0.54	0.16	-0.33
15	-4.2	-7.9	-0.7	0.83	-0.62	1.98
16	0.6	-4.5	-1.1	0.55	0.16	-0.38
17	-3.9	-5.9	1.8	-0.15	0.04	-0.20
18	-3.4	-6.0	5.3	1.10	-0.86	-0.27
19	-4.2	-7.3	-2.2	-0.38	0.34	-0.41
20	-0.7	-14.4	0.2	-0.84	0.02	-0.60
21	-4.6	-12.3	-3.5	0.02	0.12	-0.43
22	-3.5	-4.5	2.8	-0.24	0.07	-0.18
23	7.9	-3.1	7.5	0.16	-0.53	-0.38
24	-5.5	-9.3	3.3	-0.49	0.09	-0.57
25	0.9	-8.7	5.6	-0.30	-0.32	-0.44
26	1.1	-6.6	-3.3	0.50	0.00	0.19
27	-4.7	-10.8	-6.1	-0.91	0.76	-0.67
28	-6.0	4.8	4.6	0.65	-0.89	1.80
29	1.5	-1.9	-0.6	0.06	-0.08	0.38
30	-2.8	4.3	-5.8	-0.43	1.53	1.36
31	-0.5	-2.9	9.8	-0.71	0.46	0.10
32	-1.5	-5.3	1.9	-0.37	-0.05	-0.44
33	-8.5	-7.1	2.0	-0.64	0.67	-0.31
34	-4.4	-8.6	-0.3	-0.26	0.15	-0.67
35	-5.0	-8.3	1.9	-0.41	0.13	-0.51
36	0.1	0.8	0.2	0.03	-0.02	0.04
37	-5.2	-8.9	-5.7	-0.40	0.37	-0.22

J2: Boxplots of the loads

The boxplots of the loads on the digits on the metacarpal axis systems are shown below. The outliers and extreme load values on the following boxplots are the numbers marked with underline on the above tables. On the following graphs horizontal axes, the number indicates the digit (1=Thumb, 2=Index, 3=Middle, 4=Ring and 5=Little), the letter indicates the wrist orientation (F=Flexion, E=Extension, N=Neutral, RD=Radial Dev., and UD=Ulnar Dev.) and in parenthesis is the load.

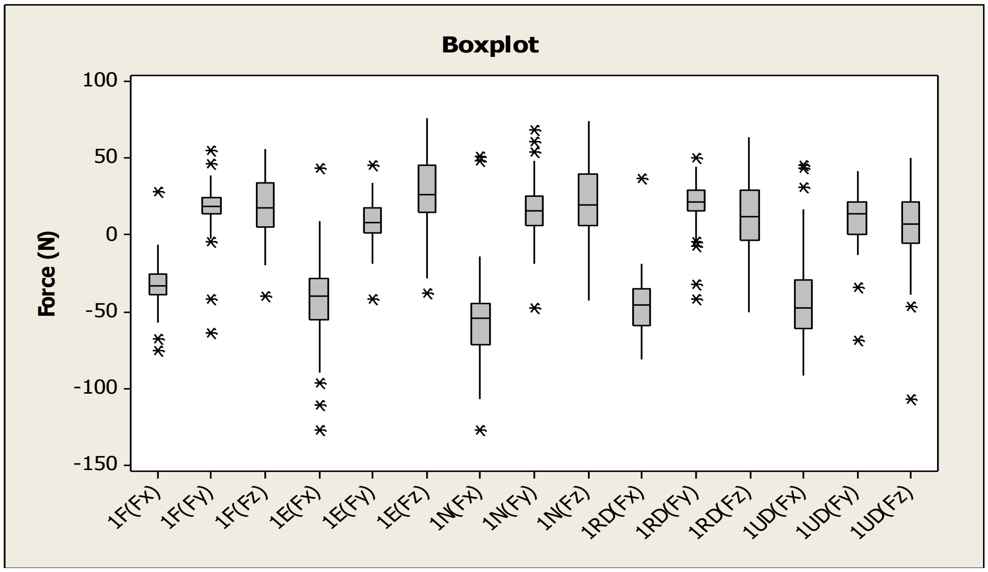


Figure J.1: *Boxplot of the forces on the thumb in the metacarpal axis system in the various wrist orientations.*

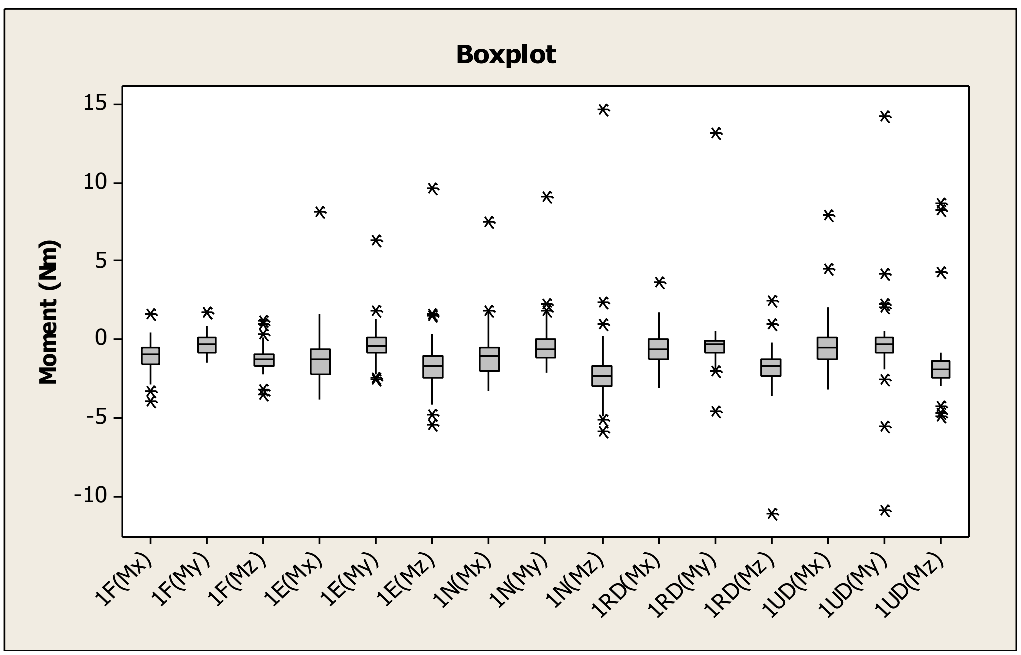


Figure J.2: *Boxplot of the moments on the thumb in the metacarpal axis system in the various wrist orientations.*

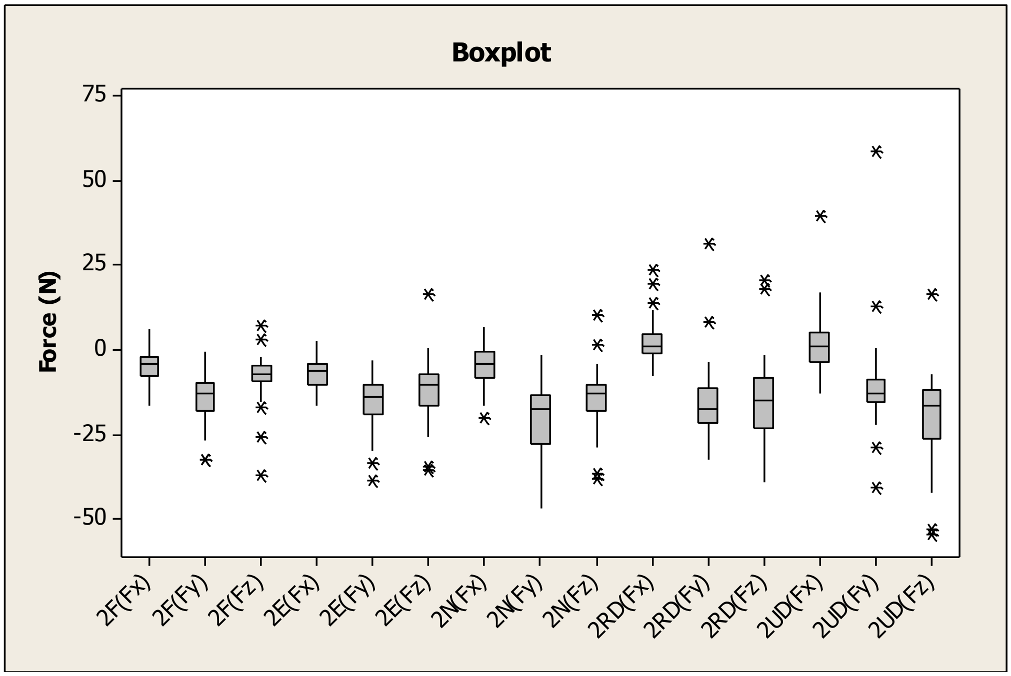


Figure J.3: *Boxplot of the forces on the index finger in the metacarpal axis system in the various wrist orientations.*

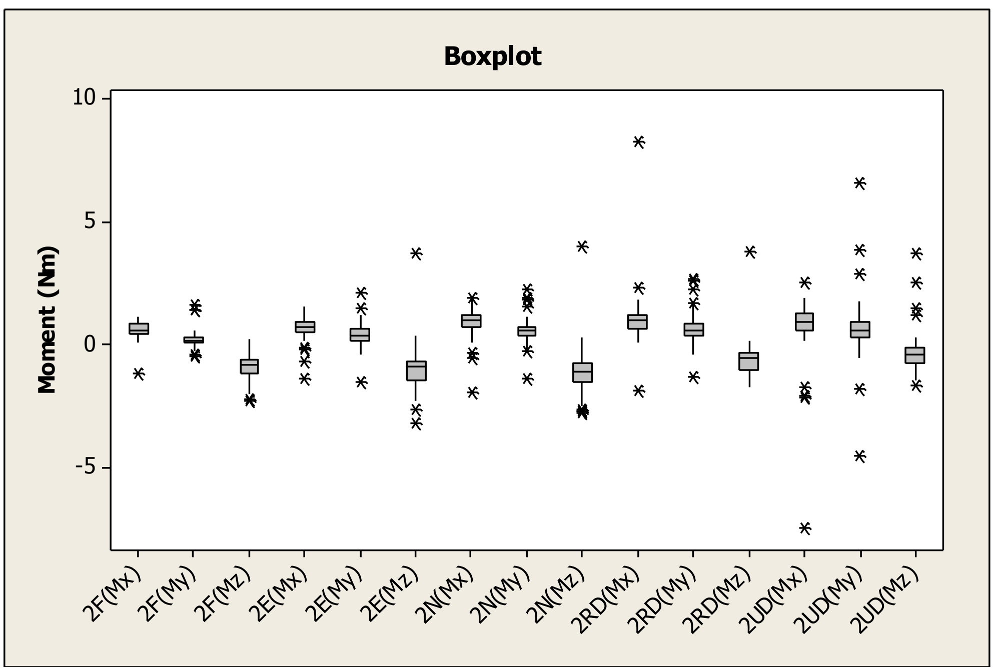


Figure J.4: *Boxplot of the moments on the index finger in the metacarpal axis system in the various wrist orientations.*

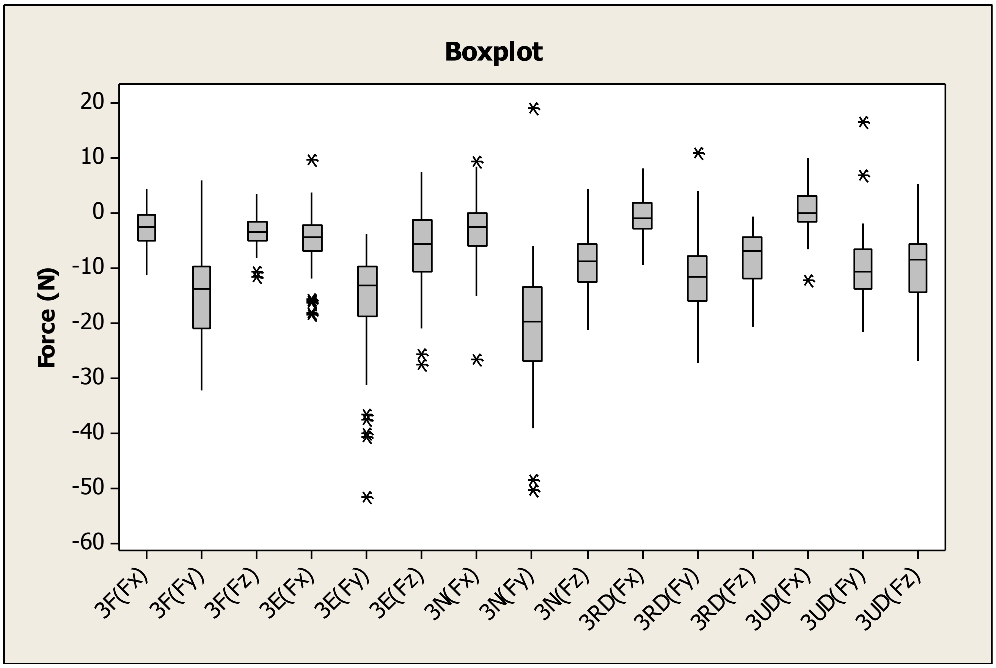


Figure J.5: *Boxplot of the forces on the middle finger in the metacarpal axis system in the various wrist orientations.*

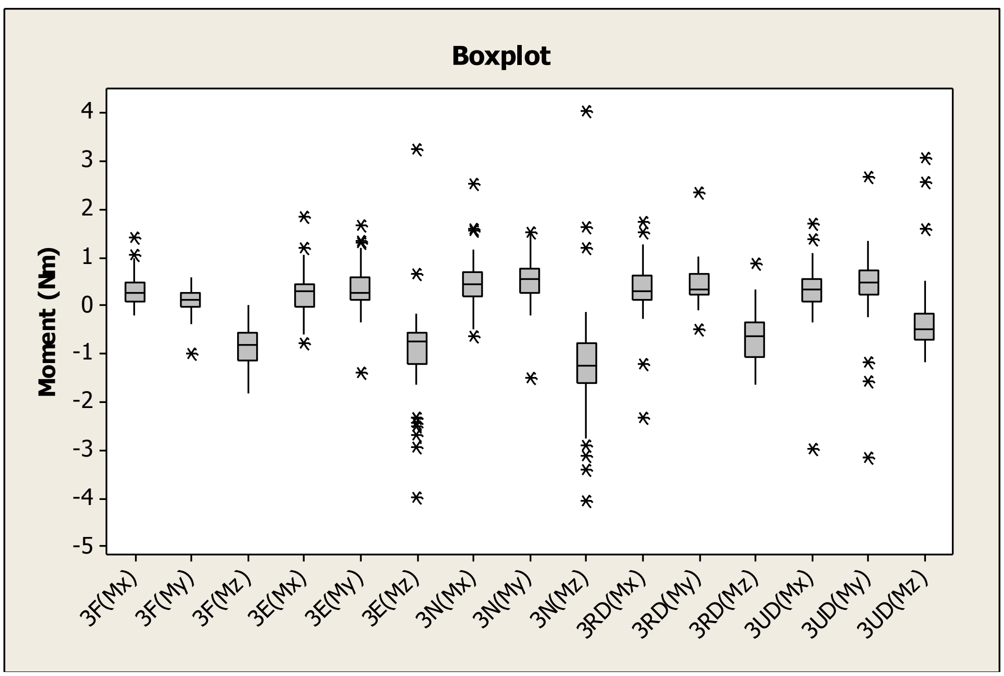


Figure J.6: *Boxplot of the moments on the middle finger in the metacarpal axis system in the various wrist orientations.*

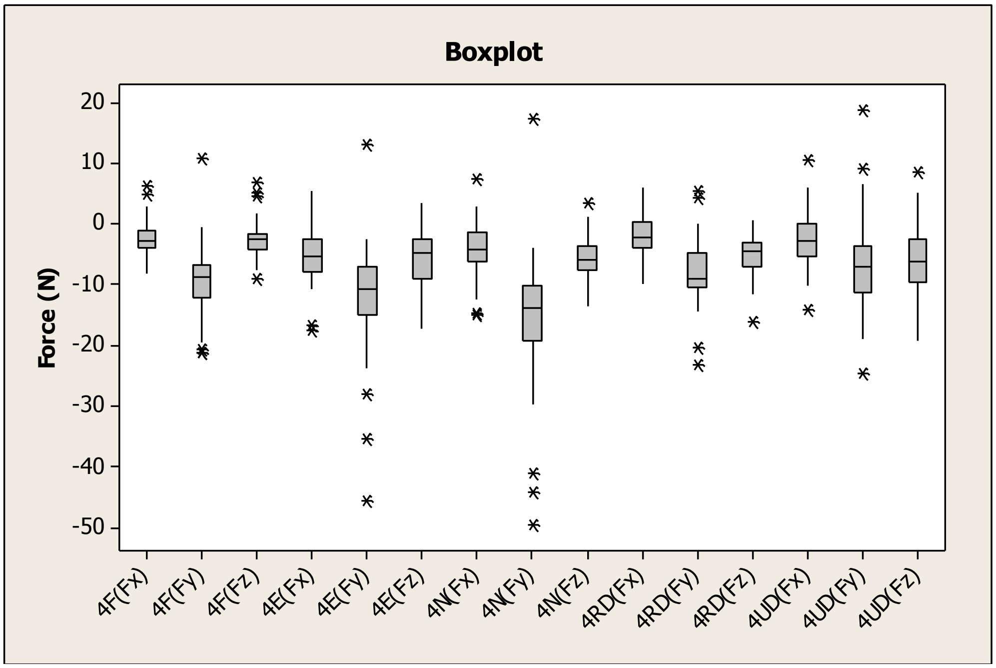


Figure J.7: *Boxplot of the forces on the ring finger in the metacarpal axis system in the various wrist orientations.*

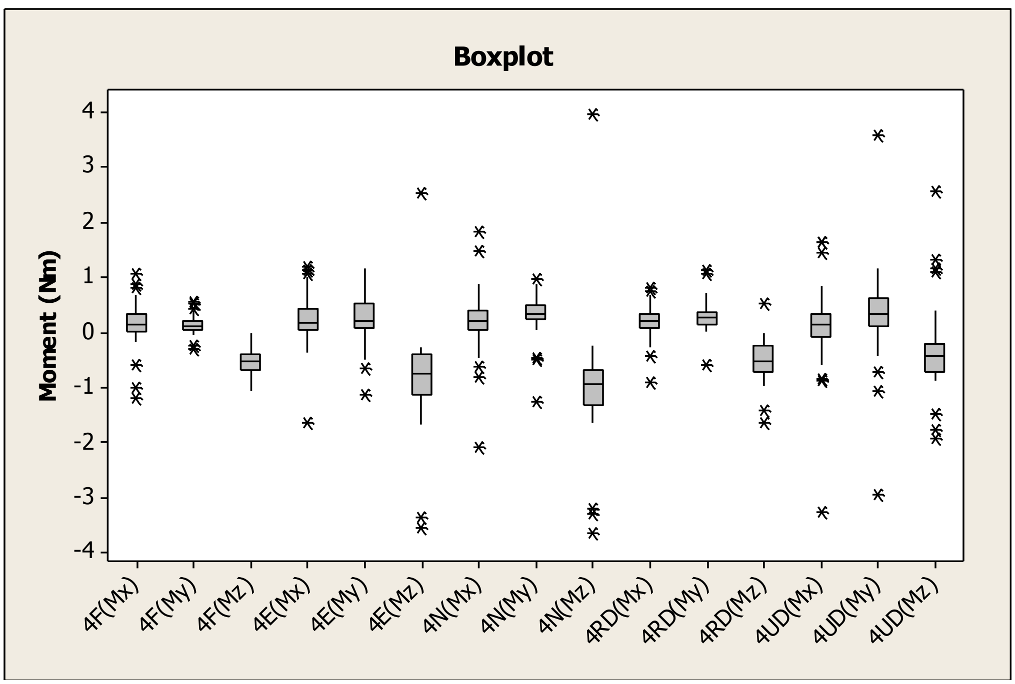


Figure J.8: *Boxplot of the forces on the ring finger in the metacarpal axis system in the various wrist orientations.*

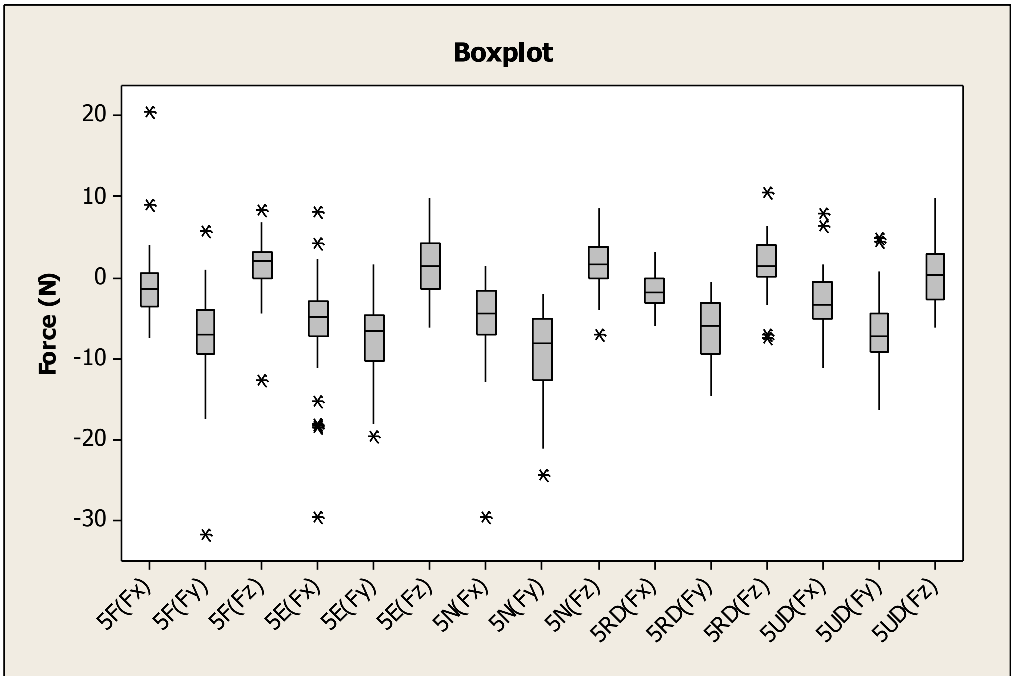


Figure J.9: *Boxplot of the forces on the little finger in the metacarpal axis system in the various wrist orientations.*

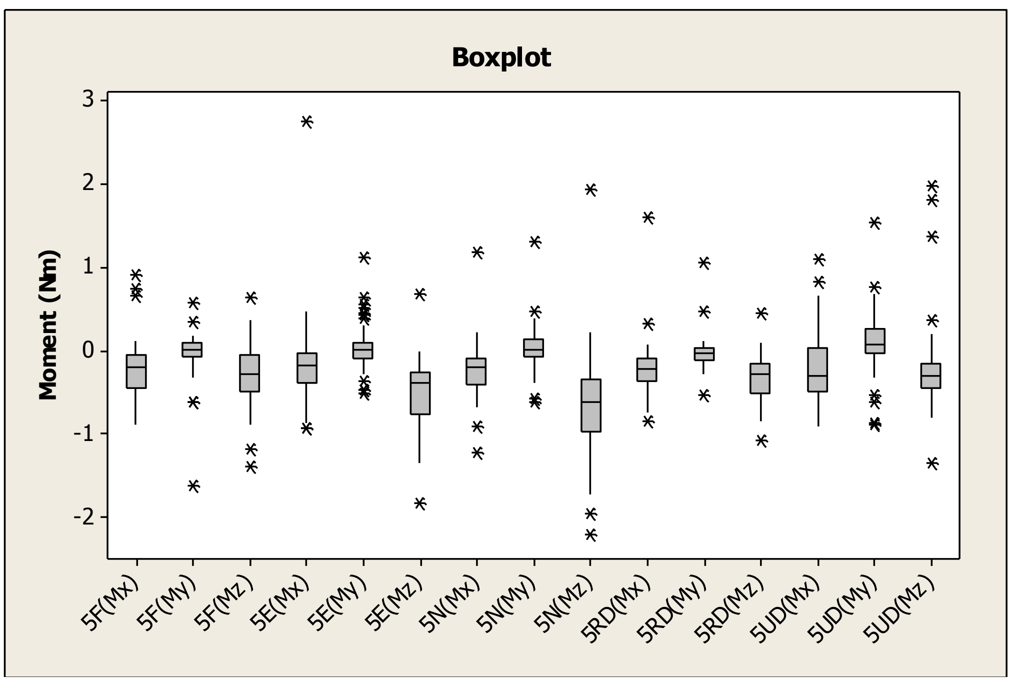


Figure J.10: *Boxplot of the moments on the little finger in the metacarpal axis system in the various wrist orientations.*

J3: Final sample size

The fine sample size, after the deduction of the extreme values, is presented in the following dataset Tables.

A1. For the **Flexion** of the wrist:

			Thumb			
No	F_x (N)	F_y (N)	F_z (N)	M_x (Nm)	M_y (Nm)	M_z (Nm)
1	-10.2	15.7	38.0	-1.86	0.27	-0.58
2	-37.3	17.8	22.9	-0.83	-0.20	-1.07
3	-37.7	36.0	18.3	-0.84	0.17	-1.93
4	-34.2	18.7	14.6	-0.69	0.21	-1.39
5	-20.1	12.8	36.1	-1.99	-1.38	-0.13
6	-50.7	19.6	42.0	-1.27	0.14	-1.55
7	-27.4	11.9	24.0	-1.13	-0.35	-0.79
8	-6.2	10.5	21.1	-0.91	0.10	-0.21
9	-45.4	22.0	-3.6	0.12	-0.12	-2.24
10	-36.4	23.9	34.0	-1.54	-0.16	-1.42
11	-32.7	16.0	42.2	-2.65	0.69	-1.83
12	-26.9	13.4	31.5	-1.68	-0.03	-0.96
13	-25.5	20.9	14.3	-0.88	-0.31	-1.10
14	-57.2	14.6	47.4	-2.17	-1.49	-2.05
15	-10.3	18.9	52.5	-2.10	-0.85	0.13
16	-12.1	17.1	32.9	-1.54	-0.39	0.18
17	-39.3	27.3	16.7	-0.93	-0.29	-1.67
18	-28.4	14.3	20.3	-1.11	-0.02	-1.12
19	-43.6	22.0	56.4	-2.46	-0.79	-1.17
20	-33.0	18.7	10.1	-0.43	-0.04	-1.26
21	-33.9	18.6	11.1	-0.13	0.53	-1.25
22	-37.8	26.3	12.8	-0.64	-0.24	-1.43
23	-29.2	15.0	18.1	-0.94	-0.48	-1.08
24	-29.0	19.2	4.6	-0.33	-0.26	-1.19
25	-35.9	12.2	11.1	-0.55	-0.15	-1.70
26	-52.7	36.8	50.0	-2.28	-0.88	-1.79
27	-45.1	15.9	5.4	-0.54	-0.79	-1.82
28	-39.1	29.8	3.8	-0.29	-0.09	-2.09
29	-23.6	20.6	-4.0	-0.55	-0.78	-0.80
30	-24.7	18.3	0.7	-0.21	-0.24	-1.29
31	-11.7	4.2	6.1	-0.35	-0.37	-0.42
32	-26.1	35.3	54.5	-2.85	-0.20	-1.23
33	-32.3	25.2	5.0	-0.73	-0.61	-1.42
34	-57.5	39.1	11.0	-1.08	-1.17	-1.56
35	-29.0	19.6	10.6	-0.72	-0.45	-1.08

36	-34.4	7.6	4.5	-0.30	-0.51	-1.19
37	-43.1	23.4	19.6	-0.59	0.33	-1.67

			Index			
No	F_x (N)	F_y (N)	F_z (N)	M_x (Nm)	M_y (Nm)	M_z (Nm)
1	-7.7	-9.6	-8.4	0.53	0.32	-0.84
2	-0.9	-10.3	-9.7	0.86	0.26	-0.37
3	-3.7	-16.8	-15.4	1.17	0.51	-0.85
4	-3.2	-15.6	-6.1	0.86	-0.09	-0.25
5	-4.6	-11.0	-2.8	0.45	0.07	-0.97
6	-2.1	-9.0	-6.4	0.64	0.15	-0.42
7	-1.9	-18.1	-7.2	0.73	0.26	-0.86
8	-6.2	-13.3	-7.2	0.63	0.10	-0.73
9	-4.1	-9.2	-3.5	0.54	-0.01	-0.59
10	-1.8	-11.3	-5.5	0.29	0.37	-0.84
11	-8.0	-17.4	-4.7	0.59	0.02	-1.07
12	-4.0	-17.9	-7.2	0.84	0.30	-1.19
13	-5.4	-9.6	-7.0	0.54	0.13	-0.60
14	-10.4	-26.9	-10.3	1.00	0.35	-1.99
15	-8.6	-15.9	-7.2	0.60	0.16	-1.10
16	-0.3	-9.1	-4.8	0.54	0.10	-0.26
17	0.4	-9.5	-2.9	0.45	0.14	-0.43
18	-11.5	-19.0	-6.2	1.00	-0.21	-1.22
19	-4.2	-12.8	-9.4	0.79	0.17	-0.57
20	-1.8	-14.2	-12.3	0.91	0.24	-0.43
21	-4.4	-11.5	-6.2	0.62	0.16	-0.73
22	-2.0	-10.9	-7.4	0.66	0.18	-0.45
23	-4.8	-17.3	-7.3	0.93	0.07	-0.78
24	1.3	-17.0	-3.6	0.84	0.27	-0.95
25	-7.9	-23.4	-10.9	0.96	0.57	-1.91
26	-2.9	-11.9	-8.6	0.74	0.36	-0.74
27	-9.9	-10.1	-2.8	0.23	0.02	-0.90
28	-1.7	-8.7	-2.0	0.12	0.11	-0.64
29	-2.9	-11.7	-5.8	0.37	0.27	-0.70
30	-3.2	-9.7	-5.4	0.45	0.14	-0.54
31	-5.6	-22.2	-8.4	1.05	0.24	-1.36
32	-0.2	-10.3	-3.6	0.73	0.05	-0.20
33	-5.6	-22.8	-9.5	0.24	0.59	-1.57
34	-2.5	-11.6	-4.9	0.54	0.12	-0.57
35	-3.8	-8.3	-9.3	0.59	0.46	-0.65
36	-3.7	-9.9	-6.0	0.45	0.22	-0.63
37	-5.7	-19.3	-7.6	0.78	0.19	-1.04
38	-15.9	-22.1	-10.4	0.44	0.46	-1.76

			Middle			
No	F_x (N)	F_y (N)	F_z (N)	M_x (Nm)	M_y (Nm)	M_z (Nm)
1	-4.0	-16.5	-1.9	0.45	0.01	-1.19
2	-0.4	-15.6	-4.3	0.14	0.23	-0.83
3	4.1	-26.9	-6.6	0.02	0.27	-1.11
4	-5.3	-15.0	3.3	-0.06	-0.18	-0.93
5	-2.5	-8.1	-0.4	0.10	-0.01	-0.44
6	-9.9	-20.7	-0.9	0.75	-0.28	-1.78
7	-4.8	-18.1	-7.8	0.97	0.18	-1.02
8	-2.7	-23.7	-8.3	0.04	0.45	-1.31
9	-5.9	-13.6	0.0	0.15	-0.06	-0.88
10	2.1	-6.8	-3.9	-0.03	0.29	-0.51
11	3.9	-24.3	-8.2	0.82	0.60	-1.37
12	-4.1	-20.5	-1.2	-0.05	0.08	-1.10
13	3.6	-21.3	-3.7	0.59	0.36	-1.58
14	-3.0	-13.2	-2.1	0.18	0.08	-0.75
15	-1.4	-25.7	-6.4	0.17	0.40	-1.67
16	-2.4	-9.2	-4.9	-0.20	0.19	-0.28
17	-8.0	-15.8	1.5	-0.20	-0.01	-1.03
18	2.1	-16.3	-2.0	0.68	0.17	-0.71
19	-0.6	-8.9	-2.2	0.11	0.11	-0.44
20	-0.4	-12.3	-5.3	0.32	0.26	-0.67
21	-6.1	-32.3	-0.6	0.60	-0.07	-1.73
22	-3.0	-10.9	-3.6	0.27	0.15	-0.66
23	0.5	-4.0	-4.4	-0.06	0.16	-0.16
24	-2.3	-10.0	-5.3	0.12	0.22	-0.47
25	-0.7	-8.5	-2.3	0.28	0.09	-0.42
26	-1.4	-14.5	-2.3	0.30	0.06	-0.62
27	-4.8	-10.0	-3.5	0.35	0.05	-0.63
28	-3.2	-27.2	-6.2	0.14	0.35	-1.62
29	-2.9	-13.8	-5.3	0.36	0.31	-1.02
30	-1.4	-22.6	-3.2	0.02	-0.03	0.03
31	0.4	-11.8	-1.8	0.28	0.12	-0.78
32	-0.7	-8.8	-4.3	0.36	0.16	-0.38
33	-2.7	-11.0	-1.7	0.08	0.08	-0.63
34	0.3	-1.5	0.7	-0.05	-0.05	-0.08
35	-9.4	-25.4	-2.5	0.47	-0.01	-1.80
36	-1.9	-11.8	0.1	0.25	-0.06	-0.70
37	-6.0	-27.0	-1.3	0.31	-0.01	-1.49
38	-6.6	-15.6	-5.3	0.63	0.02	-0.94
39	-2.5	-12.2	-3.5	0.21	0.15	-0.68
40	0.6	-13.2	-1.7	0.46	0.08	-0.53
41	-4.7	-19.1	-4.6	0.21	0.22	-1.09

			Ring			
No	F_x (N)	F_y (N)	F_z (N)	M_x (Nm)	M_y (Nm)	M_z (Nm)
1	-4.4	-7.9	-2.1	-0.13	0.25	-0.67
2	-0.9	-8.1	-7.6	0.00	0.40	-0.42
3	-3.5	-11.2	1.8	-0.17	-0.04	-0.64
4	-3.3	-7.4	-2.0	0.14	0.06	-0.43
5	-3.0	-9.1	-2.1	0.43	0.02	-0.68
6	-0.9	-10.3	-3.1	0.33	0.15	-0.58
7	-3.1	-6.5	-1.1	0.03	0.06	-0.45
8	-1.3	-4.0	-1.0	0.16	-0.01	-0.17
9	-6.1	-14.6	-1.9	-0.04	0.09	-0.53
10	-2.5	-9.2	-2.4	0.34	0.05	-0.52
11	-2.0	-8.5	-4.4	0.40	0.10	-0.37
12	-7.5	-8.8	-4.5	0.20	0.18	-0.70
13	-1.2	-8.4	-4.1	0.04	0.22	-0.46
14	-1.3	-11.7	-6.9	0.19	0.32	-0.58
15	-2.6	-6.1	-1.8	0.17	0.04	-0.39
16	-2.9	-11.2	-3.6	-0.14	0.30	-0.83
17	-1.7	-8.0	-3.5	0.10	0.13	-0.34
18	-3.7	-8.4	-2.2	0.23	0.05	-0.51
19	-1.5	-3.6	-1.5	0.07	0.06	-0.21
20	-4.6	-7.0	-2.6	0.14	0.08	-0.46
21	-5.6	-12.7	-1.8	0.08	0.12	-1.03
22	0.6	-10.7	-2.6	0.38	0.10	-0.31
23	-0.5	-8.4	-2.2	0.32	0.11	-0.45
24	-3.2	-5.9	-2.6	0.11	0.09	-0.33
25	-1.0	-4.0	-1.9	0.12	0.07	-0.20
26	0.0	-0.7	-0.6	0.02	0.02	-0.03
27	-3.2	-11.0	-4.4	0.35	0.18	-0.69
28	-3.9	-7.9	-4.9	0.37	0.17	-0.56
29	-4.9	-17.4	-2.8	0.06	0.17	-1.04
30	-1.3	-5.3	-1.7	0.00	0.09	-0.27
31	-2.6	-7.7	1.0	-0.12	-0.02	-0.41
32	-4.4	-9.7	-1.6	0.07	0.07	-0.58
33	0.6	-19.6	-6.7	0.53	0.31	-0.85

			Little			
No	F_x (N)	F_y (N)	F_z (N)	M_x (Nm)	M_y (Nm)	M_z (Nm)
1	-3.6	-3.6	2.3	-0.28	0.07	-0.33
2	-1.4	-3.6	2.8	-0.08	-0.03	-0.08
3	-1.4	-7.0	3.2	-0.47	0.18	0.12
4	-7.3	-9.5	2.7	0.04	-0.22	-0.75
5	-2.4	-8.9	6.4	-0.49	-0.32	-0.62
6	-3.2	-5.9	5.0	-0.26	0.11	-0.03

7	-1.4	-14.0	-0.7	-0.77	0.09	0.35
8	-0.4	-2.9	-0.7	0.03	0.04	-0.16
9	0.0	0.9	3.3	0.08	0.12	-0.04
10	-0.8	-5.8	2.8	-0.03	-0.05	-0.14
11	1.1	-8.7	2.9	-0.68	-0.22	-0.40
12	-3.1	-9.5	6.8	-0.89	0.05	-0.34
13	-5.2	-6.8	2.7	-0.34	0.12	-0.37
14	-1.3	-4.0	-0.9	-0.16	0.09	-0.15
15	0.0	-8.5	0.6	-0.42	-0.01	-0.27
16	-3.9	-6.5	2.7	-0.12	0.01	-0.22
17	-5.0	-1.9	0.1	0.00	0.00	-0.40
18	4.0	0.0	1.9	-0.16	-0.17	0.34
19	0.0	-4.6	2.5	-0.19	-0.03	-0.04
20	-3.5	-10.6	4.7	-0.48	0.15	0.00
21	-0.8	-4.0	-0.4	-0.16	0.05	-0.11
22	-0.3	-3.9	2.1	-0.31	0.00	-0.05
23	-0.5	-6.4	3.6	-0.29	-0.07	-0.16
24	-3.7	-4.0	-0.1	-0.10	0.11	-0.51
25	-4.2	-7.1	0.5	-0.20	0.10	-0.34
26	-0.2	-4.3	0.9	-0.11	-0.04	-0.21
27	-0.6	-9.3	-0.3	-0.41	0.05	-0.35
28	1.6	-2.4	1.5	-0.20	-0.02	0.18
29	1.0	-0.2	0.4	-0.03	-0.03	0.06
30	-3.0	-8.9	2.0	-0.20	-0.06	-0.67
31	-3.1	-11.7	2.7	-0.77	0.15	-0.39
32	2.8	-14.4	0.4	-0.50	-0.08	-0.53
33	-2.8	-4.8	0.7	-0.22	0.08	-0.35
34	-2.0	-7.7	-0.5	-0.22	0.09	-0.48
35	1.0	-7.8	3.0	-0.44	-0.09	-0.15
36	-4.8	-10.6	4.6	-0.57	0.07	-0.46

A2. For the **Extension** of the wrist:

			Thumb			
No	F_x (N)	F_y (N)	F_z (N)	M_x (Nm)	M_y (Nm)	M_z (Nm)
1	-19.0	27.2	37.9	-1.87	0.55	-1.27
2	-42.1	9.0	17.9	-0.49	-0.14	-1.19
3	-44.3	15.5	28.0	-1.31	0.29	-2.16
4	-50.9	6.8	25.7	-1.57	-0.33	-2.22
5	-15.0	34.4	50.8	-3.78	-0.80	0.34
6	-68.5	12.6	7.0	0.08	1.32	-2.40
7	-40.3	-0.4	45.9	-2.34	-0.70	-0.88
8	-46.1	-15.1	29.1	-1.17	-0.61	-1.84

9	-89.3	-9.5	44.8	-2.12	-1.68	-3.38
10	-27.7	16.6	53.0	-3.80	0.87	-2.20
11	-24.2	18.7	42.8	-2.00	-0.09	-0.55
12	-31.6	16.1	17.8	-0.98	-0.03	-1.73
13	-78.6	-19.0	26.0	-1.10	-1.04	-4.15
14	-18.4	17.9	48.3	-2.38	-0.21	-0.08
15	-33.3	8.3	32.8	-2.01	-0.30	-1.74
16	-29.4	3.9	42.7	-2.94	-0.32	-1.02
17	-78.1	-6.5	58.3	-2.17	-1.15	-2.44
18	-50.8	19.2	-1.6	0.28	0.29	-2.19
19	-79.8	13.8	53.3	-2.33	-1.54	-3.15
20	-36.3	26.6	23.3	-0.76	0.21	-1.37
21	-36.2	17.2	31.0	-1.65	-0.43	-1.78
22	-35.7	8.0	14.5	-0.65	-0.62	-1.32
23	-39.6	6.0	40.2	-1.74	-1.05	-1.57
24	-25.2	17.8	21.2	-1.01	-0.28	-0.92
25	-28.1	12.4	20.1	-0.83	0.17	-1.23
26	-34.3	8.6	58.7	-2.09	-1.35	-1.05
27	-60.3	-6.1	-13.9	0.74	-0.67	-2.84
28	-43.8	8.8	19.3	-0.94	0.08	-2.23
29	-31.0	4.3	-2.2	0.07	-0.72	-1.86
30	-23.0	13.5	14.7	-0.80	-0.15	-1.06
31	-18.4	3.2	9.7	-0.46	-0.51	-0.70
32	-48.4	13.6	67.0	-3.00	-0.59	-2.16
33	-34.8	-8.6	-9.3	0.61	-0.92	-1.30
34	-89.4	3.1	19.6	-0.80	-2.20	-3.56
35	-38.9	8.1	18.6	-0.90	-0.58	-1.68
36	-49.7	1.9	-14.8	0.80	-0.66	-2.42
37	-35.6	0.2	26.2	-1.14	0.09	-1.56
38	-77.7	21.5	42.2	-2.26	-0.91	-3.83

			Index			
No	F_x (N)	F_y (N)	F_z (N)	M_x (Nm)	M_y (Nm)	M_z (Nm)
1	-7.7	-18.2	-13.9	0.93	0.66	-1.41
2	-0.4	-13.5	-10.1	0.82	0.31	-0.47
3	-2.1	-14.3	-21.0	1.53	0.63	-0.59
4	-5.3	-22.6	-0.5	0.64	-0.11	-1.40
5	-0.8	-12.1	-10.1	0.98	0.18	-0.28
6	-9.8	-21.5	0.4	0.74	-0.35	-1.63
7	-0.9	-10.5	-7.6	0.75	0.25	-0.43
8	-1.8	-24.6	-13.7	0.76	0.46	-0.94
9	-7.8	-12.2	-13.2	0.76	0.26	-0.67
10	-7.8	-10.2	-16.6	0.92	0.39	-0.68
11	-15.0	-24.9	-14.6	1.00	0.52	-1.92

12	-5.7	-10.2	-16.2	1.12	0.80	-0.92
13	-5.9	-15.6	-7.8	0.61	0.19	-0.84
14	-13.4	-5.3	-26.0	1.10	1.23	-0.85
15	-5.8	-23.1	-7.1	0.69	0.34	-1.60
16	-3.3	-14.7	-11.3	1.01	0.17	-0.53
17	-10.8	-13.2	-13.0	0.98	0.25	-1.11
18	-3.1	-15.3	-8.4	1.00	0.28	-0.89
19	-10.0	-18.7	-24.4	1.56	0.52	-1.03
20	-7.3	-15.0	-17.0	0.90	0.38	-0.73
21	-4.0	-16.5	-21.3	1.53	0.85	-0.97
22	-5.5	-19.0	-10.9	0.83	0.23	-0.81
23	-4.0	-8.5	-10.8	0.87	0.20	-0.48
24	-3.5	-9.3	-10.1	0.68	0.41	-0.64
25	-0.5	-14.5	-6.4	0.65	0.30	-0.70
26	-8.6	-14.2	-7.0	0.75	-0.07	-0.74
27	-0.9	-12.4	-6.0	0.67	0.39	-0.88
28	-16.0	-23.7	-9.1	0.39	0.45	-1.82
29	-5.5	-8.8	-16.7	0.56	0.90	-0.66
30	-11.4	-12.5	-3.1	0.34	0.02	-1.24
31	-7.3	-7.8	-6.1	0.22	0.34	-0.71
32	-16.7	-11.5	-21.4	1.33	0.60	-1.45
33	-6.6	-15.3	-17.5	0.78	0.76	-0.94
34	-6.2	-8.7	-4.4	0.38	0.05	-0.63
35	-13.2	-23.7	-23.8	1.37	0.88	-1.68
36	2.6	-3.0	-8.5	0.43	0.39	-0.01
37	-5.5	-10.8	-9.7	0.78	0.12	-0.57
38	-6.0	-11.0	-9.7	0.57	0.43	-0.83
39	-4.9	-11.9	-15.5	0.65	0.77	-0.82
40	-6.5	-9.4	-7.3	0.55	0.20	-0.73

			Middle			
No	F_x (N)	F_y (N)	F_z (N)	M_x (Nm)	M_y (Nm)	M_z (Nm)
1	1.3	-16.7	-6.4	0.60	0.45	-1.06
2	0.3	-16.2	-8.2	-0.09	0.46	-0.91
3	-0.3	-10.0	-4.4	0.18	0.26	-0.60
4	-4.6	-11.2	2.1	-0.60	0.14	-0.58
5	-6.1	-18.0	-5.1	0.32	0.27	-1.34
6	-4.9	-15.9	1.7	0.70	-0.31	-0.87
7	-4.5	-23.9	-14.2	0.75	0.84	-1.65
8	-12.1	-19.5	-3.9	0.45	-0.02	-1.29
9	-2.3	-7.6	-12.5	0.44	0.59	-0.44
10	-6.9	-17.9	-15.7	-0.07	0.91	-1.01
11	-0.2	-6.1	0.1	0.24	-0.02	-0.53
12	-2.8	-19.7	-5.1	0.28	0.21	-0.96

13	-0.8	-4.4	-3.2	-0.12	0.13	-0.15
14	-2.6	-11.8	-12.0	0.20	0.85	-0.90
15	3.5	-14.2	-1.5	0.74	0.23	-0.39
16	-2.8	-7.6	-3.6	0.25	0.15	-0.51
17	-3.4	-13.8	-5.4	0.35	0.31	-1.06
18	-4.7	-13.2	-9.2	0.39	0.35	-0.71
19	-3.9	-13.2	-1.2	-0.24	0.14	-0.71
20	-6.2	-15.9	-5.7	0.38	0.23	-1.05
21	-1.0	-7.6	-1.5	0.14	0.06	-0.44
22	-8.8	-13.2	-0.9	-0.21	0.22	-1.17
23	-3.5	-14.3	-5.1	0.27	0.23	-0.82
24	-4.3	-8.7	-0.9	0.14	-0.01	-0.43
25	-5.1	-12.6	-3.0	1.06	-0.26	-0.71
26	-6.8	-12.0	-0.9	-0.18	0.15	-0.74
27	-1.2	-12.1	-13.5	0.37	0.84	-0.78
28	-2.8	-5.3	-5.5	0.24	0.31	-0.43
29	-2.9	-10.1	-10.9	0.25	0.58	-0.61
30	-4.7	-8.4	0.8	-0.05	-0.02	-0.57
31	-4.4	-4.9	2.3	-0.22	0.02	-0.37
32	-11.6	-14.9	-8.0	0.35	0.36	-1.17
33	-2.1	-3.9	-7.1	0.25	0.37	-0.27
34	-6.0	-10.9	-5.8	0.43	0.12	-0.67
35	-6.8	-9.2	-5.6	0.30	0.17	-0.64
36	-1.5	-11.3	-10.7	0.37	0.62	-0.74
37	-6.5	-9.8	-7.0	0.40	0.23	-0.69

			Ring			
No	F_x (N)	F_y (N)	F_z (N)	M_x (Nm)	M_y (Nm)	M_z (Nm)
1	-1.8	-5.9	-1.1	0.05	0.08	-0.46
2	-2.1	-10.8	-7.1	0.16	0.42	-0.68
3	-4.0	-9.3	-7.5	0.19	0.39	-0.58
4	-5.1	-10.0	-2.4	0.46	-0.09	-0.60
5	-5.4	-15.8	-7.3	0.41	0.36	-1.08
6	-5.2	-12.1	2.1	0.35	-0.30	-0.96
7	-3.5	-23.1	-5.8	0.89	0.21	-1.35
8	5.3	-14.1	-11.4	0.10	0.65	-0.76
9	-8.1	-11.0	-3.3	0.08	0.19	-0.83
10	-5.0	-7.0	-11.9	0.02	0.70	-0.42
11	-10.8	-15.1	-13.1	0.00	0.77	-0.87
12	-1.9	-11.1	-4.0	0.50	0.34	-1.16
13	-0.7	-12.4	-2.5	0.48	0.06	-0.43
14	-1.2	-6.3	-4.8	0.35	0.17	-0.32
15	-7.3	-9.5	-5.5	0.09	0.49	-0.94
16	-9.6	-21.9	-2.9	0.00	0.22	-1.54

17	-4.8	-14.9	-2.9	-0.04	0.16	-0.76
18	-6.0	-9.5	-5.8	0.23	0.29	-0.70
19	-10.5	-20.4	-13.6	0.11	0.73	-1.17
20	-2.4	-8.6	-4.1	0.18	0.14	-0.40
21	-2.8	-5.8	-0.9	-0.10	0.12	-0.43
22	-5.9	-8.5	-1.3	-0.05	0.11	-0.49
23	-7.7	-9.6	-2.9	0.09	0.17	-0.76
24	-5.4	-11.2	-3.6	0.32	0.11	-0.74
25	0.4	-12.2	-9.0	1.01	0.25	-0.29
26	-2.3	-4.4	-1.2	0.06	0.05	-0.27
27	-4.0	-5.0	-0.5	0.04	0.00	-0.29
28	-8.0	-10.6	-8.8	0.51	0.12	-0.61
29	-7.3	-15.2	-9.2	0.30	0.57	-1.19
30	-6.0	-11.1	-6.5	0.57	-0.08	-0.39
31	-2.4	-5.3	-4.3	0.31	0.16	-0.37
32	-5.1	-10.2	-7.8	0.27	0.32	-0.60
33	-2.7	-4.9	-0.7	0.07	0.01	-0.31
34	-2.8	-2.5	-1.8	0.07	0.10	-0.26
35	-9.4	-12.6	-11.4	0.64	0.32	-0.87
36	-4.0	-5.4	-13.0	0.27	0.76	-0.40
37	-10.0	-14.5	-13.9	0.33	0.74	-1.02
38	-8.3	-9.4	3.1	-0.33	0.05	-0.75
39	-7.1	-6.9	-3.5	0.04	0.22	-0.52
40	-6.8	-19.1	-7.4	-0.37	0.62	-1.19
41	-9.4	-10.3	-3.4	0.22	0.06	-0.77
42	0.1	-18.3	-13.0	0.58	0.92	-1.29

			Little			
No	F_x (N)	F_y (N)	F_z (N)	M_x (Nm)	M_y (Nm)	M_z (Nm)
1	0.8	-4.6	-0.1	0.46	0.08	-0.04
2	2.2	-8.0	-1.9	-0.26	0.02	-0.39
3	-11.2	-6.4	-2.4	0.20	-0.11	-0.67
4	-3.8	-7.5	3.0	0.00	-0.19	-0.49
5	-2.3	-10.8	2.1	-0.24	-0.09	-0.66
6	-8.0	-9.3	1.3	-0.13	0.00	-0.80
7	-5.8	-6.7	-3.5	0.19	0.04	-0.39
8	-7.0	-6.5	-2.1	-0.20	0.30	-0.31
9	-5.0	-5.2	2.6	-0.12	-0.04	-0.31
10	-6.2	-16.0	8.4	-0.92	-0.09	-0.85
11	-5.0	-4.7	2.3	-0.22	0.07	-0.36
12	-2.6	-13.5	0.7	-0.78	0.10	-1.01
13	-4.3	-6.5	7.4	-0.52	-0.10	-0.39
14	-6.7	-9.2	1.8	-0.18	0.05	-0.37
15	-4.8	-5.3	2.4	-0.19	0.04	-0.29

16	-4.4	-5.9	1.1	-0.07	-0.05	-0.59
17	-2.2	-3.5	-0.6	0.08	-0.03	-0.15
18	-3.8	-12.0	4.7	-0.42	-0.29	-1.06
19	-3.6	-1.4	0.6	-0.04	0.05	-0.13
20	-6.2	-4.3	5.5	-0.31	-0.05	-0.40
21	-4.7	-6.2	-1.8	-0.05	0.15	-0.39
22	-4.5	-7.2	6.4	-0.50	-0.13	-0.50
23	-1.2	-1.5	1.1	-0.09	0.01	-0.09
24	-2.9	-2.3	1.5	-0.08	-0.02	-0.22
25	-7.0	-9.0	5.4	-0.52	0.09	-0.52
26	-4.8	-4.9	1.4	-0.03	-0.06	-0.30
27	-3.4	-3.2	0.0	-0.07	0.07	-0.28
28	-8.8	-11.3	-6.1	-0.02	0.29	-0.51
29	-0.6	1.5	6.0	-0.36	0.04	-0.04
30	-1.1	-1.6	1.3	-0.16	0.00	-0.13
31	-7.1	-9.6	2.2	0.04	-0.22	-0.80
32	-5.2	-5.2	1.5	-0.14	0.06	-0.30
33	0.0	0.0	0.0	0.00	0.00	0.00
34	-5.5	-4.6	2.6	-0.08	-0.09	-0.33
35	-8.4	-13.5	9.8	-0.59	-0.29	-0.90

A3. For the **Neutral** wrist position:

			Thumb			
No	F_x (N)	F_y (N)	F_z (N)	M_x (Nm)	M_y (Nm)	M_z (Nm)
1	-21.7	20.3	40.6	-1.99	0.55	-1.31
2	-80.4	11.7	18.2	-0.67	-0.76	-2.88
3	-63.0	11.9	3.1	-0.51	-0.24	-2.59
4	-59.4	17.1	32.2	-2.65	-2.16	-2.46
5	-45.3	-4.6	41.0	-2.45	-2.10	-2.37
6	-49.3	-8.5	35.1	-1.85	0.67	-2.44
7	-54.8	14.8	40.6	-2.07	-0.98	-1.48
8	-46.3	10.0	31.4	-1.22	-0.48	-1.49
9	-98.0	11.9	13.7	-0.39	-1.68	-3.27
10	-87.4	15.4	-12.0	0.58	-0.04	-3.97
11	-79.9	32.2	14.9	-1.15	-0.16	-4.88
12	-53.0	24.0	39.8	-1.98	-0.71	-1.70
13	-30.9	16.0	18.8	-1.11	-0.29	-1.63
14	-73.9	-17.9	37.3	-1.61	-1.88	-4.02
15	-49.4	-9.6	24.3	-0.85	-0.86	-2.11
16	-13.6	21.4	74.5	-3.31	-0.62	0.24
17	-53.0	25.2	39.4	-2.18	-1.17	-1.55
18	-53.0	18.1	61.3	-3.25	-1.25	-1.42

19	-41.9	1.7	44.3	-2.98	0.00	-1.83
20	-107.2	26.6	30.7	-1.38	-1.65	-4.16
21	-71.2	24.6	1.7	0.04	-0.25	-3.10
22	-51.8	29.4	60.1	-2.86	-0.57	-2.14
23	-43.2	6.4	31.5	-1.51	0.19	-2.09
24	-56.0	16.5	20.3	-1.04	-0.63	-2.56
25	-61.1	13.9	12.6	-0.63	-0.98	-2.19
26	-55.8	10.1	10.3	-0.52	-0.61	-2.44
27	-55.0	24.2	19.2	-0.84	-0.62	-1.84
28	-52.8	20.5	17.6	-0.84	-0.16	-2.48
29	-57.4	31.8	54.0	-2.59	-1.39	-1.89
30	-45.7	10.6	-9.3	0.45	-0.25	-2.51
31	-41.6	32.6	18.6	-0.76	0.21	-2.08
32	-31.1	22.0	0.2	-0.64	-0.94	-1.85
33	-51.0	-18.0	-43.1	1.79	-0.71	-1.79
34	-33.9	5.7	10.9	-0.49	-0.65	-1.18
35	-66.1	37.6	70.4	-3.23	-0.34	-2.93
36	-63.9	44.3	4.8	-1.17	-1.60	-2.71
37	-91.5	9.0	-16.9	0.54	-1.21	-3.77
38	-33.7	12.4	6.8	-0.51	-0.48	-1.72
39	-46.9	5.6	-19.0	0.96	-0.67	-2.48
40	-58.8	8.5	19.6	-0.77	0.10	-2.41
41	-92.0	48.1	65.5	-1.90	-1.22	-2.00

			Index			
No	F_x (N)	F_y (N)	F_z (N)	M_x (Nm)	M_y (Nm)	M_z (Nm)
1	-8.7	-16.3	-11.5	0.76	0.55	-1.39
2	5.3	-13.2	-12.9	1.15	0.50	-0.09
3	-2.8	-28.2	-15.0	1.35	0.61	-1.42
4	-5.4	-20.5	-7.8	0.80	0.28	-1.26
5	4.0	-14.0	-12.0	1.06	0.33	-0.06
6	-2.6	-16.2	-15.7	1.16	0.74	-0.96
7	1.3	-9.8	-10.5	1.02	0.38	-0.23
8	-8.1	-14.2	-13.4	0.88	0.43	-1.06
9	-3.0	-17.4	-14.8	1.00	0.44	-0.72
10	0.6	-22.7	-15.3	1.17	0.56	-0.78
11	-4.0	-27.9	-13.6	1.27	0.63	-1.66
12	-2.5	-10.6	-9.9	0.60	0.48	-0.66
13	-10.1	-28.1	-20.3	1.04	0.65	-1.46
14	-5.7	-21.6	-8.6	0.80	0.25	-1.12
15	0.8	-25.4	-13.0	1.11	0.66	-1.18
16	-6.7	-28.6	-11.2	0.90	0.48	-1.67
17	1.7	-16.6	-16.0	1.28	0.42	-0.34
18	-3.2	-22.0	-18.6	0.87	0.71	-1.06

19	-0.6	-14.0	-10.8	1.18	0.38	-0.55
20	1.5	-38.7	-23.7	1.67	1.14	-1.75
21	-8.6	-12.6	-16.0	1.18	0.17	-0.77
22	-2.6	-13.7	-18.5	1.27	0.46	-0.52
23	-4.3	-11.3	-11.6	0.72	0.49	-0.75
24	-5.1	-13.6	-12.8	0.29	0.72	-0.90
25	5.1	-17.9	-9.3	0.95	0.61	-0.62
26	-9.3	-21.5	-8.4	0.95	0.04	-1.15
27	-0.3	-16.6	-7.0	0.79	0.60	-1.46
28	-1.5	-12.4	-12.9	0.78	0.61	-0.67
29	-2.0	-9.4	-4.4	0.32	0.29	-0.76
30	-15.1	-17.6	-24.2	1.46	0.72	-1.53
31	-4.6	-18.1	-17.2	0.75	0.87	-1.11
32	-4.6	-13.3	-7.2	0.52	0.22	-0.75
33	6.6	-34.4	-6.6	1.92	0.62	-1.23
34	0.4	-16.6	-13.3	1.03	0.65	-0.77
35	-2.7	-11.4	-10.6	0.58	0.62	-0.81
36	-1.7	-13.6	-17.9	0.71	1.02	-0.86
37	-4.5	-17.5	-18.1	1.12	0.69	-0.92
38	-8.5	-33.5	-13.6	0.33	0.94	-2.48

			Middle			
No	F_x (N)	F_y (N)	F_z (N)	M_x (Nm)	M_y (Nm)	M_z (Nm)
1	-2.4	-13.6	-4.7	0.49	0.28	-1.06
2	3.3	-25.1	-3.6	0.30	0.23	-1.35
3	-4.2	-14.9	-5.9	0.05	0.41	-1.07
4	-4.5	-12.4	-7.3	0.42	0.35	-0.85
5	-1.9	-15.0	-9.6	0.68	0.71	-1.25
6	-2.6	-15.2	-12.7	1.16	0.58	-0.92
7	3.7	-21.8	-17.8	0.52	1.08	-1.28
8	-8.5	-24.9	-7.4	0.67	0.25	-1.60
9	2.9	-9.4	-6.4	0.46	0.37	-0.33
10	-6.0	-28.0	-13.4	0.04	0.83	-1.75
11	-3.5	-22.5	-8.5	0.37	0.49	-1.43
12	-2.7	-6.9	-7.5	-0.26	0.27	-0.15
13	-6.9	-24.3	-1.7	-0.12	0.14	-1.50
14	8.3	-19.6	-4.7	1.08	0.63	-0.73
15	-1.8	-24.3	-12.5	0.60	0.73	-1.52
16	-0.9	-15.7	-6.0	0.61	0.27	-0.85
17	-7.9	-39.4	-13.1	0.74	0.75	-2.74
18	-0.8	-14.6	-9.2	0.64	0.56	-0.93
19	-9.6	-19.7	-5.7	-0.14	0.52	-1.60
20	-10.9	-8.5	-1.6	-0.19	0.37	-0.68
21	-3.9	-9.8	-7.9	0.20	0.43	-0.64

22	2.4	-25.5	-12.3	0.85	0.76	-1.46
23	-5.5	-12.4	-12.7	0.42	0.82	-1.00
24	0.3	-30.6	-9.8	1.02	0.52	-1.59
25	-5.5	-20.0	-4.8	0.38	0.17	-1.17
26	-0.7	-23.2	-9.3	0.53	0.62	-1.60
27	0.7	-15.4	-8.9	0.56	0.58	-0.96
28	-0.5	-13.7	-5.7	0.80	0.41	-1.08
29	2.0	-15.9	-13.7	0.65	0.78	-0.82
30	-4.0	-21.6	-4.9	0.12	0.31	-1.47
31	-9.6	-11.9	4.3	-0.49	0.14	-0.72
32	-11.1	-26.9	-12.3	0.26	0.84	-2.05
33	-2.9	-29.1	-9.1	0.74	0.60	-2.12
34	1.4	-36.7	-20.4	0.27	1.53	-2.73
35	-9.6	-18.3	-12.5	0.43	0.75	-1.42
36	-3.2	-10.3	-5.6	0.31	0.29	-0.72
37	-1.0	-9.8	-9.2	0.37	0.62	-0.72
38	-0.8	-6.2	-5.1	0.24	0.30	-0.39

			Ring			
No	F_x (N)	F_y (N)	F_z (N)	M_x (Nm)	M_y (Nm)	M_z (Nm)
1	-1.4	-7.3	-1.2	-0.12	0.11	-0.55
2	-1.5	-19.2	-11.8	0.04	0.87	-1.40
3	0.3	-18.4	-6.0	0.20	0.33	-0.98
4	-6.2	-12.7	-3.4	0.20	0.16	-0.95
5	-3.5	-16.6	-7.4	0.51	0.38	-1.07
6	-4.3	-16.6	-3.6	0.29	0.26	-1.52
7	-0.1	-16.6	-7.9	0.82	0.49	-1.05
8	-3.2	-12.2	-7.5	0.14	0.51	-0.94
9	-7.6	-14.3	-4.9	0.11	0.31	-1.05
10	0.2	-14.5	-8.8	0.43	0.48	-0.75
11	0.3	-21.4	-7.6	0.83	0.38	-1.02
12	-4.5	-19.2	-9.6	0.31	0.54	-1.25
13	2.8	-6.7	-3.1	0.12	0.35	-0.67
14	-1.4	-17.5	-6.8	0.52	0.37	-1.05
15	-3.2	-6.7	-3.6	0.34	0.07	-0.43
16	-7.6	-14.8	-5.1	-0.03	0.48	-1.36
17	-3.3	-10.3	-5.4	0.07	0.28	-0.58
18	-9.1	-20.5	-6.1	0.18	0.31	-1.29
19	-6.5	-19.0	-8.1	-0.16	0.61	-1.31
20	-1.8	-20.6	-11.1	0.24	0.70	-1.38
21	-6.0	-21.6	-11.9	0.22	0.81	-1.59
22	-4.0	-10.1	-5.4	0.13	0.40	-0.83
23	-5.9	-19.5	-2.7	-0.48	0.35	-1.46
24	-5.1	-5.0	-0.9	-0.02	0.09	-0.36

25	-5.3	-11.6	-4.3	0.03	0.26	-0.77
26	-6.1	-10.6	-6.8	0.39	0.34	-0.89
27	0.6	-11.1	-4.1	0.16	0.23	-0.59
28	-5.8	-10.2	-3.7	0.15	0.14	-0.60
29	-3.5	-13.9	-7.3	0.43	0.30	-0.77
30	-2.5	-10.0	-3.7	0.20	0.21	-0.73
31	-0.9	-8.4	-2.8	0.35	0.05	-0.26
32	-1.4	-12.5	-1.3	0.24	0.06	-0.96
33	-4.1	-13.9	-7.9	0.35	0.35	-0.79
34	-5.3	-8.5	-7.5	0.19	0.49	-0.68
35	-4.4	-5.1	-4.3	0.15	0.24	-0.43
36	-3.9	-12.2	-7.8	0.57	0.33	-0.80
37	-4.6	-8.0	-7.8	0.24	0.54	-0.70
38	-5.1	-18.3	-8.7	0.21	0.62	-1.42
39	-1.8	-4.0	-3.4	0.06	0.23	-0.30
40	-5.3	-13.8	-5.1	-0.35	0.50	-0.99
41	-11.0	-21.8	-7.8	0.46	0.33	-1.57

			Little			
No	F_x (N)	F_y (N)	F_z (N)	M_x (Nm)	M_y (Nm)	M_z (Nm)
1	-4.4	-5.5	1.4	-0.30	0.13	-0.44
2	-3.1	-9.7	-0.2	-0.21	0.08	-0.67
3	-9.1	-13.2	8.3	-0.29	-0.22	-0.73
4	-4.9	-9.7	5.9	-0.08	-0.35	-0.65
5	-10.6	-16.9	5.3	-0.20	-0.28	-1.28
6	-12.9	-14.8	3.0	-0.54	0.16	-1.57
7	-8.1	-12.3	0.0	-0.27	0.18	-1.03
8	-0.8	-6.3	2.7	-0.44	-0.08	-0.31
9	-2.9	-7.8	-0.6	-0.05	0.06	-0.54
10	-0.6	-5.1	-0.7	-0.09	0.06	-0.29
11	-2.0	-4.0	0.7	-0.07	0.00	-0.23
12	-5.3	-16.2	-0.2	-0.03	0.03	-1.31
13	-4.5	-12.6	1.6	-0.17	-0.06	-0.97
14	-6.9	-9.3	3.8	-0.20	-0.13	-0.70
15	-10.0	-17.2	3.9	-0.68	0.14	-1.15
16	-5.7	-7.0	2.2	-0.23	0.03	-0.50
17	-5.9	-12.5	2.0	-0.58	0.12	-0.99
18	-0.5	-2.7	0.9	-0.11	-0.03	-0.14
19	-5.3	-8.8	7.2	-0.55	-0.14	-0.60
20	-7.8	-12.6	1.3	-0.48	0.21	-0.77
21	-5.6	-6.6	-0.9	-0.19	0.24	-0.60
22	-4.0	-13.3	6.9	-0.31	-0.38	-0.91
23	-10.3	-20.2	-4.0	0.18	0.21	-1.52
24	-1.1	-4.6	0.4	0.09	-0.05	-0.35

25	-1.4	-6.6	1.7	-0.11	-0.13	-0.59
26	-9.6	-5.8	1.8	-0.16	0.08	-0.52
27	-9.6	-12.1	6.5	-0.56	0.03	-0.76
28	-4.9	-9.0	-0.4	-0.06	0.06	-0.66
29	-2.3	-6.9	-1.0	-0.24	0.15	-0.48
30	-0.3	-3.4	0.3	-0.11	0.00	-0.16
31	0.8	-3.5	1.9	-0.20	-0.08	-0.07
32	-1.3	-7.7	3.0	-0.40	-0.08	-0.40
33	-1.8	-4.3	0.0	0.04	-0.02	-0.33
34	-3.1	-5.1	2.5	-0.20	-0.05	-0.34
35	-1.2	-2.8	1.0	-0.15	-0.02	-0.21
36	-4.8	-11.3	-2.6	-0.03	0.15	-0.63
37	1.4	-2.6	8.5	-0.65	0.39	0.22
38	-0.9	-2.1	1.8	-0.22	-0.02	-0.13
39	-5.7	-18.7	4.2	-0.11	-0.28	-1.39
40	1.1	-3.2	1.6	-0.26	-0.18	-0.17
41	-2.9	-8.8	-0.1	-0.02	0.01	-0.71
42	-3.1	-7.5	0.7	-0.15	0.01	-0.66
43	-4.0	-5.3	-2.3	-0.14	0.32	-0.50
44	-4.8	-5.9	1.6	-0.17	0.00	-0.49

A4. For the **Radial Deviation** of the wrist:

			Thumb			
No	F_x (N)	F_y (N)	F_z (N)	M_x (Nm)	M_y (Nm)	M_z (Nm)
1	-59.5	28.1	25.4	-0.99	-0.56	-1.74
2	-38.8	32.4	26.7	-1.19	0.03	-1.67
3	-47.2	27.9	-5.0	0.00	-0.20	-1.98
4	-49.2	36.2	35.2	-3.04	-1.84	-1.43
5	-39.6	29.7	44.9	-2.50	-1.37	-0.93
6	-68.5	16.6	10.4	-0.11	0.60	-2.06
7	-38.3	17.2	29.1	-1.25	-0.84	-0.66
8	-44.5	3.5	33.6	-0.57	-0.62	-0.72
9	-59.4	44.9	25.6	-1.06	0.25	-2.30
10	-72.8	37.3	17.0	-0.66	-0.19	-2.70
11	-65.7	29.4	-14.0	0.63	0.20	-2.50
12	-57.5	21.2	28.8	-1.95	-0.19	-3.57
13	-36.8	30.0	6.2	-0.25	0.06	-1.69
14	-58.4	37.0	13.1	-0.30	0.37	-2.62
15	-31.1	20.7	17.4	-0.96	-0.22	-1.38
16	-40.0	24.9	47.2	-2.17	-0.59	-1.40
17	-38.2	25.5	30.2	-1.76	-0.67	-1.22
18	-68.6	15.0	53.7	-2.61	-1.45	-1.95

19	-63.1	16.7	6.9	-0.18	-0.26	-1.82
20	-33.4	20.6	36.0	-1.62	-0.28	-1.34
21	-62.1	24.8	2.5	-0.01	-0.09	-2.51
22	-58.9	23.6	35.5	-1.59	0.23	-2.73
23	-42.0	22.0	-7.0	0.12	0.19	-1.20
24	-19.2	42.9	-12.5	1.40	-0.18	-2.57
25	-40.0	23.2	25.5	-1.39	-0.71	-1.64
26	-46.5	16.0	10.7	-0.51	-0.30	-1.83
27	-51.6	5.8	21.9	-1.04	-0.10	-2.29
28	-35.8	22.7	-4.8	-0.06	-0.41	-1.53
29	-21.3	21.0	3.2	-0.76	-0.69	-0.43
30	-31.7	16.1	12.3	-0.84	-0.33	-1.66
31	-29.0	3.1	12.0	-0.52	-0.89	-1.01
32	-32.7	28.1	15.2	-1.15	-0.87	-1.04
33	-70.3	39.4	2.8	-0.48	-0.79	-2.70
34	-28.9	19.6	8.9	-0.61	-0.23	-1.44
35	-54.8	21.2	-1.1	0.03	0.28	-1.29
36	-73.5	16.3	10.2	-0.36	-1.10	-1.37

			Index			
No	F_x (N)	F_y (N)	F_z (N)	M_x (Nm)	M_y (Nm)	M_z (Nm)
1	5.4	-12.7	-14.0	1.04	0.53	-0.09
2	-1.3	-21.7	-15.3	1.21	0.76	-1.17
3	1.2	-20.3	-6.8	0.75	0.37	-0.99
4	8.5	-17.3	-13.3	1.14	0.49	0.05
5	-0.4	-14.1	-9.4	1.00	0.46	-0.72
6	2.0	-25.3	-7.7	1.34	0.35	-0.77
7	7.5	-19.3	-21.5	1.17	0.91	-0.44
8	-0.3	-14.0	-9.8	0.77	0.27	-0.42
9	-4.3	-19.2	-16.4	1.27	0.11	-0.49
10	-6.1	-22.7	-15.5	1.27	0.69	-1.40
11	1.0	-32.5	-32.2	1.75	0.84	-0.84
12	6.6	-17.8	-13.7	0.86	0.58	-0.38
13	1.8	-5.3	-31.6	1.19	0.80	-0.06
14	-1.6	-12.6	-15.1	1.10	0.52	-0.54
15	3.6	-14.5	-12.6	1.13	0.37	-0.12
16	1.3	-23.0	-24.1	0.95	0.71	-0.78
17	11.6	-16.5	-22.3	1.14	0.93	-0.08
18	3.8	-17.0	-7.7	1.28	0.40	-0.26
19	3.8	-21.7	-19.6	1.26	0.68	-0.49
20	-2.6	-19.7	-23.7	1.90	0.82	-0.89
21	-1.2	-12.3	-8.3	0.88	0.12	-0.29
22	-1.9	-17.6	-8.0	0.36	0.48	-1.16
23	0.5	-17.0	-17.4	1.02	0.58	-0.56

24	-6.0	-10.3	-4.8	0.36	0.23	-0.94
25	-0.3	-12.4	-6.1	0.20	0.38	-0.81
26	-1.0	-18.4	-14.4	0.97	0.61	-0.84
27	-2.0	-9.1	-7.4	0.63	0.24	-0.44
28	-0.2	-4.7	-7.5	0.12	1.62	-1.01
29	1.2	-31.7	-13.6	1.79	0.71	-1.57
30	1.0	-11.3	-1.4	0.70	0.08	-0.18
31	-0.9	-26.1	-21.8	0.40	1.29	-1.56
32	-0.1	-11.2	-9.4	0.64	0.53	-0.62
33	4.8	-20.0	-23.3	1.29	0.85	-0.46
34	-7.9	-27.6	-23.1	0.83	1.04	-1.49

			Middle			
No	F_x (N)	F_y (N)	F_z (N)	M_x (Nm)	M_y (Nm)	M_z (Nm)
1	-2.5	-16.2	-5.2	0.11	0.34	-1.12
2	-2.3	-10.2	-4.9	0.10	0.28	-0.63
3	-1.7	-7.8	-4.6	0.16	0.23	-0.46
4	-2.4	-19.4	-5.3	0.86	0.26	-1.33
5	-2.2	-21.6	-8.5	1.01	0.31	-1.04
6	-3.0	-13.0	-13.2	0.04	0.79	-0.79
7	-6.2	-15.0	-2.9	0.13	0.14	-0.97
8	1.3	-7.9	-8.5	0.39	0.27	-0.20
9	1.8	-22.9	-14.1	0.93	1.00	-1.50
10	-3.3	-12.4	-8.0	0.48	0.56	-1.06
11	-1.5	-7.0	-9.8	0.30	0.48	-0.39
12	3.0	-3.2	-1.7	0.18	0.26	-0.22
13	0.3	-9.9	-7.3	0.41	0.36	-0.49
14	-0.3	-19.3	-12.1	0.41	0.70	-1.13
15	1.3	-6.7	-7.4	-0.27	0.34	-0.35
16	1.7	4.0	-6.9	1.29	-0.11	0.26
17	2.0	-8.5	-13.9	0.13	0.98	-0.58
18	-9.1	-15.0	-4.4	-0.02	0.32	-1.08
19	5.9	-11.6	-5.3	0.76	0.54	-0.34
20	0.5	-19.8	-10.4	0.49	0.62	-1.14
21	0.0	-4.3	-6.6	0.19	0.33	-0.23
22	-3.9	-15.2	-4.5	0.75	0.05	-0.86
23	-0.2	-14.9	-13.2	0.75	0.71	-0.81
24	-8.8	-19.4	-13.1	-0.06	0.98	-1.41
25	0.6	-0.4	-1.3	-0.03	0.06	-0.03
26	-3.8	-16.1	-4.4	0.25	0.20	-0.94
27	-1.3	-14.3	-10.3	0.57	0.79	-1.18
28	5.9	-2.1	-6.1	-0.18	0.54	-0.35
29	-1.3	-11.0	-5.5	0.25	0.24	-0.57
30	-1.3	-10.9	-7.9	0.63	0.36	-0.60

31	1.8	-3.0	-1.3	0.09	0.12	-0.15
32	1.6	-10.2	-14.3	0.64	0.64	-0.39
33	-4.4	-9.0	-2.3	0.17	0.09	-0.68
34	-9.6	-9.9	-1.8	-0.19	0.32	-0.77
35	-3.8	-12.7	-0.9	0.46	-0.08	-0.84
36	-0.3	-21.7	-16.0	0.49	0.89	-1.25
37	-2.5	-10.0	-6.8	0.41	0.29	-0.58
38	1.9	-8.6	-6.8	0.19	0.34	-0.38
39	4.4	-11.7	-12.5	0.66	0.72	-0.43

			Ring			
No	F_x (N)	F_y (N)	F_z (N)	M_x (Nm)	M_y (Nm)	M_z (Nm)
1	1.1	-12.6	-2.0	0.62	0.20	-0.87
2	-1.9	-10.7	-6.3	0.03	0.42	-0.73
3	-1.8	-10.8	-4.1	0.64	0.01	-0.32
4	-3.4	-8.2	-3.2	0.10	0.17	-0.53
5	-1.5	-10.5	-3.3	0.30	0.14	-0.58
6	1.7	-10.1	-11.5	0.24	0.71	-0.58
7	-4.5	-12.3	-3.7	0.04	0.22	-0.77
8	-3.2	-6.7	-6.5	0.18	0.19	-0.29
9	6.0	-14.3	-7.4	0.68	0.68	-0.74
10	-4.6	-9.3	-4.3	0.20	0.35	-0.97
11	0.8	-9.6	-7.2	0.19	0.34	-0.44
12	-4.4	-6.1	-4.2	0.09	0.38	-0.65
13	-0.5	-5.3	-3.4	0.22	0.13	-0.23
14	0.0	-3.8	-3.9	0.26	0.16	-0.16
15	-0.3	0.1	0.7	-0.17	0.02	-0.08
16	-3.1	-6.4	-4.9	0.07	0.36	-0.51
17	-9.9	-13.2	-8.8	0.34	0.38	-0.97
18	-4.9	-9.5	-5.4	-0.02	0.41	-0.70
19	-2.0	-10.5	-2.3	0.23	0.09	-0.58
20	-3.5	-9.1	-8.2	0.32	0.45	-0.63
21	-2.5	-9.3	-1.0	-0.27	0.13	-0.57
22	1.2	-1.7	-6.1	-0.10	0.31	-0.13
23	-3.7	-6.2	-2.6	0.12	0.12	-0.45
24	0.5	-1.1	-3.6	-0.08	0.27	-0.10
25	-3.9	-4.7	-3.9	0.11	0.17	-0.33
26	-4.3	-10.9	-5.5	0.51	0.16	-0.71
27	3.0	-6.0	-2.7	0.32	0.21	-0.12
28	0.4	-5.4	-1.4	0.15	0.10	-0.34
29	-3.9	-9.4	-9.0	0.41	0.32	-0.51
30	-3.8	-4.8	-2.9	0.19	0.09	-0.40
31	-2.8	-3.2	-5.4	0.22	0.34	-0.31
32	-4.1	-11.5	-6.2	0.54	0.20	-0.71

33	-2.3	-9.5	-5.9	0.33	0.30	-0.59
34	-1.0	-10.5	-8.5	0.19	0.51	-0.66
35	-2.4	-3.2	-2.6	0.06	0.15	-0.24
36	0.2	-1.8	-7.0	0.09	0.29	-0.07
37	2.2	-6.6	-5.5	0.32	0.30	-0.23

			Little			
No	F_x (N)	F_y (N)	F_z (N)	M_x (Nm)	M_y (Nm)	M_z (Nm)
1	-5.4	-6.1	2.2	-0.37	0.12	-0.59
2	-2.4	-2.4	2.5	-0.25	0.03	-0.21
3	-0.4	-4.8	5.4	-0.17	-0.21	-0.21
4	-5.0	-10.5	4.9	-0.37	-0.13	-0.63
5	-1.5	-6.6	4.6	-0.44	-0.10	-0.28
6	3.2	-8.7	0.4	-0.51	-0.20	-0.15
7	-1.9	-3.7	0.0	0.00	0.01	-0.27
8	-2.0	-6.4	0.5	-0.10	0.01	-0.23
9	1.2	-10.4	-0.3	-0.20	0.00	-0.51
10	0.6	-5.9	0.5	-0.08	-0.02	-0.20
11	0.3	-2.4	1.9	-0.08	-0.07	-0.07
12	2.2	-3.6	1.5	-0.19	-0.08	0.10
13	-2.4	-3.2	1.4	-0.19	0.04	-0.22
14	-0.9	-14.6	0.0	-0.74	0.05	-0.85
15	-3.8	-8.7	2.3	-0.28	0.00	-0.47
16	-4.8	-11.5	0.9	-0.32	0.08	-0.56
17	1.8	-14.0	2.1	-0.27	-0.14	-0.77
18	-2.2	-4.2	4.3	-0.30	-0.07	-0.22
19	-2.2	-3.2	0.3	0.00	-0.03	-0.24
20	-0.9	-6.3	4.6	-0.29	-0.20	-0.33
21	-0.1	-0.9	0.3	-0.04	0.00	0.00
22	-3.2	-4.4	4.1	-0.41	-0.02	-0.35
23	-0.6	-5.7	2.6	-0.23	-0.21	-0.50
24	1.1	-2.9	-1.2	-0.28	0.01	-0.26
25	0.6	-1.2	-0.3	-0.09	-0.06	0.03
26	-4.6	-6.0	0.8	-0.03	-0.05	-0.64
27	-3.3	-11.3	-3.4	0.08	0.12	-0.51
28	-0.9	-5.0	1.8	-0.18	-0.06	-0.31
29	-0.2	-0.7	6.3	-0.45	0.07	0.00
30	-0.3	-2.3	0.3	-0.13	-0.01	-0.18
31	-1.9	-9.4	5.0	-0.19	-0.21	-0.48
32	-3.5	-6.0	4.0	-0.39	-0.11	-0.50
33	-0.2	-5.3	1.5	-0.16	-0.04	-0.16
34	0.4	-2.4	1.1	-0.23	0.00	0.10
35	-3.0	-8.0	1.4	-0.21	0.05	-0.12
36	-3.3	-12.4	-0.7	-0.10	0.04	-0.29

A5. For the **Ulnar Deviation** of the wrist:

			Thumb			
No	F_x (N)	F_y (N)	F_z (N)	M_x (Nm)	M_y (Nm)	M_z (Nm)
1	-15.1	6.4	42.5	-2.23	0.39	-0.84
2	-43.0	10.8	30.8	-1.57	-0.07	-2.14
3	-43.6	35.1	2.9	-0.21	-0.14	-2.03
4	-63.0	4.5	0.0	-0.26	-0.34	-2.54
5	-59.5	25.9	17.9	-1.97	-1.91	-2.46
6	-56.8	14.1	0.0	0.14	0.55	-1.77
7	-52.3	-2.2	29.5	-1.04	-0.83	-1.58
8	-64.1	22.6	-14.9	0.52	0.04	-2.04
9	-57.1	4.6	21.1	-1.28	-0.50	-3.01
10	-50.2	19.9	3.7	-0.26	-0.31	-2.13
11	-68.3	37.7	0.9	0.10	0.15	-2.72
12	-37.4	-1.7	24.6	-1.03	-0.68	-1.65
13	-22.1	15.9	32.3	-1.88	-0.18	-0.79
14	-56.9	3.4	25.0	-1.33	-0.73	-2.46
15	-62.5	21.1	14.1	-0.75	-0.44	-2.14
16	-69.4	11.5	29.6	-1.66	-0.84	-2.80
17	-47.9	17.8	22.1	-1.25	0.17	-2.63
18	-33.3	37.1	15.1	-0.87	-0.20	-1.73
19	-42.7	15.0	10.6	-0.63	-0.50	-1.78
20	-31.5	18.6	7.1	-0.59	-0.54	-1.48
21	-35.3	14.2	8.2	-0.45	-0.05	-1.63
22	-28.7	12.3	-1.4	-0.06	-0.33	-1.44
23	-31.1	-1.9	8.7	-0.32	-0.87	-1.42
24	-49.5	0.7	-15.7	0.59	-1.37	-1.91
25	-30.4	17.9	2.1	-0.29	-0.34	-1.37
26	-63.1	-8.1	-28.5	0.96	-0.34	-1.91
27	-58.6	15.1	-11.6	0.47	0.35	-1.94

			Index			
No	F_x (N)	F_y (N)	F_z (N)	M_x (Nm)	M_y (Nm)	M_z (Nm)
1	-12.0	-13.8	-16.8	0.92	0.50	-1.07
2	1.0	-13.4	-11.6	1.48	0.19	-0.12
3	6.6	-17.0	-22.0	1.51	0.75	-0.14
4	2.4	-16.9	-8.9	0.59	0.33	-0.47
5	11.1	-10.0	-21.3	1.04	0.84	0.14
6	-3.3	-14.4	-16.1	0.99	0.63	-0.76
7	-0.9	-14.5	-12.2	0.93	0.35	-0.48
8	2.3	-11.7	-18.2	0.79	0.52	-0.25
9	2.9	-14.7	-23.4	1.33	0.91	-0.40
10	-3.0	-8.5	-15.2	0.61	0.69	-0.51
11	1.1	-12.1	-34.3	1.16	1.74	-0.55

12	0.3	-13.2	-18.3	0.98	0.38	-0.26
13	2.3	-0.4	-42.1	1.62	0.75	0.03
14	-3.9	-5.6	-11.3	0.74	0.43	-0.45
15	1.7	-9.7	-29.3	1.22	1.14	-0.31
16	8.8	-13.1	-19.7	1.00	1.02	-0.28
17	3.8	-14.1	-23.6	1.51	0.95	-0.31
18	-3.1	-19.9	-29.2	1.81	0.98	-0.83
19	-1.1	-13.0	-7.2	0.84	0.10	-0.30
20	-4.9	-11.1	-9.9	0.77	0.31	-0.71
21	5.2	-13.0	-14.4	0.93	0.70	-0.28
22	-6.5	-11.7	-14.4	0.93	0.20	-0.59
23	-3.4	-8.5	-10.3	0.64	0.21	-0.37
24	5.1	-3.2	-12.6	0.62	0.61	0.08
25	2.3	-12.4	-20.2	1.02	0.91	-0.44
26	-6.2	-9.3	-9.8	0.61	0.33	-0.71
27	7.6	-20.4	-39.7	1.22	1.78	-0.72
28	4.9	-16.8	-29.2	1.49	0.60	-0.10

			Middle			
No	F_x (N)	F_y (N)	F_z (N)	M_x (Nm)	M_y (Nm)	M_z (Nm)
1	-1.4	-12.4	-5.9	0.54	0.30	-0.74
2	-5.0	-11.5	-2.6	0.22	0.11	-0.91
3	2.1	-10.9	-6.2	0.29	0.36	-0.55
4	3.8	-11.2	-6.5	0.04	0.25	-0.42
5	-1.5	-8.6	-16.7	0.54	0.81	-0.48
6	2.8	-16.4	-8.3	1.04	0.55	-0.73
7	2.2	-18.5	-14.7	1.08	0.68	-0.68
8	1.9	-11.8	-15.2	0.31	0.64	-0.50
9	5.8	-6.9	-14.2	0.57	0.85	-0.19
10	4.1	-16.3	-15.4	-0.04	0.77	-0.82
11	2.2	-7.1	-8.5	0.34	0.70	-0.50
12	3.1	-6.0	-10.1	0.42	0.51	-0.17
13	4.7	-10.0	-8.7	0.33	0.56	-0.47
14	-6.0	-12.0	-10.1	0.40	0.44	-0.76
15	-0.2	-2.7	-5.9	0.10	0.37	-0.16
16	2.0	-14.7	-15.1	0.55	0.85	-0.75
17	-4.7	-19.7	-20.1	0.78	1.03	-1.18
18	-2.5	-5.4	-6.3	0.02	0.40	-0.36
19	-0.9	-18.9	-7.8	0.77	0.28	-0.75
20	-1.4	-12.3	-6.7	0.46	0.30	-0.66
21	-0.9	-2.0	-5.6	0.05	0.37	-0.15
22	0.8	-8.1	-5.0	0.45	0.12	-0.14
23	-0.9	-3.9	-12.1	-0.09	0.96	-0.31
24	2.7	-8.0	-6.5	0.63	0.67	-0.54

25	-1.5	-6.3	-3.9	0.19	0.17	-0.33
26	-6.8	-7.0	-2.8	0.02	0.21	-0.60
27	-0.4	-12.1	-16.3	0.46	1.02	-0.77
28	-1.7	-8.4	-10.5	0.49	0.55	-0.53
29	-3.4	-14.7	-5.8	0.43	0.17	-0.70
30	2.8	-11.1	-10.5	0.16	0.62	-0.61
31	-0.1	-4.5	-10.8	-0.36	0.48	-0.20

			Ring			
No	F_x (N)	F_y (N)	F_z (N)	M_x (Nm)	M_y (Nm)	M_z (Nm)
1	-1.6	-4.8	-1.4	-0.05	0.12	-0.35
2	-2.9	-9.3	-0.8	0.35	-0.06	-0.62
3	3.8	-6.3	-4.3	0.24	0.42	-0.42
4	-6.2	-9.8	-6.9	0.05	0.41	-0.64
5	-5.1	-6.9	-13.4	0.33	0.73	-0.51
6	-0.1	-5.3	-5.7	0.11	0.33	-0.30
7	5.1	-13.0	-10.7	0.49	0.77	-0.71
8	0.4	-16.6	-15.0	-0.09	0.74	-0.82
9	2.5	-6.2	-9.1	-0.03	0.93	-0.65
10	-2.3	-11.3	-8.2	0.46	0.43	-0.72
11	-3.5	-2.5	-1.3	-0.09	0.18	-0.13
12	-3.7	-3.6	-8.6	0.21	0.45	-0.27
13	-3.2	-13.7	-19.4	0.31	1.17	-0.88
14	-2.2	-11.9	-10.4	0.11	0.66	-0.76
15	-2.5	-7.6	-2.9	-0.06	0.21	-0.51
16	-5.7	-12.3	-2.4	0.12	0.11	-0.87
17	-5.2	-8.4	-6.0	0.37	0.27	-0.67
18	-3.4	-7.3	-3.2	0.13	0.17	-0.51
19	-4.8	-3.4	0.3	-0.18	0.21	-0.20
20	2.7	-3.7	-8.1	0.08	0.66	-0.26
21	-0.8	-3.8	-3.1	0.15	0.13	-0.21
22	-1.6	-2.1	-4.9	0.21	0.28	-0.19
23	-7.1	-7.2	-10.3	0.29	0.17	-0.34
24	-7.8	-10.6	0.7	-0.58	0.37	-0.69
25	-2.6	-5.3	-3.7	0.09	0.17	-0.32
26	-4.3	-7.2	-8.5	-0.27	0.61	-0.38
27	0.2	-6.3	-6.9	0.25	0.36	-0.32

			Little			
No	F_x (N)	F_y (N)	F_z (N)	M_x (Nm)	M_y (Nm)	M_z (Nm)
1	-1.5	-4.3	2.7	-0.40	0.00	-0.23
2	-2.7	-8.1	7.8	-0.63	-0.13	-0.36
3	-0.4	-11.3	2.2	-0.13	-0.06	-0.34
4	-7.3	-9.3	3.2	-0.45	0.27	-0.17

5	-5.0	-5.4	-3.6	0.20	0.00	-0.26
6	-1.3	-9.0	1.1	-0.57	0.05	-0.11
7	-6.5	-10.9	-1.0	-0.41	0.27	-0.38
8	-1.5	-6.3	-6.2	-0.20	0.25	-0.21
9	-1.7	-7.1	-1.1	-0.20	0.08	-0.27
10	-3.0	-2.9	1.2	-0.18	0.07	-0.13
11	-6.1	-10.7	-4.2	-0.11	0.24	-0.47
12	-8.7	-11.0	8.4	-0.54	0.16	-0.33
13	0.6	-4.5	-1.1	0.55	0.16	-0.38
14	-3.9	-5.9	1.8	-0.15	0.04	-0.20
15	-4.2	-7.3	-2.2	-0.38	0.34	-0.41
16	-0.7	-14.4	0.2	-0.84	0.02	-0.60
17	-4.6	-12.3	-3.5	0.02	0.12	-0.43
18	-3.5	-4.5	2.8	-0.24	0.07	-0.18
19	-5.5	-9.3	3.3	-0.49	0.09	-0.57
20	0.9	-8.7	5.6	-0.30	-0.32	-0.44
21	1.1	-6.6	-3.3	0.50	0.00	0.19
22	-0.5	-2.9	9.8	-0.71	0.46	0.10
23	-1.5	-5.3	1.9	-0.37	-0.05	-0.44
24	-8.5	-7.1	2.0	-0.64	0.67	-0.31
25	-4.4	-8.6	-0.3	-0.26	0.15	-0.67
26	-5.0	-8.3	1.9	-0.41	0.13	-0.51
27	0.1	0.8	0.2	0.03	-0.02	0.04
28	-5.2	-8.9	-5.7	-0.40	0.37	-0.22

APPENDIX (K): **PCA**

K1: The *p*-values (Table K1.1) and the coefficients of determination (Table K1.2) of the correlation matrix.

TableK1.1: *p-values (continues)*

Variables	Age	Gender	3^{rd}_L	Circumf	Ulna_L	WJLS	N_Degrees
Age	**0**	0.680	0.648	**0.022**	0.265	0.071	0.573
Gender	0.680	**0**	**0.003**	**< 0.0001**	**< 0.0001**	0.452	0.834
3^{rd}_L	0.648	**0.003**	**0**	**0.000**	**< 0.0001**	0.849	0.264
Circumf	**0.022**	**< 0.0001**	**0.000**	**0**	**< 0.0001**	0.172	0.294
Ulna_L	0.265	**< 0.0001**	**< 0.0001**	**< 0.0001**	**0**	0.312	0.797
WJLS	0.071	0.452	0.849	0.172	0.312	**0**	0.520
N_Degrees	0.573	0.834	0.264	0.294	0.797	0.520	**0**
ΣFT	0.122	**< 0.0001**	**0.021**	**< 0.0001**	**0.001**	0.473	0.703
ΣMT	0.149	0.652	0.492	0.584	0.833	0.490	0.793
FzT	0.124	**< 0.0001**	**0.024**	**< 0.0001**	**0.001**	0.459	0.716
Fx	0.595	**0.000**	0.109	**0.001**	**0.007**	0.834	0.740
Fy	0.167	**0.048**	0.621	**0.019**	**0.025**	0.538	**0.006**
Fz	**0.034**	**0.040**	0.992	0.135	0.312	0.137	0.793
Mx	**0.021**	0.832	0.407	0.602	0.786	0.289	**0.018**
My	0.202	0.717	0.252	0.961	0.916	0.344	**0.011**
Mz	0.488	0.502	0.786	0.087	0.222	0.754	**0.033**

Values in bold are different from 0 with a significance level alpha=0.05

p-values:

Variables	ΣFT	ΣMT	FzT	Fx	Fy	Fz	Mx	My	Mz
Age	0.122	0.149	0.124	0.595	0.167	**0.034**	**0.021**	0.202	0.488
Gender	**< 0.0001**	0.652	**< 0.0001**	**0.000**	**0.048**	**0.040**	0.832	0.717	0.502
3^{rd}_L	**0.021**	0.492	**0.024**	0.109	0.621	0.992	0.407	0.252	0.786
Circumf	**< 0.0001**	0.584	**< 0.0001**	**0.001**	**0.019**	0.135	0.602	0.961	0.087
Ulnar_L	**0.001**	0.833	**0.001**	**0.007**	**0.025**	0.312	0.786	0.916	0.222
WJLS	0.473	0.490	0.459	0.834	0.538	0.137	0.289	0.344	0.754
N_Degrees	0.703	0.793	0.716	0.740	**0.006**	0.793	**0.018**	**0.011**	**0.033**
ΣFT	**0**	**0.003**	**< 0.0001**	**< 0.0001**	**0.002**	**0.029**	0.684	0.618	0.254
ΣMT	**0.003**	**0**	**0.003**	0.088	0.373	**0.039**	**0.019**	0.075	0.569
FzT	**< 0.0001**	**0.003**	**0**	**< 0.0001**	**0.003**	**0.027**	0.680	0.609	0.259
Fx	**< 0.0001**	0.088	**< 0.0001**	**0**	**0.002**	0.112	0.868	0.323	**0.013**
Fy	**0.002**	0.373	**0.003**	**0.002**	**0**	**0.009**	0.106	0.106	**0.013**
Fz	**0.029**	**0.039**	**0.027**	0.112	**0.009**	**0**	**0.001**	0.903	0.524
Mx	0.684	**0.019**	0.680	0.868	0.106	**0.001**	**0**	**< 0.0001**	**< 0.0001**
My	0.618	0.075	0.609	0.323	0.106	0.903	**< 0.0001**	**0**	**< 0.0001**
Mz	0.254	0.569	0.259	**0.013**	**0.013**	0.524	**< 0.0001**	**< 0.0001**	**0**

Values in bold are different from 0 with a significance level alpha=0.05

Table K1.2*: Coefficients of determination (R^2)*
(continues)

Variables	Age	Gender	3^{rd}_L	Circumf	Ulnar_L	WJLS	N_Degrees	ΣFT
Age	**1**	0.004	0.004	**0.105**	0.026	0.066	0.007	0.049
Gender	0.004	**1**	**0.171**	**0.442**	**0.483**	0.012	0.001	**0.310**
3^{rd}_Ll	0.004	**0.171**	**1**	**0.234**	**0.301**	0.001	0.026	**0.106**
Circumf	**0.105**	**0.442**	**0.234**	**1**	**0.450**	0.039	0.023	**0.379**
Ulnar_L	0.026	**0.483**	**0.301**	**0.450**	**1**	0.021	0.001	**0.213**
WJLS	0.066	0.012	0.001	0.039	0.021	**1**	0.009	0.011
N_Degrees	0.007	0.001	0.026	0.023	0.001	0.009	**1**	0.003
ΣFT	0.049	**0.310**	**0.106**	**0.379**	**0.213**	0.011	0.003	**1**
ΣMT	0.043	0.004	0.010	0.006	0.001	0.010	0.001	**0.167**
FzT	0.049	**0.312**	**0.102**	**0.369**	**0.207**	0.011	0.003	**0.999**
Fx	0.006	**0.255**	0.053	**0.198**	**0.143**	0.001	0.002	**0.471**
Fy	0.039	**0.079**	0.005	**0.109**	**0.100**	0.008	**0.148**	**0.178**
Fz	**0.091**	**0.085**	0.000	0.046	0.021	0.046	0.001	**0.095**
Mx	**0.106**	0.001	0.014	0.006	0.002	0.023	**0.111**	0.003
My	0.034	0.003	0.027	0.000	0.000	0.019	**0.128**	0.005
Mz	0.010	0.009	0.002	0.060	0.031	0.002	**0.092**	0.027

Coefficients of determination (R^2)

Variables	ΣMT	FzT	Fx	Fy	Fz	Mx	My	Mz
Age	0.043	0.049	0.006	0.039	**0.091**	**0.106**	0.034	0.010
Gender	0.004	**0.312**	**0.255**	**0.079**	**0.085**	0.001	0.003	0.009
3^{rd}_L	0.010	**0.102**	0.053	0.005	0.000	0.014	0.027	0.002
Circumf	0.006	**0.369**	**0.198**	**0.109**	0.046	0.006	0.000	0.060
Ulnar_L	0.001	**0.207**	**0.143**	**0.100**	0.021	0.002	0.000	0.031
WJLS	0.010	0.011	0.001	0.008	0.046	0.023	0.019	0.002
N_Degrees	0.001	0.003	0.002	**0.148**	0.001	**0.111**	**0.128**	**0.092**
ΣFT	**0.167**	**0.999**	**0.471**	**0.178**	**0.095**	0.003	0.005	0.027
ΣMT	**1**	**0.171**	0.059	0.017	**0.086**	**0.109**	0.065	0.007
FzT	**0.171**	**1**	**0.477**	**0.174**	**0.097**	0.004	0.005	0.026
Fx	0.059	**0.477**	**1**	**0.184**	0.052	0.001	0.020	**0.123**
Fy	0.017	**0.174**	**0.184**	**1**	**0.134**	0.053	0.053	**0.121**
Fz	**0.086**	**0.097**	0.052	**0.134**	**1**	**0.213**	0.000	0.008
Mx	**0.109**	0.004	0.001	0.053	**0.213**	**1**	**0.372**	**0.396**
My	0.065	0.005	0.020	0.053	0.000	**0.372**	**1**	**0.547**
Mz	0.007	0.026	**0.123**	**0.121**	0.008	**0.396**	**0.547**	**1**

K2: The *p*-values (Table K2.1) and the coefficients of determination (Table K2.2) of the correlation matrix.

Table K2.1: *p-values (continues)*

Variables	Age	Gender	3rd_L	Circumf	Ulnar_L	N_Degrees	ΣMT
Age	**0**	0.680	0.648	**0.022**	0.265	0.573	0.149
Gender	0.680	**0**	**0.003**	**< 0.0001**	**< 0.0001**	0.834	0.652
3rd_L	0.648	**0.003**	**0**	**0.000**	**< 0.0001**	0.264	0.492
Circumf	**0.022**	**< 0.0001**	**0.000**	**0**	**< 0.0001**	0.294	0.584
Ulnar_L	0.265	**< 0.0001**	**< 0.0001**	**< 0.0001**	**0**	0.797	0.833
N_Degrees	0.573	0.834	0.264	0.294	0.797	**0**	0.793
ΣMT	0.149	0.652	0.492	0.584	0.833	0.793	**0**
FzT	0.124	**< 0.0001**	**0.024**	**< 0.0001**	**0.001**	0.716	**0.003**
Fx	0.595	**0.000**	0.109	**0.001**	**0.007**	0.740	0.088
Fy	0.167	**0.048**	0.621	**0.019**	**0.025**	**0.006**	0.373
Fz	**0.034**	**0.040**	0.992	0.135	0.312	0.793	**0.039**
Mx	**0.021**	0.832	0.407	0.602	0.786	**0.018**	**0.019**
My	0.202	0.717	0.252	0.961	0.916	**0.011**	0.075
Mz	0.488	0.502	0.786	0.087	0.222	**0.033**	0.569

Values in bold are different from 0 with a significance level alpha=0.05

p-values:

Variables	FzT	Fx	Fy	Fz	Mx	My	Mz
Age	0.124	0.595	0.167	**0.034**	**0.021**	0.202	0.488
Gender	**< 0.0001**	**0.000**	**0.048**	**0.040**	0.832	0.717	0.502
3rd_L	**0.024**	0.109	0.621	0.992	0.407	0.252	0.786
Circumf	**< 0.0001**	**0.001**	**0.019**	0.135	0.602	0.961	0.087
Ulnar_L	**0.001**	**0.007**	**0.025**	0.312	0.786	0.916	0.222
N_Degrees	0.716	0.740	**0.006**	0.793	**0.018**	**0.011**	**0.033**
ΣMT	**0.003**	0.088	0.373	**0.039**	**0.019**	0.075	0.569
FzT	**0**	**< 0.0001**	**0.003**	**0.027**	0.680	0.609	0.259
Fx	**< 0.0001**	**0**	**0.002**	0.112	0.868	0.323	**0.013**
Fy	**0.003**	**0.002**	**0**	**0.009**	0.106	0.106	**0.013**
Fz	**0.027**	0.112	**0.009**	**0**	**0.001**	0.903	0.524
Mx	0.680	0.868	0.106	**0.001**	**0**	**< 0.0001**	**< 0.0001**
My	0.609	0.323	0.106	0.903	**< 0.0001**	**0**	**< 0.0001**
Mz	0.259	**0.013**	**0.013**	0.524	**< 0.0001**	**< 0.0001**	**0**

Values in bold are different from 0 with a significance level alpha=0.05

Table K2.2: *Coefficients of determination (R^2) (continues)*

Variables	Age	Gender	3rd_L	Circumf	Ulnar_L	N_Degrees	ΣMT
Age	**1**	0.004	0.004	**0.105**	0.026	0.007	0.043
Gender	0.004	**1**	**0.171**	**0.442**	**0.483**	0.001	0.004
3rd_L	0.004	**0.171**	**1**	**0.234**	**0.301**	0.026	0.010
Circumf	**0.105**	**0.442**	**0.234**	**1**	**0.450**	0.023	0.006
Ulnar_L	0.026	**0.483**	**0.301**	**0.450**	**1**	0.001	0.001
N_Degrees	0.007	0.001	0.026	0.023	0.001	**1**	0.001
ΣMT	0.043	0.004	0.010	0.006	0.001	0.001	**1**
FzT	0.049	**0.312**	**0.102**	**0.369**	**0.207**	0.003	**0.171**
Fx	0.006	**0.255**	0.053	**0.198**	**0.143**	0.002	0.059
Fy	0.039	**0.079**	0.005	**0.109**	**0.100**	**0.148**	0.017
Fz	**0.091**	**0.085**	0.000	0.046	0.021	0.001	**0.086**
Mx	**0.106**	0.001	0.014	0.006	0.002	**0.111**	**0.109**
My	0.034	0.003	0.027	0.000	0.000	**0.128**	0.065
Mz	0.010	0.009	0.002	0.060	0.031	**0.092**	0.007

Coefficients of determination (R^2):

Variables	FzT	Fx	Fy	Fz	Mx	My	Mz
Age	0.049	0.006	0.039	**0.091**	**0.106**	0.034	0.010
Gender	**0.312**	**0.255**	**0.079**	**0.085**	0.001	0.003	0.009
3rd_L	**0.102**	0.053	0.005	0.000	0.014	0.027	0.002
Circumf	**0.369**	**0.198**	**0.109**	0.046	0.006	0.000	0.060
Ulnar_L	**0.207**	**0.143**	**0.100**	0.021	0.002	0.000	0.031
N_Degrees	0.003	0.002	**0.148**	0.001	**0.111**	**0.128**	**0.092**
ΣMT	**0.171**	0.059	0.017	**0.086**	**0.109**	0.065	0.007
FzT	**1**	**0.477**	**0.174**	**0.097**	0.004	0.005	0.026
Fx	**0.477**	**1**	**0.184**	0.052	0.001	0.020	**0.123**
Fy	**0.174**	**0.184**	**1**	**0.134**	0.053	0.053	**0.121**
Fz	**0.097**	0.052	**0.134**	**1**	**0.213**	0.000	0.008
Mx	0.004	0.001	0.053	**0.213**	**1**	**0.372**	**0.396**
My	0.005	0.020	0.053	0.000	**0.372**	**1**	**0.547**
Mz	0.026	**0.123**	**0.121**	0.008	**0.396**	**0.547**	**1**

K3: The *p*-values (Table K3.1) and the coefficients of determination (Table K3.2) of the correlation matrix.

Table K3.1: *p-values (continues)*

Variables	Gender	3rd_L	Circumf	Ulnar_L	N_Degrees	ΣMT
Gender	**0**	**0.003**	**< 0.0001**	**< 0.0001**	0.834	0.652
3rd_L	**0.003**	**0**	**0.000**	**< 0.0001**	0.264	0.492
Circumf	**< 0.0001**	**0.000**	**0**	**< 0.0001**	0.294	0.584
Ulnar_L	**< 0.0001**	**< 0.0001**	**< 0.0001**	**0**	0.797	0.833
N_Degrees	0.834	0.264	0.294	0.797	**0**	0.793
ΣMT	0.652	0.492	0.584	0.833	0.793	**0**
FzT	**< 0.0001**	**0.024**	**< 0.0001**	**0.001**	0.716	**0.003**
Fx	**0.000**	0.109	**0.001**	**0.007**	0.740	0.088
Fy	**0.048**	0.621	**0.019**	**0.025**	**0.006**	0.373
Fz	**0.040**	0.992	0.135	0.312	0.793	**0.039**
Mx	0.832	0.407	0.602	0.786	**0.018**	**0.019**
My	0.717	0.252	0.961	0.916	**0.011**	0.075
Mz	0.502	0.786	0.087	0.222	**0.033**	0.569

Values in bold are different from 0 with a significance level alpha=0.05

p-values:

Variables	FzT	Fx	Fy	Fz	Mx	My	Mz
Gender	**< 0.0001**	**0.000**	**0.048**	**0.040**	0.832	0.717	0.502
3rd_L	**0.024**	0.109	0.621	0.992	0.407	0.252	0.786
Circumf	**< 0.0001**	**0.001**	**0.019**	0.135	0.602	0.961	0.087
Ulnar_L	**0.001**	**0.007**	**0.025**	0.312	0.786	0.916	0.222
N_Degrees	0.716	0.740	**0.006**	0.793	**0.018**	**0.011**	**0.033**
ΣMT	**0.003**	0.088	0.373	**0.039**	**0.019**	0.075	0.569
FzT	**0**	**< 0.0001**	**0.003**	**0.027**	0.680	0.609	0.259
Fx	**< 0.0001**	**0**	**0.002**	0.112	0.868	0.323	**0.013**
Fy	**0.003**	**0.002**	**0**	**0.009**	0.106	0.106	**0.013**
Fz	**0.027**	0.112	**0.009**	**0**	**0.001**	0.903	0.524
Mx	0.680	0.868	0.106	**0.001**	**0**	**< 0.0001**	**< 0.0001**
My	0.609	0.323	0.106	0.903	**< 0.0001**	**0**	**< 0.0001**
Mz	0.259	**0.013**	**0.013**	0.524	**< 0.0001**	**< 0.0001**	**0**

Values in bold are different from 0 with a significance level alpha=0.05

Table K3.2: *Coefficients of determination (R^2)(continues):*

Variables	Gender	3rd_L	Circumf	Ulnar_L	N_Degrees	ΣMT
Gender	**1**	**0.171**	**0.442**	**0.483**	0.001	0.004
3rd_L	**0.171**	**1**	**0.234**	**0.301**	0.026	0.010
Circumf	**0.442**	**0.234**	**1**	**0.450**	0.023	0.006
Ulnar_L	**0.483**	**0.301**	**0.450**	**1**	0.001	0.001
N_Degrees	0.001	0.026	0.023	0.001	**1**	0.001
ΣMT	0.004	0.010	0.006	0.001	0.001	**1**
FzT	**0.312**	**0.102**	**0.369**	**0.207**	0.003	**0.171**
Fx	**0.255**	0.053	**0.198**	**0.143**	0.002	0.059
Fy	**0.079**	0.005	**0.109**	**0.100**	**0.148**	0.017
Fz	**0.085**	0.000	0.046	0.021	0.001	**0.086**
Mx	0.001	0.014	0.006	0.002	**0.111**	**0.109**
My	0.003	0.027	0.000	0.000	**0.128**	0.065
Mz	0.009	0.002	0.060	0.031	**0.092**	0.007

Coefficients of determination (R^2):

Variables	FzT	Fx	Fy	Fz	Mx	My	Mz
Gender	**0.312**	**0.255**	**0.079**	**0.085**	0.001	0.003	0.009
3rd_L	**0.102**	0.053	0.005	0.000	0.014	0.027	0.002
Circumf	**0.369**	**0.198**	**0.109**	0.046	0.006	0.000	0.060
Ulnar_L	**0.207**	**0.143**	**0.100**	0.021	0.002	0.000	0.031
N_Degrees	0.003	0.002	**0.148**	0.001	**0.111**	**0.128**	**0.092**
ΣMT	**0.171**	0.059	0.017	**0.086**	**0.109**	0.065	0.007
FzT	**1**	**0.477**	**0.174**	**0.097**	0.004	0.005	0.026
Fx	**0.477**	**1**	**0.184**	0.052	0.001	0.020	**0.123**
Fy	**0.174**	**0.184**	**1**	**0.134**	0.053	0.053	**0.121**
Fz	**0.097**	0.052	**0.134**	**1**	**0.213**	0.000	0.008
Mx	0.004	0.001	0.053	**0.213**	**1**	**0.372**	**0.396**
My	0.005	0.020	0.053	0.000	**0.372**	**1**	**0.547**
Mz	0.026	**0.123**	**0.121**	0.008	**0.396**	**0.547**	**1**

K4: The *p*-values (Table K4.1) and the coefficients of determination (Table K4.2) of the correlation matrix.

Table K4.1: *p-values:*

Variables	Gender	Circumf	Ulnar_L	N_Degrees	ΣMT
Gender	**0**	**< 0.0001**	**< 0.0001**	0.834	0.652
Circumf	**< 0.0001**	**0**	**< 0.0001**	0.294	0.584
Ulnar_L	**< 0.0001**	**< 0.0001**	**0**	0.797	0.833
N_Degrees	0.834	0.294	0.797	**0**	0.793
ΣMT	0.652	0.584	0.833	0.793	**0**
FzT	**< 0.0001**	**< 0.0001**	**0.001**	0.716	**0.003**
Fx	**0.000**	**0.001**	**0.007**	0.740	0.088
Fy	**0.048**	**0.019**	**0.025**	**0.006**	0.373
Fz	**0.040**	0.135	0.312	0.793	**0.039**
Mx	0.832	0.602	0.786	**0.018**	**0.019**
My	0.717	0.961	0.916	**0.011**	0.075
Mz	0.502	0.087	0.222	**0.033**	0.569

Values in bold are different from 0 with a significance level alpha=0.05

p-values:

Variables	FzT	Fx	Fy	Fz	Mx	My	Mz
Gender	**< 0.0001**	**0.000**	**0.048**	**0.040**	0.832	0.717	0.502
Circumf	**< 0.0001**	**0.001**	**0.019**	0.135	0.602	0.961	0.087
Ulnar_L	**0.001**	**0.007**	**0.025**	0.312	0.786	0.916	0.222
N_Degrees	0.716	0.740	**0.006**	0.793	**0.018**	**0.011**	**0.033**
ΣMT	**0.003**	0.088	0.373	**0.039**	**0.019**	0.075	0.569
FzT	**0**	**< 0.0001**	**0.003**	**0.027**	0.680	0.609	0.259
Fx	**< 0.0001**	**0**	**0.002**	0.112	0.868	0.323	**0.013**
Fy	**0.003**	**0.002**	**0**	**0.009**	0.106	0.106	**0.013**
Fz	**0.027**	0.112	**0.009**	**0**	**0.001**	0.903	0.524
Mx	0.680	0.868	0.106	**0.001**	**0**	**< 0.0001**	**< 0.0001**
My	0.609	0.323	0.106	0.903	**< 0.0001**	**0**	**< 0.0001**
Mz	0.259	**0.013**	**0.013**	0.524	**< 0.0001**	**< 0.0001**	**0**

Values in bold are different from 0 with a significance level alpha=0.05

Table K4.2: *Coefficients of determination (R^2)(continues):*

Variables	Gender	Circumf	Ulnar_L	N_Degrees	ΣMT
Gender	**1**	**0.442**	**0.483**	0.001	0.004
Circumf	**0.442**	**1**	**0.450**	0.023	0.006
Ulnar_L	**0.483**	**0.450**	**1**	0.001	0.001
N_Degrees	0.001	0.023	0.001	**1**	0.001
ΣMT	0.004	0.006	0.001	0.001	**1**
FzT	**0.312**	**0.369**	**0.207**	0.003	**0.171**
Fx	**0.255**	**0.198**	**0.143**	0.002	0.059
Fy	**0.079**	**0.109**	**0.100**	**0.148**	0.017
Fz	**0.085**	0.046	0.021	0.001	**0.086**
Mx	0.001	0.006	0.002	**0.111**	**0.109**
My	0.003	0.000	0.000	**0.128**	0.065
Mz	0.009	0.060	0.031	**0.092**	0.007

Coefficients of determination (R^2):

Variables	FzT	Fx	Fy	Fz	Mx	My	Mz
Gender	**0.312**	**0.255**	**0.079**	**0.085**	0.001	0.003	0.009
Circumf	**0.369**	**0.198**	**0.109**	0.046	0.006	0.000	0.060
Ulnar_L	**0.207**	**0.143**	**0.100**	0.021	0.002	0.000	0.031
N_Degrees	0.003	0.002	**0.148**	0.001	**0.111**	**0.128**	**0.092**
ΣMT	**0.171**	0.059	0.017	**0.086**	**0.109**	0.065	0.007
FzT	**1**	**0.477**	**0.174**	**0.097**	0.004	0.005	0.026
Fx	**0.477**	**1**	**0.184**	0.052	0.001	0.020	**0.123**
Fy	**0.174**	**0.184**	**1**	**0.134**	0.053	0.053	**0.121**
Fz	**0.097**	0.052	**0.134**	**1**	**0.213**	0.000	0.008
Mx	0.004	0.001	0.053	**0.213**	**1**	**0.372**	**0.396**
My	0.005	0.020	0.053	0.000	**0.372**	**1**	**0.547**
Mz	0.026	**0.123**	**0.121**	0.008	**0.396**	**0.547**	**1**